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RESEARCH ARTICLE

# Plastic ingestion by Newell's (*Puffinus newelli*) and wedge-tailed shearwaters (*Ardenna pacifica*) in Hawaii

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**Abstract** The ingestion of plastic by seabirds has been used as an indicator of pollution in the marine environment. On Kaua'i, HI, USA, 50.0 % of Newell's (*Puffinus newelli*) and 76.9 % of wedge-tailed shearwater (*Ardenna pacifica*) fledglings necropsied during 2007–2014 contained plastic items in their digestive tract, while 42.1 % of adult wedge-tailed shearwaters had ingested plastic. For both species, the frequency of plastic ingestion has increased since the 1980s with some evidence that the mass and the number of items ingested per bird have also increased. The color of plastic ingested by the shearwaters was assessed relative to beach-washed plastics by using Jaccard's index (where $J = 1$ complete similarity). The color ($J = 0.65$–$0.68$) of items ingested by both species, and the type ingested by wedge-tailed shearwaters ($J = 0.85$–$0.87$), overlapped with plastic available in the local environment indicating moderate selection for plastic color and type. This study has shown that the Hawaiian populations of shearwaters, like many seabird species, provide useful but worrying insights into plastic pollution and the health of our oceans.

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## Introduction

Plastic products have revolutionized our way of life and have become ubiquitous in our daily lives (Thompson et al. 2009). While providing benefits for the society, the volume of plastic production coupled with the durability of plastic materials and improper waste disposal has contributed to the accumulation of more than five trillion plastic items floating in the surface layer of the world's oceans (Barnes et al. 2009; Derraik 2002; Eriksen et al. 2014). Fishing-related materials account for around 10 % of the debris entering the marine environment (Macfadyen et al. 2009), with the remainder, around 20 million items per day (Barnes 2005; Gregory 2009), resulting from deliberate or accidental dumping at sea and litter from beaches and storm drains (Andrady 2011).

The number of species confirmed to be at risk from ingesting or becoming entangled in plastic debris has increased from around 265 species in the mid-1990s (Laist 1997) to more than 690 (Gall and Thompson 2015; Vegter et al. 2014), including sea turtles (Carr 1987), fish (Carson 2013), and seabirds (Ryan 1990) as well as species lower down in marine food webs (Wright et al. 2013). While the number of quantitative studies demonstrating impacts is limited (Rochman et al. 2016), there is increasing evidence that plastic could pose a threat at the population level with ingestion of plastic linked to reduced survival and breeding rates in shearwaters, fish, and oysters (Lavers et al. 2014; Rochman et al. 2013b; Sussarellu et al. 2016).

Globally, many seabird populations are experiencing declines (Croxall et al. 2012). While entanglement in marine plastic debris currently accounts for low levels of mortality

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of seabird species (i.e., the threat is largely at the level of the individual; Lavers et al. 2013; Nel and Nel 1999; Votier et al. 2011), members of the order Procellariiformes (albatrosses, petrels, and shearwaters) are particularly susceptible to harm by ingested plastics which can impair gastrointestinal function (Ryan 2015; Sievert and Sileo 1993) and carry contaminants (Lavers and Bond 2016b; Lavers et al. 2014; Tanaka et al. 2013; Tanaka et al. 2015). The ingestion of plastic by Hawaiian seabirds, such as the Laysan albatross (*Phoebastria immutabilis*), has received much attention (Kenyon and Kridler 1969; Lavers and Bond 2016b; Pettit et al. 1981; Sievert and Sileo 1993; Young et al. 2009). In contrast, data on the frequency of plastic ingestion and potential impacts on Hawaiian populations of wedge-tailed shearwaters (*Ardenna pacifica*), and in particular the globally endangered Newell's shearwater (*Puffinus newelli*), are rare.

