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Comparing plastic ingestion in juvenile and adult stranded short-tailed shearwaters (*Puffinus tenuirostris*) in eastern Australia

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ABSTRACT

Numerous species of seabirds have been shown to ingest anthropogenic debris, but few studies have compared ingestion rates between adults and juveniles of the same species. We investigated marine debris ingestion by short-tailed shearwaters (*Puffinus tenuirostris*) obtained through two stranding events on North Stradbroke Island, Australia in 2010 (n = 102; adult) and 2012 (n = 27; juveniles). Necropsies were conducted and solid contents found in guts were categorized into type and color. Over 67% of birds ingested anthropogenic debris: 399 pieces of debris were identified. We found no significant relationship between body condition of birds which had ingested anthropogenic debris and those that had not. Juvenile birds were more likely to ingest debris than were adult birds and juveniles ingested significantly more pieces of debris than did adults. Male and female birds ingested similar amounts and weights of debris. To determine if *P. tenuirostris* actively selects for certain types of debris, we compared ingested debris to samples obtained from boat-based tows. Significant differences were found, suggesting that the birds select for hard plastic, rubber and balloons.

1. Introduction

Marine debris, defined as anthropogenic waste that reaches the ocean, is a global issue. It is composed primarily of plastic polymers (Derraik, 2002), despite the fact that plastics have existed for less than a century (Gorman, 1993). It has been suggested that the deposition rate of plastics has now outgrown production rate (Moore, 2008) and that plastics are overly represented in the environment due to their slow and variable decomposition times (Gregory, 1978). Many plastic polymers are buoyant, allowing them to be entrained in currents and increasing their ability to travel long distances far from their source. This buoyancy means they are available to a wide range of pelagic-feeding marine species (Schuyler et al., 2013).

Worldwide, at least 267 marine species are known to have been affected by plastic debris including numerous pelagic seabirds (Laist, 1987). Many studies have hypothesized why marine animals ingest anthropogenic debris. However, the role of selectivity by seabirds when assessing marine debris as a potential food item is currently not fully understood. Selectivity relies heavily on the foraging strategy of the animals, which will automatically include or exclude certain types of debris due to its specific gravity (does it float, sink or is it neutrally buoyant) and its visual characteristics (does it mimic a prey item in shape or color). Hypotheses as to why wildlife ingest food include misidentification of prey items (Mrosovsky et al., 2009; Schuyler et al., 2012) and debris becoming hidden or masked within natural food sources (Balazs, 1985).

Derraik (2002) suggested that the ingestion of plastic by seabirds is directly connected to diet, foraging strategy and foraging location. For example researchers in Alaska found that plastic fragments in bird stomachs were small and brown, leading to the conclusion that these could have been mistaken as fish eggs or larvae, the natural prey items of the focal species (Day, 1980). Also, birds that forage via "pursuit diving" in open ocean areas tend to have increased plastic ingestion (Day et al., 1985). Procellariiformes such as shearwaters are pursuit divers that take advantage of gyres and upwellings (Hunt et al., 1996), where debris also accumulates (Laist, 1987; Lebreton et al., 2012).

It is important to understand the possible mechanisms that may drive birds to ingest debris. For example, is there selectivity for color or size? Moser and Lee (1992) presented evidence that some seabirds select certain shapes and colors of plastic, possibly mistaking them for prey items. Azzarello and Van Vleet (1987) believed that planktivores are more likely to ingest plastic particles than are piscivores, while starving birds might not be selective at all. Furthermore, in some studies, plastic loads in adults and juveniles have been shown to differ, with juveniles containing

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higher plastic loads than adults of two related shearwater species off the east coast of Australia (Hutton et al., 2008).

Our focal species, the short-tailed Shearwater (*Puffinus tenuirostris*; Temminck 1835) feeds primarily at sea and is known to forage by pursuit diving (plunging from height while searching for surface prey) and hydroplaning (Morgan, 1982; Ogi, 1990). It is likely that while on the wing it is hard to distinguish between prey and debris, particularly if debris are similar in size, shape or color to prey items (Day et al., 1985). It has been proposed that vision is the main sense used by seabirds when searching for food (Lovvorn et al., 2001; Martin, 1998). This is supported by the suggestion that if seabirds feed through tactile or chemical cues, they would be less likely to ingest non-food items (Martin and Prince, 2001).