Global production of plastics is predicted to reach 33 billion tons by 2050 (Rochman et al. 2013a), a dramatic increase from the 275 million tons produced in 2010 (Jambeck et al. 2015) and the 1.5 million tons produced in 1950 (UNEP 2014). The risk posed to marine wildlife is likely to increase in line with plastic production (Gall and Thompson 2015; van Franeker and Law 2015); therefore, understanding the propensity for seabirds to ingest plastic is an important step toward reducing its impact on populations. Here, we identify species-specific differences in the frequency of occurrence and composition of plastic ingested by Newell's and wedge-tailed shearwaters from Kaua'i in relation to features such as the availability of plastic in the local environment.

## Materials and methods

This study was conducted on the island of Kaua'i, HI, USA (22.1° N, 159.5° W). Populations of endangered Newell's shearwater on Kaua'i are confined to high-altitude mountainous areas, mainly toward the northwest of the island (BirdLife International 2013; KESRP unpublished data). Wedge-tailed shearwaters are more numerous and are found in colonies scattered along lowland coastlines (Byrd et al. 1983). Adult and fledgling Newell's and wedge-tailed shearwater carcasses were collected by the Kaua'i Endangered Seabird Recovery Project (KESRP), the Save Our Shearwaters program, and the Hawaii State Division of Forestry and Wildlife during 2007–2014. Carcasses included birds that had either been killed by introduced predators or were victims of light attraction and power line collisions. Necropsies and processing of ingested plastic items were undertaken in November 2013 and from May to August 2014 following protocols set out by the Save the North Sea monitoring program (van Franeker 2011; van Franeker et al. 2005). The entire digestive system was removed, from esophagus to cloaca. Digestive track contents were flushed with water and plastic items separated from organic matter.

Plastic items were gently washed to remove organic material, dried at room temperature, and weighed to the nearest 0.0001 g by using an electronic balance. The maximum length, width, and depth of each item were measured to the nearest 0.1 mm by using Vernier calipers. Plastic items collected from inside the shearwaters were then separated into plastic types based on standardized categories established by van Franeker (2011) including industrial plastic pellets ("nurdles") and user plastics, which were further subdivided into sheet (soft plastics such as bags), threads (e.g., fishing line and rope), fragments, and others (e.g., rubber). Plastic items were further sorted into the following six color categories: white (including clear), black (including gray and brown), yellow, green, red (including pink), and blue.

Plastics found on beaches are thought to reflect availability in the surrounding marine environment (Thiel et al. 2013). During July–September 2014, plastic items were collected from North Aliomanu Beach, located on the north shore of Kaua'i (22.2° N, 159.3° W), where the heaviest accumulation of beach-washed plastic items has been shown to occur (Cooper and Corcoran 2010). In order to ensure consistent sampling, the beach was divided into four areas. Once a week, a 1 × 1-m quadrat was established along the high tide mark within one of the four randomly selected areas of the beach. The quadrat was marked with stakes at each corner, and the sediment to a depth of 1 cm was sifted (1-mm mesh size) for plastic. Beach-washed plastic items were separated into the same type and color categories and measured as described above.

Statistical analyses were carried out by using R 3.2.4 (R Core Team 2016). Frequency and mass are presented as mean ± standard deviation (SD). The proportion of colors and types of ingested plastic was compared with the proportion found on North Aliomanu Beach by using two metrics. First, we examined the overall similarity in color and type proportions by using Jaccard's index (Real and Vargas 1996). The resulting value ($J$) ranges from 0 to 1, where $J = 0$ indicates complete dissimilarity and $J = 1$ complete similarity in the proportions of colors or types of plastics. Values of $J \geq 0.60$ are considered to represent significant overlap (Bond et al. 2012; Lavers and Bond 2016a). We then looked for evidence of shearwater preference or avoidance of individual colors or types by using Ivlev's electivity index ($E_i$):

$$E_i = (r_i - P_i) \Big/ (r_i + P_i) \quad (1)$$

where $r_i$ is the proportion of color or plastic type $i$ ingested by the shearwaters and $P_i$ is the proportion of color or plastic type $i$ in the environment relative to the total available plastic. A value of −1 indicates an item that was ignored or avoided, and a value of +1 describes an item that was highly favored

(Ivlev 1961). We tested for difference in the size of individual pieces, measured using the volume in cubic millimeters, between beach plastic and plastic found in the proventriculus and gizzard of both species by using an analysis of variance, with $\alpha = 0.05$.

## Results

A total of 30 Newell's shearwater fledglings (no adults) were sampled along with 19 adult and 13 fledgling wedge-tailed shearwaters. Plastic items were recovered from the proventriculus and the gizzard of both species, with no plastic detected in the intestinal tract. Fifteen (50.0 %) of the Newell's shearwater fledglings were found to contain plastic, with an average of 1.20 ± 1.50 pieces of plastic per bird, weighing 0.01 ± 0.01 g (Table 1). For wedge-tailed shearwaters, the frequency of ingested plastic was considerably higher in fledgling wedge-tailed shearwaters (76.9 %) when compared to adults (42.1 %; Table 1). The mass and the number of items ingested by fledgling wedge-tailed shearwaters (0.03 ± 0.03 g, 2.39 ± 1.94 pieces/bird) and adult (0.22 ± 0.91 g, 3.68 ± 9.29 pieces/bird) wedge-tailed shearwaters varied considerably.

Locations of plastics were variable between age classes and species. Adult wedge-tailed shearwaters had similar quantities of plastics in the gizzard and proventriculus (54.3 and 45.7 %), while wedge-tailed shearwater fledglings had 77.4 % of plastics found in gizzard and 22.6 % in proventriculus. Newell's shearwater fledglings had a similar distribution of plastics between gizzard and proventriculus to that of wedge-tailed shearwater fledglings, having 61.1 % of plastics found in gizzard with 38.9 % found in proventriculus.

Newell's shearwater fledglings contained a total of 36 pieces of plastic, most of which were white ($n = 28$, 77.8 %) and black ($n = 5$, 13.9 %; Table 2). Wedge-tailed shearwater fledglings ($n = 13$) ingested a total of 31 pieces of plastic, the majority of which was white ($n = 24$, 77.4 %) with only small amounts of other colors (Table 2). Wedge-tailed shearwater adults ($n = 19$) ingested a total of 69 pieces of plastic (and one nonplastic item, see below), the majority of which was white ($n = 57$, 82.6 %; Table 2).

Newell's shearwater fledglings contained mostly small threads (sections of line or rope; $n = 22$, 61.1 %) and hard

**Table 1** Summary of plastic ingestion studies for adult (A) and fledgling (F) wedge-tailed and Newell's shearwaters

| Year | Age | Location | Number | FO | Mean pieces | Max pieces | Mean mass (g) | Max mass (g) | Reference |
|---|---|---|---|---|---|---|---|---|---|
| Wedge-tailed shearwater | | | | | | | | | |
| 1978–1981 | A and F[a] | Hawaii, USA | 233 | 0.0 | 0.0 | ND | ND | ND | Day et al. (1985) |
| 1984 | A | Manana Is., Oahu, USA | 20 | 60.0 | ND | ND | ND | ND | Fry et al. (1987) |
| 1984–1988 | A and F | Equatorial Pacific | 35 | 2.9 | 1.0 | ND | ND | ND | Ainley et al. (1985) |
| 1986–1987 | A | Hawaii, USA | 247 | 13.7 | ND | ND | ND | ND | Sileo et al. (1990) |
| 1986–1987 | F | Hawaii, USA | 18 | 28.0 | ND | ND | ND | ND | Sileo et al. (1990) |
| 1984–1991 | F[b] | Tropical Pacific Ocean | 85 | 24.0 | 3.5 | 9 | ND | ND | Spear et al. (1995b) |
| 2005 | F[c] | Lord Howe Is., Australia | 30 | 43.0 | ND | ND | 0.70 | ND | Hutton et al. (2008) |
| 2005 | F[d] | Lord Howe Is., Australia | 22 | 14.0 | ND | ND | 5.83 | 11.0 | Hutton et al. (2008) |
| 2012 | F | Heron Is., Australia | 24 | 20.8 | 3.2 | 5 | 0.06 | 0.11 | Verlis et al. (2013) |
| 2012 | A | Heron Is., Australia | 32 | 0.0 | ND | ND | ND | ND | Verlis et al. (2013) |
| *2011–2014* | *A* | *Kaua'i, USA* | *19* | *42.1* | *3.68 ± 9.29* | *40* | *0.22 ± 0.91* | *0.08* | *This study* |
| *2011–2013* | *F* | *Kaua'i, USA* | *13* | *76.9* | *2.38 ± 1.94* | *31* | *0.03 ± 0.03* | *0.13* | *This study* |
| Newell's shearwater | | | | | | | | | |
| 1987 | F | Kaua'i, USA | 18 | 11.0 | ND | ND | ND | ND | Sileo et al. (1990) |
| *2007–2013* | *F* | *Kaua'i, USA* | *30* | *50.0* | *1.20 ± 1.49* | *5* | *0.01 ± 0.01* | *0.06* | *This study* |