With respect to visual acuity and perception of prey, the retina of the wedge-tailed shearwater (*Puffinus pacificus*), a closely related species, contains five different types of visual pigments in seven different classes of photoreceptors, giving them enhanced color vision (Hart, 2004). It is reasonable to expect that the closely allied short-tailed shearwater shares the same photoreceptors. An important question becomes 'are plastic particles likely mistaken for familiar prey items?' Pursuit or plunge diving birds must cope with the refraction of the position of the underwater prey and also with the reflection of skylight from the surface (Katzir, 1993; Lythgoe, 1979) so it is possible that species with different photoreceptors and/or foraging strategies may be more or less likely to ingest particular types, colors, sizes or shapes of debris.

Like other pursuit diving Procellariformes, short-tailed shearwaters have a narrow passage connecting the proventriculus to the gizzard, which restricts their ability to regurgitate non-digestible material (Carey, 2011). The gizzard is a thick-walled part of a bird's gastrointestinal system, in which food is physically broken down by muscular action and contact with small stones. Indigestible items such as cephalopod beaks, fish otoliths and plastics are often found trapped within the narrow-necked gizzard (Furness, 1985). This can potentially become a problem when chicks are fed by their parents. Because chicks have a reduced ability to regurgitate, debris ingestion can retard growth and development, and debris ingestion has been identified as a source of mortality in some seabirds (Auman et al., 1997; Fry et al., 1987; Priddel et al., 2006; Sileo, 1993).

By understanding the characteristics of the marine debris available in the oceans, we can better understand potential selectivity by marine fauna. This requires comparing what is available in the environment to what is found within the gastrointestinal system of targeted taxa. For example, Schuyler et al. (2012) showed a positive selectivity for soft clear plastics by sea turtles, beyond what was available in the environment.

Our aim was to quantify and describe marine debris ingested by short-tailed shearwaters (*P. tenuirostris*) during two separate stranding incidents in 2010 and 2012 and to ask the following questions: (1) Do *P. tenuirostris* ingest anthropogenic debris? If so, what type(s) of debris do they eat? (2) Is there a difference in the quantity or type of debris ingested between birds of differing ages or sexes? (3) Is there a discernible difference in body condition between birds which had and had not ingested debris? (4) Is debris ingested by *P. tenuirostris* representative of that which we find in the marine environment, or do they select for certain types or colours of debris?

2. Material and methods

2.1. Study area and focal species

North Stradbroke Island is located 40 km east of Brisbane, along the southeast coast of Queensland, Australia (27°20′–27°45′S153°20′–153°33′E). In October 2010 and April 2012, mass-strandings of short-tailed shearwaters occurred along the eastern shore of the island along Main Beach (Fig. 1A). One hundred and two short-tailed shearwaters were collected at random from the estimated 1200 birds washed ashore during the 2010 event. These birds were labeled and frozen for later necropsy. In April 2012, a similar yet smaller stranding event occurred at the same location. As in 2010, weather conditions were rough (wind speeds up to 33 km/h with rainfall in the region of 19–193 mm (Australian Bureau of Meteorology, 2012), which likely contributed to the stranding event. Twenty-seven dead shearwaters were in suitable state to necropsy.

Birds were necropsied using standard techniques (following van Franeker 2004) and stomach, gizzard and intestinal contents were recorded separately. For each of the three sections of the digestive tract, contents were washed in water and strained through a 0.33 mm mesh sieve to separate prey or other solid items ingested. Solid fragments including anthropogenic debris as well as squid beaks, pumice, small rocks and digestion remains, were quantified and identified using a light microscope (Olympus SZ51). The length and width of the ingested contents were measured using electronic calipers and weighed using a high precision digital scale (HM-202). We recorded the type and color of each item. Particles were scraped using a scalpel to determine original colors. All collected items were assessed for positive or negative buoyancy in sea water.