Data from current study reported in italic font

*FO* frequency of occurrence (%), *ND* no data available

[a] 80 % of wedge-tailed shearwater samples from adults and 20 % from dependent young (Harrison et al. 1983 cited in Day et al. 1985)

[b] Fledgling status recorded only in the first 4 months following postfledging dispersal; therefore, some birds may have been first-year juveniles (Spear et al. 1995b)

[c] Proventriculus of live fledglings sampled using stomach flushing (Hutton et al. 2008)

[d] Necropsied fledglings found freshly dead in the colony (Hutton et al. 2008)

**Table 2** Dimensions (mm ± SD) and frequency of occurrence (%FO) of the color and the number of plastic items ingested by wedge-tailed shearwaters (WTSH) and Newell's shearwaters (NESH) and recorded on Aliomanu Beach, Kaua'i

| Category | Age class | Max length (mm) | Max width (mm) | Max depth (mm) | White | Blue | Green | Yellow | Red | Black |
|---|---|---|---|---|---|---|---|---|---|---|
| WTSH | Adult | 6.2 ± 3.8 | 4.5 ± 3.1 | 1.8 ± 1.3 | 57 (82.6) | 5 (7.2) | 3 (4.3) | 4 (5.8) | 0 (0.0) | 0 (0.0) |
| WTSH | Fledgling | 4.0 ± 1.7 | 2.8 ± 1.2 | 1.1 ± 1.0 | 24 (77.4) | 0 (0.0) | 2 (6.5) | 2 (6.5) | 1 (3.2) | 2 (6.5) |
| NESH | Fledgling | 3.9 ± 2.6 | 1.0 ± 1.4 | 0.4 ± 0.6 | 28 (77.8) | 1 (2.8) | 2 (5.6) | 0 (0.0) | 0 (0.0) | 5 (13.9) |
| Aliomanu Beach | N/A | 7.4 ± 8.8 | 4.3 ± 3.0 | 1.5 ± 1.0 | 75 (66.4) | 20 (17.7) | 5 (4.4) | 1 (0.9) | 4 (3.5) | 7 (6.2) |

plastic fragments ($n$ = 13 including one piece of melted plastic, 36.1 %; Table 3), while adult and fledgling wedge-tailed shearwaters primarily ingested hard plastic fragments (adults $n$ = 60 including one melted plastic and one bottle cap, 87.0 %; fledglings $n$ = 26, 83.9 % (Table 3)). Seventy percent of items ingested by Newell's and wedge-tailed shearwater fledglings ($n$ = 21 items per species) were classified as microplastics (1–5 mm), while only 59 % of wedge-tailed shearwater adults had consumed microplastics ($n$ = 41 pieces; Table 2). In total, 113 individual pieces of plastic were recovered from North Aliomanu Beach in northern Kaua'i. Of the plastic items collected, the majority were white ($n$ = 75, 66.4 %) or blue ($n$ = 20, 17.7 %; Table 2). The majority of plastic items recovered from the beach were hard plastic fragments ($n$ = 92, 81.4 %), followed by industrial pellets ($n$ = 12, 10.6 %) and thread (n = 4, 3.5 %), with small amounts of foam (Table 3). Overall, 58 % ($n$ = 66) of plastic items found on the beach were classified as microplastics (1–5 mm; Table 2).