2.2. Trawl sampling

Between November 2011 and May 2012, 41 tows for marine debris in the nearshore environment were collected at different locations in Queensland, Australia (Fig. 1B), using a manta trawl net (mouth size 600 × 200 mm). All trawls were conducted for 30 min at a speed of 1–5 knots. All debris items >0.33 mm were collected and analyzed the same way as for the gut contents.

To compare near-coast debris with oceanic marine debris, a pilot study was conducted using the same type manta trawl net (described above) to sample for floating debris in the high seas. Four tows were conducted along the coast between Yeppoon and Townsville, through the Southern Great Barrier Reef aboard the AIMS (Australian Institute of Marine Science) Research Vessel Cape Ferguson during two days in May 2012 (Fig. 1B). Each tow was conducted for 30 min, at a speed of 3–5 knots. The samples were analyzed the same way as for near-coast trawl samping.

2.3. Statistical analyses

Data were analyzed using R (Studio Version 0.95.263 2009 – 2011 R Studio, Inc.). To check for equal representation of the different classes of debris, we divided debris into the following categories: Hard Plastic, Soft Plastic, Rope/String, Rubber, and Balloon and analyzed using a Chi-Square test. We used generalized linear models (GLM) to estimate whether birds of different ages or genders differ in the quantity, total area, or weight of debris ingested, and whether the quantity, total area, or weight of ingested debris affected the BMI of the birds. Body mass index (BMI) was calculated as the ratio between mass and wing length (Jones et al., 2009). BMI of birds that had and had not ingested debris were also compared using a GLM.

We used the Adonis model (package vegan) (Oksanen et al., 2013) to run permutational multivariate ANOVA (PERMANOVA) tests to determine whether ingestion of different categories and different colours of debris differed for birds of different ages or sexes.

To discern whether there was a difference between anthropogenic debris in high seas and near-shore environments we used a PERMANOVA test. We then compared anthropogenic debris

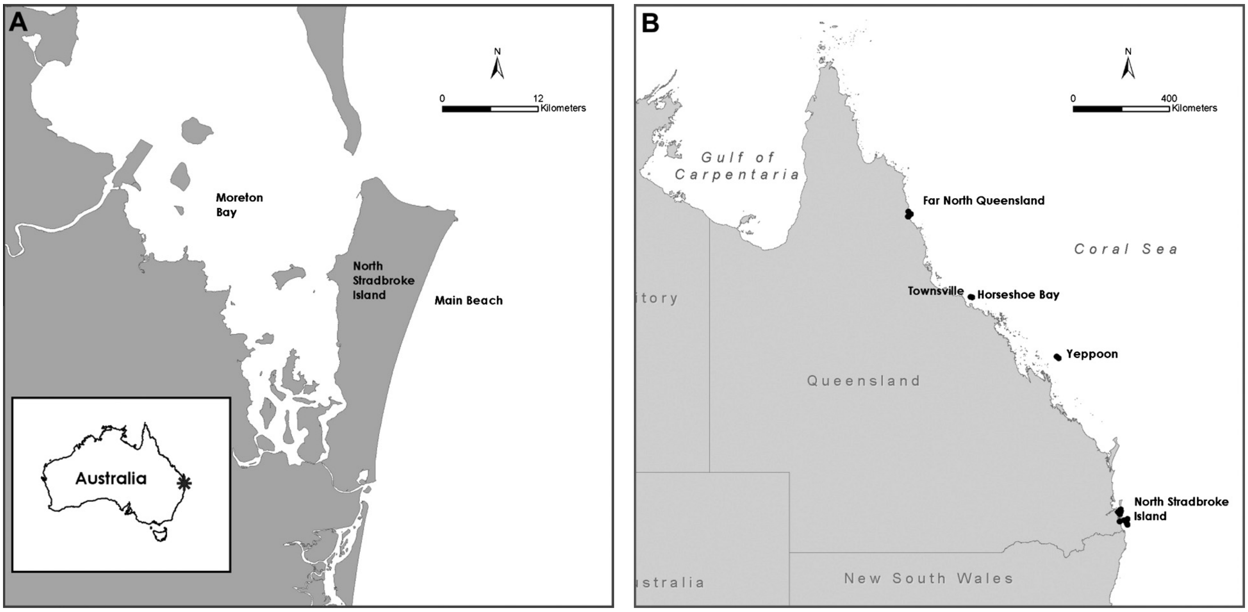

Fig. 1. (A) North Stradbroke Island including Main Beach where stranded birds were surveyed and collected for necropsy and (B) trawl sampling zones.

ingested by beach washed birds to debris available in the marine environment as sampled from our surface trawls. We employed the same procedures as above to test for color preference.