We found a high degree of similarity between ingested and beach-washed plastic colors in both wedge-tailed and Newell's shearwater fledglings ($J$ = 0.68 and 0.66, respectively) and wedge-tailed shearwater adults ($J$ = 0.65). There was also evidence of overlap in the color of items ingested by fledglings of both species ($J$ = 0.81). While the type of plastic ingested by Newell's shearwaters did not overlap significantly with that found on the beach ($J$ = 0.27), there was considerable overlap in the type of plastic ingested by adult ($J$ = 0.87) and fledgling ($J$ = 0.85) wedge-tailed shearwaters and beach plastic. We also found no significant difference in the volume of pieces ingested by either species in either portion of the gastrointestinal tract and plastic found from beach surveys ($F_{4, 239}$ = 1.93, $p$ = 0.11; Table 2).

There was little evidence for active selection of plastic by color for either species or age class. Shearwaters tended to not ingest colors that were found in low proportions on beaches, suggesting an effect of sample size. The exception to this is blue, which comprised 18.0 % of beach plastic but only 0–7.0 % of plastic in shearwaters (Table 2). There was a considerable preference for ingesting threads by Newell's shearwaters ($E_i$ = 1.00), which was completely absent from juvenile wedge-tailed shearwaters (Tables 4 and 5). Wedge-tailed shearwater ingestion of fragments closely matched that found in beach plastics ($E_i$ = −0.02 to −0.05; Table 5).

## Discussion

The proportion of Newell's shearwater fledglings ingesting plastic in Kaua'i appears to have increased from 11.0 % in 1987 (Sileo et al. 1990) to 50.0 % in 2007–2013 (Table 1). In Hawaii, the proportion of wedge-tailed shearwater fledglings and adults ingesting plastic is somewhat variable but appears to have more than doubled, from 13.7 and 28.0 % in 1986–1987, respectively, to 76.9 and 42.1 % during 2007–2012 (Table 1). For both species, there is some evidence that the mass and the number of items ingested per bird have also increased since the 1980s (Table 1). Larger amounts of plastic being consumed by a greater proportion of the population in more recent years have also been observed in Laysan and black-footed albatrosses (*P. nigripes*) as well as Bonin petrels (*Pterodroma hypoleuca*) from Hawaii (Gray et al. 2012; Lavers and Bond 2016b); this is thought to parallel the deteriorating condition of the surrounding marine environment (Lavers and Bond 2016b). An alternative hypothesis is that

**Table 3** Frequency of occurrence (%FO) of the type and the number of plastic items ingested by wedge-tailed shearwaters (WTSH) and Newell's shearwaters (NESH) and recorded on Aliomanu Beach, Kaua'i

| | Age class | Pellet | Thread | Sheet | Foam | Fragment | Other |
|---|---|---|---|---|---|---|---|
| WTSH | Adult | 6 (8.5) | 1 (0.02) | 0 (0.0) | 0 (0.0) | 64 (98.5) | 0 (0.0) |
| WTSH | Fledgling | 4 (12.9) | 0 (0.0) | 1 (3.7) | 0 (0.0) | 26 (96.3) | 1 (1.4) |
| NESH | Fledgling | 0 (0.0) | 25 (62.5) | 0 (0.0) | 0 (0.0) | 14 (35.0) | 1 (0.03) |
| Aliomanu Beach | NA | 12 (10.6) | 5 (0.05) | 0 (0.0) | 2 (0.2) | 94 (93.1) | N/A[a] |

Plastic categories based on van Franeker (2011; see Materials and methods section)