3. Results

A total of 129 birds were sampled during the two stranding events: 102 adult birds in 2010 and 27 juvenile birds in 2012. Given that stranding event in 2010 took place when adults are likely completing migration to their breeding grounds in southern Australia, we expected that stranded birds were adults. Gonad state and plumage characteristics supported this assumption. Birds in the 2012 stranding event were identified as juveniles based on plumage, time of year and gonad state.

66 Birds were females, 49 were males and 14 were of unknown sex. 67% of our total birds sampled had ingested a total of 399 pieces of anthropogenic debris. Anthropogenic debris items averaged 11.36 mm in length (range of 0.97–80.79, $\pm$5.57), 3.98 mm in width (range of 0.24–44.07 + 2.85) and 3.86 g in mass (range of 0.01–58.06 + 0.10).

Of the 102 adult birds, 63% ($N = 64$) had ingested debris. Gender was approximately even: 52% of sampled birds were females. The average weight was 360 g (310–400 g) and the mean BMI was 13.0 (range = 10.5–16.2). In the second stranding event, 85% of the necropsied birds had ingested anthropogenic debris. Of these juvenile birds (as determined by plumage and moult) 48% were females. The average weight was 291 g (range of 208–538 g) with a BMI of 12.6 (range = 9.0–19.5).

In total, we found 305 pieces of ingested anthropogenic litter from the 2010 stranding event. Of these, 261 pieces were plastic, accounting for 48% of the total of solid items found in the guts of adult birds. Other debris items including rubber, string and balloon were also recorded. Among the non-anthropogenic dietary items were squid beaks, pumices and small rocks, small gastropods, bits of wood and seeds (Table 1).

In 2012, plastic accounted for 50% of items found in gut by quantity with a total of 129 particles out of 168 pieces of anthropogenic debris. Hard plastic, rubber, string, balloons, foam and an intact glowstick are examples of anthropogenic debris that were consumed by birds sampled in this study. Other dietary items included squid beaks, pumice, wood, seeds and gastropods, as well as algae, pieces of clay, insects, fish vertebrae and teeth (Table 1).

Most anthropogenic debris was found in the gizzard (51% and 67% respectively for 2010 and 2012), followed by the stomach with 37% and 23%, respectively (Fig. 2). The average number of particles per birds was 4.5 for adult birds and 7.14 for juveniles. Overall, 70% and 72% (2010, 2012 respectively) of particles were positively buoyant.

Near-coast trawls and offshore trawls showed no significant difference in color categories ($p = 0.415$), so they were combined for all color analyses. Significant differences were observed when comparing color of debris ingested by birds and that available in the marine environment from our trawl samples ($p = 0.001$, Fig. 3). Near-coast and ocean trawls differed, however, when we compared the presence of different categories of debris ($p = 0.021$), which may be due to the small number of ocean trawl samples. For this reason, we used only near-coast trawls in our analyses of selectivity of debris categories.

Table 1
Breakdown of items ingested by short-tailed shearwaters (by count) from stranding events in 2010 and 2012.

Items	2010 (Adults)	2012 (Juveniles)	Total proportion (%)
Anthropogenic			
Plastic	261	129	48.99
Rubber	33	3	4.52
Foam	0	21	2.64
Balloon	7	13	2.51
String	4	2	0.75
Natural			
Pumice	103	18	15.20
Squid beak	60	41	12.69
Small rock	41	10	6.41
Gastropod	21	4	3.14
Seed	2	7	1.13
Wood	3	2	0.63
Feather/fur	3	0	0.38
Algae	0	3	0.38
Fish vertebrae	0	1	0.13
Fish tooth	0	1	0.13
Clay	0	1	0.13
Insect	0	2	0.25