[a] Nonplastic items were not collected during beach surveys

**Table 4** Ivlev's electivity index ($E_i$) for plastic colors ($n$ = 112) in wedge-tailed shearwaters (WTSH) and Newell's shearwaters (NESH) relative to plastic items recorded on Aliomanu Beach, Kaua'i ($n$ = 113)

| Species | Age class | White | Blue | Green | Yellow | Red | Black |
|---|---|---|---|---|---|---|---|
| NESH | Fledgling | +0.14 | −0.69 | +0.19 | −1.00 | −1.00 | −0.37 |
| WTSH | Adult | +0.12 | −0.42 | −0.22 | +0.73 | −1.00 | −1.00 |
| WTSH | Fledgling | +0.08 | −1.00 | +0.19 | +0.76 | −0.05 | −0.05 |

Values range from −1 (complete avoidance) to +1 (complete preference)

these species have switched key foraging areas between the two study periods perhaps due to ocean warming and changes in ocean currents, biological productivity, and fish stock movement (which might then expose birds to marine areas with different degrees of plastic debris), although this seems like a less likely scenario.

Variable rates of plastic ingestion have been recorded in Australian populations of wedge-tailed shearwaters, with 23.9–30.7 % of fledglings sampled on Lord Howe Island during 2005–2016 containing plastic (Hutton et al. 2008; Lavers et al., Trends in the ingestion of marine debris by Wedge-tailed Shearwaters (Ardenna pacifica) on Lord Howe Island during 2005-2016. Marine Pollution Bulletin, submitted) compared to only 20.8 % on Heron Island in 2012 (Verlis et al. 2013). The differences between these studies may reflect a difference in foraging ranges. Seabirds foraging within areas of higher plastic concentration have been shown to exhibit a higher incidence of plastic consumption (Young et al. 2009); therefore, temporal or spatial variation in the level of plastic contamination in the waters surrounding Kaua'i may also explain the differential ingestion rates for Newell's and wedge-tailed shearwaters, as well as differences in type of plastics ingested by two species.

On Kaua'i, differences in prevalence of plastic ingestion may also be due to the foraging behavior of Newell's shearwaters which feed primarily in offshore (pelagic) waters by pursuit plunging to depths of up to 50 m (T. Joyce unpublished data; Ainley et al. 2014; Spear et al. 1995a). In contrast, wedge-tailed shearwaters from Hawaii tend to feed closer to their breeding islands and primarily in surface waters (Hyrenbach et al. 2014) where they are more likely to encounter floating plastic (Avery-Gomm et al. 2013; Morris 1980; Ryan 1987). The prevalence of ingestion and the color of plastic consumed by seabirds may also be influenced by their prey preferences, as some North Pacific fish species have been shown to ingest plastic (Boerger et al. 2010; Jantz et al. 2013).

**Table 5** Ivlev's electivity index ($E_i$) for plastic type ($n$ = 102) in wedge-tailed shearwaters (WTSH) and Newell's shearwaters (NESH) relative to plastic items recorded on Aliomanu Beach, Kaua'i ($n$ = 113)

| Species | Age class | Pellet | Sheet | Thread | Foam | Fragment | Other |
|---|---|---|---|---|---|---|---|
| NESH | Fledgling | −1.00 | NA | +1.00 | −1.00 | −0.41 | −0.21 |
| WTSH | Adult | −0.11 | NA | +1.00 | −1.00 | −0.02 | −1.00 |
| WTSH | Adult | +0.10 | +1.00 | NA | −1.00 | −0.05 | −1.00 |

Values range from −1 (complete avoidance) to +1 (complete preference)