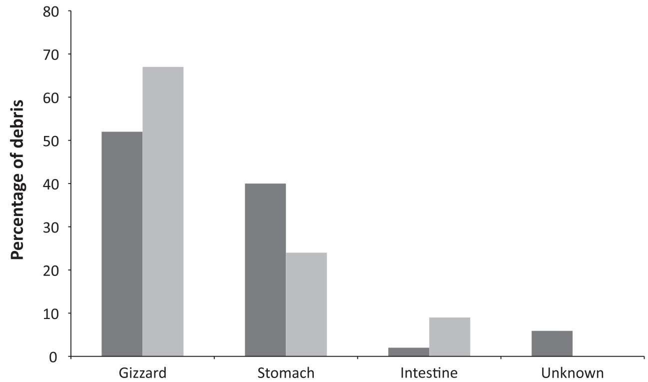

Fig. 2. The percentage of debris in the various sections of the gastrointestinal system of stranded short-tailed shearwaters in 2010 (dark grey) and 2012 (light grey).

We found a significant difference in the proportion of debris categories ingested by the shearwaters as compared to trawl samples ($p = 0.001$), suggesting birds were selecting for certain types of debris (Fig. 4). However, juveniles and adults showed no difference in ingestion of debris types ($p = 0.204$) nor was there a difference between males and females ($p = 0.866$). Overall 48 and 50% of all items found to be ingested by shearwaters in 2010 and 2012 were plastic. This was followed by pumice (19%) and squid beaks (11%) for 2010 birds, and squid beaks (15%), foam (8%) and pumice (6%) by 2012 birds.

There was no significant difference in the size (area), weight or number of pieces of debris ingested between males and females ($p > 0.2$ in all cases). Juveniles did not differ from adults in the size or weight of debris pieces they ingested; however they did ingest significantly higher numbers of pieces of debris ($p < 0.0001$).

The BMI was not affected by either the total weight or number of pieces of debris that were ingested. The BMI was significantly lower in birds that had ingested a larger total size of debris ($p = 0.00188$); however this was due to one outlier. When the outlier was removed, there was no correlation between BMI and number of pieces of debris ingested. Also, there was no significant difference in BMI between birds that had and had not ingested debris. Birds sampled in 2010 (adults) had a higher BMI ($p = 0.00188$) than birds sampled in 2012 (juveniles). Overall, birds were underweight compared to the known average mass for short-tailed shearwaters (see discussion).

4. Discussion

We found that 67% of stranded *P. tenuirostris* had marine debris in their gastrointestinal system (GIS), with the majority of the debris being plastic in composition. This is comparable to other studies which have shown that among all seabirds, Procellariiformes (especially shearwaters) are most likely to ingest plastic, with at least 80% of Procellariiformes recorded to contain plastic in their GIS (Colabuono et al., 2009; Robards et al., 1995; Ryan, 2008). For that reason, *Fulmarus glacialis* (Northern Fulmar) has been used in the North Atlantic and North Pacific Oceans as a monitoring tool for the health of the environment regarding marine debris trends (van Franeker et al., 2011). Other researchers have also observed that plastic debris found on the beach contains peck marks made by birds, suggested that birds could be mistaking plastic fragments for natural prey items such as cuttlebones, which are commonly and intentionally ingested by birds (Cadée, 2002).

We found significant differences in the amount and type of marine debris consumed by juvenile and adult birds. Substantially more juvenile than adult birds were found to have ingested marine debris in our study (85% vs. 62.7%), and the juveniles ingested more debris by count than adults ingested. Young birds may be more prone to ingesting marine debris because they are naïve consumers. Additionally, these birds might still be carrying particles fed to them by their parents before fledging, (Carey 2011; Rodriguez et al. 2012). Adults would have been foraging in Australian waters during the breeding season and may have picked up plastic debris they subsequently fed to their young. Therefore, juveniles would have ingested debris coming from Australian waters in either case, whether through direct feeding or receiving food from adults prior to fledging. Conversely, adult short-tailed shearwaters maintain an annual cycle in the offloading of plastics when they feed debris to their chicks (Ryan et al., 1988). Perhaps this is why Skira (1986) noticed a reduction in plastic load in adult birds when they were in their southern breeding season compared to the Northern hemisphere.

The birds in 2010 (adults on their southward migration) had consumed plastic particles comprised of primarily clear and dark colors and fledging birds in 2012 consumed mostly clear particles (Fig. 3). Perhaps the slight differences in colours consumed by the

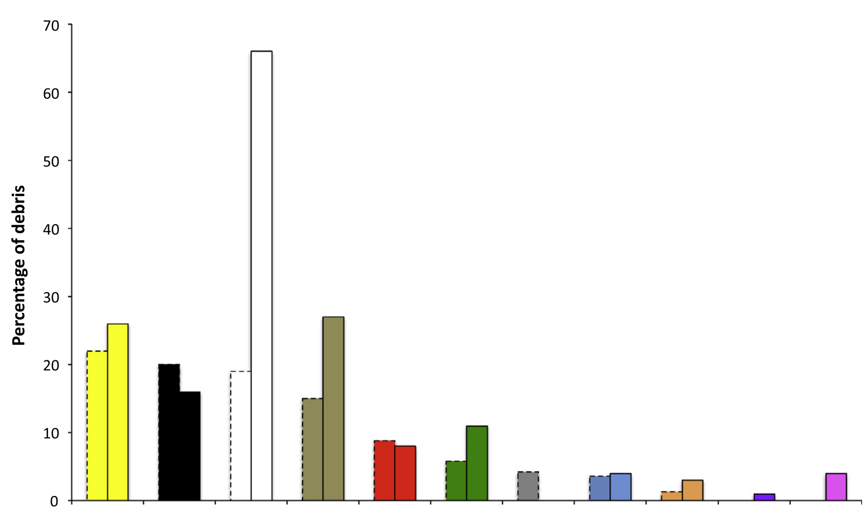

Fig. 3. The percentage of different colored anthropogenic debris found in various sections of the gastrointestinal system of short-tailed shearwaters in 2010 (dashed columns) and 2012 (solid columns).

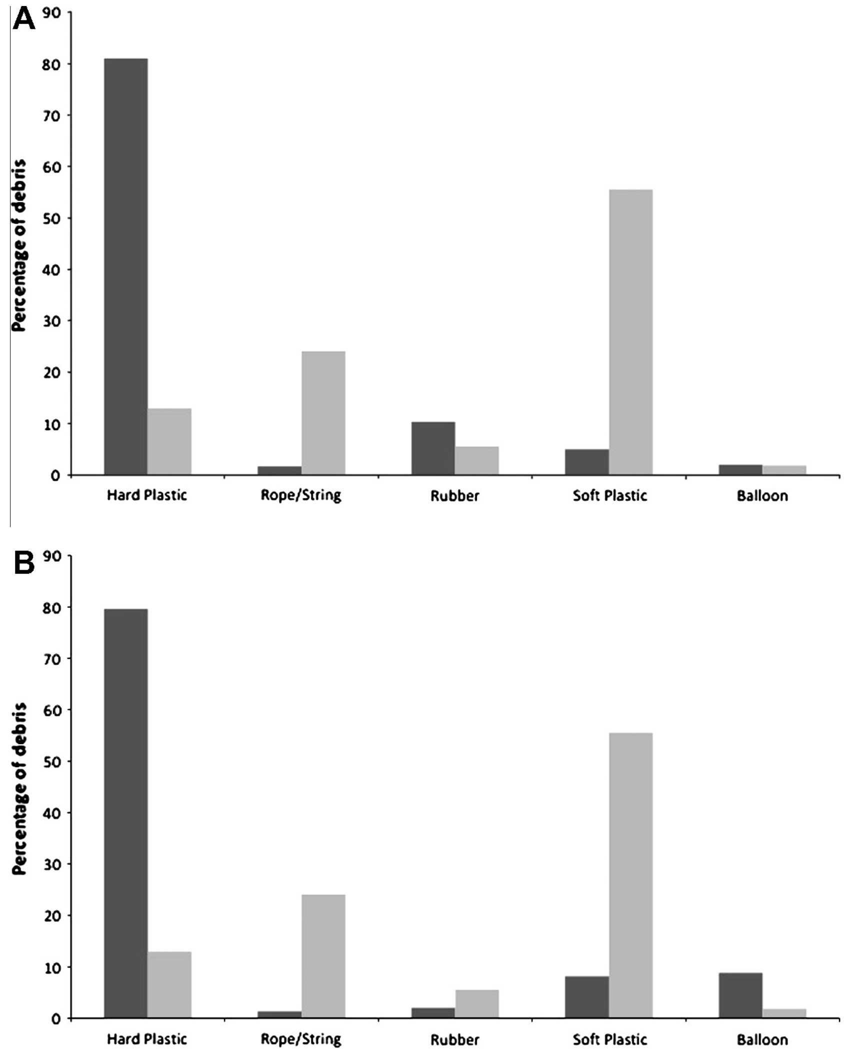

Fig. 4. Types of debris ingested by shearwaters (dark bars) compared to debris observed in surface trawls (light bars) in (A) 2010 and (B) 2012.

two age classed birds sampled in two different years reflects the different foraging grounds and the colours of plastics available in these regions. Carey (2011) found a prevalence of clear plastics ingested by juvenile short-tailed shearwaters, although grey, black and red plastics were also recorded. Other recent studies indicate that short- tailed shearwaters have a preference for light colors (Vlietstra and Parga, 2002), while Skira (1986) reported that short-tailed shearwaters in Tasmania selected bright colors such as yellow, green and red. In contrast, Day (1980) suggested that shearwaters show no color preference and that the ingestion of particular colors might reflect regional patterns or that starving birds might pick anything when they are in poor body condition.

Stranding events are common in shearwaters perhaps because they travel long distances between their breeding and feeding grounds. Such events also appear to occur more frequently in inexperienced immature birds (Work and Rameyer, 1999; Gould et al., 2000). This may simply be a function of weather during fledgling periods or may also be associated with naivety in searching for food. We did not find a significant relationship between the quantity of debris consumed and the body condition of the birds, a finding consistent with those of other authors who also did not detect clear evidence of an impact on the body condition of birds that had ingested plastics (Carey 2011; Rodriguez et al. 2012). In contrast, Connors and Smith (1982) found a negative correlation between the amount of plastic ingested and fat deposits in Red Phalaropes (*Phalaropus fulicarius*); however phalaropes are coastal feeding birds. Spear et al. (1995) found that heavier seabirds had higher plastic loads and he hypothesized that birds in better physical condition are more prone to ingesting plastics because they are more fit and they feed in different areas. However, among the birds that had consumed plastics, the number of particles were negatively correlated with body condition indicators (Spear et al., 1995). While ideally we would have ideally sampled adult and juvenile birds during the same year, stranding events are serendipitous and we did not have this opportunity.

Adult birds had a significantly higher BMI and were heavier than juveniles (mean mass of 360 and 291 g, respectively). We attributed this difference to age. Overall, however, birds sampled in this study were notably underweight: the average weight for an adult short-tailed shearwater should range from 480 to 800 g (Onley and Scofield, 2007). Given that beached washed birds were often wet and/or covered in sand, BMI results should be taken with caution. While studies often find that pre-fledging chicks weigh more than adults, it is worth noting that in both sampling years birds typically had no fat or only a trace of fat and likely would have been in poor health prior to stranding.

Our work suggests that birds select anthropogenic debris in different proportions to that which is available in the marine environment, with short-tailed shearwaters disproportionately consuming hard plastic, rubber and balloons (Fig. 4). Perhaps some of these items are more conspicuous in the marine environment or birds may be selecting them for some other currently unknown reason. It has been suggested that balloons may be mistaken for cephalopods, a common prey item of shearwaters (Weimerskirch and Cherel, 1998). Keeping consistent, detailed records of ingested debris type and comparing ingested debris to that available in the environment will increase our understanding of the role that choice plays in ingestion of anthropogenic debris.

This study adds to a growing body of literature quantifying the types and amounts of anthropogenic debris ingested by marine taxa. Importantly, we also compared types of debris ingested to that available in the marine environment which is a relevant addition that we hope other studies can also include. Seabirds have been shown to be good indicators of marine health (Furness and Camphuysen, 1997). Monitoring the occurrence of plastic in marine taxa and understanding where marine fauna are encountering and ingesting debris demonstrates the utility of using wildlife as indicators of environmental health.

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