White plastic was the most common item consumed by wedge-tailed and Newell's shearwater adults and fledglings from Kaua'i, accounting for 77–83 % of items ingested (Table 2). The majority of plastic items ingested by shearwater species in Australia foraging in the Tasman Sea and 21 species of North Atlantic seabird are also white (Lavers et al. 2014; Moser and Lee 1992; Verlis et al. 2013). White was also the most common color (66.3 %) of plastic recorded during beach surveys on Kaua'i, followed by blue (17.7 %) and black (6.2 %; Table 2), and there was significant overlap in the color of items on local beaches and those ingested by the shearwaters ($J$ = 0.65–0.68; Table 4). While light-colored items are generally more abundant in the marine environment (Day et al. 1990; Shaw and Day 1994), some seabird species, including Newell's and wedge-tailed shearwaters, appear to exhibit selection for certain colors of plastic (Table 2), presumably based on resemblance to preferred prey as has been reported in other seabird species (Blight and Burger 1997; Cooper et al. 2004; Lavers and Bond 2016a). For example, wedge-tailed shearwaters exhibited strong selection for yellow plastic ($E_i$ > 0.70, Table 2), while adult Newell's shearwater avoided yellow completely (i.e., no yellow plastic items were fed to fledging Newell's by the parent birds; $E_i > -1.00$, Table 2). Both species avoided blue and brown plastics ($E_i > -0.40$, Table 2), possibly due to the inconspicuous nature of darker items on the ocean surface and/or the relatively low occurrence of these colors in the shearwater's natural prey.

Newell's shearwater fledglings ingested primarily small threads (line or rope ≤5 mm in length) and hard plastic fragments (Tables 2 and 3), with threads in much greater proportion than was available in the environment ($E_i$ = 0.86). In contrast, wedge-tailed shearwater fledglings ingested mostly hard microplastic fragments and industrial pellets (≤5 mm; Table 2), similar to what was found on the beach (Table 3). A recent review of plastic ingestion by marine wildlife found that among 208 seabird species, fragments were the most commonly ingested type of plastic (Gall and Thompson 2015). The type and color of beach-washed plastic items exhibited a moderate degree of overlap with plastic ingested by fledglings and adults of both shearwater species ($J$ > 0.65; Tables 3 and 4). Newell's shearwaters and wedge-tailed shearwaters have foraging areas that overlap (Ainley et al. 1997; Whittow 1997), suggesting that both species are subjected to similar types and amounts of plastics in foraging areas of Hawaii.

The high frequency of threads found in Newell's shearwaters, which was absent entirely in wedge-tailed shearwaters, may be explained by the depth or primary prey species on which this species feeds. Newell's shearwater diet primarily consists of purpleback flying squid (*Sthenoteuthis* *oualaniensis*) (Ainley et al. 2014). This species of squid feeds on myctophids (Shchetinnikov 1992), which have been shown to ingest plastic pieces (Boerger et al. 2010). Therefore, it is plausible that Newell's shearwaters obtained plastics, at least in part, through secondary consumption (Hammer et al. 2016).

Young seabirds, especially those within the Procellariformes, often contain more plastics than adults (Lavers and Bond 2016a; Spear et al. 1995b; van Franeker et al. 2011). A similar pattern was observed for wedge-tailed shearwaters on Kaua'i, with fledglings containing approximately eight times more plastic by mass than adults (Table 1), likely due to adults offloading plastic to their chicks during the breeding season (Carey 2011; Hammer et al. 2016; Rodríguez et al. 2012).

While plastic has been found in the intestinal tract of fish and turtle species (Davison and Asch 2011; Lutz 1990), no plastic items were recovered from the intestines of Newell's or wedge-tailed shearwaters examined during this study or from the intestinal tract of 21 seabird species from the North Atlantic (Moser and Lee 1992). This suggests that plastic is retained by many seabird species within the proventriculus and gizzard (plastic retention times reported for seabirds ranges from 40 days to 12 months; Day 1980; Pettit et al. 1981; Ryan 2015), with many species exhibiting little or no capacity to excrete large or indigestible plastic items.

## Conclusion

The amount of plastic in the oceans is increasing and poses an increased risk of entanglement, ingestion, and thus morbidity and mortality for marine life (Rochman et al. 2016). Plastic ingested by seabirds has been shown to block and take up space in the digestive tract, contributing to dehydration and in some cases starvation (Spear et al. 1995b). The increased prevalence and amount of plastic consumed by shearwaters on Kaua'i compared to earlier studies is therefore disturbing, particularly in light of new data showing that consumption of even small quantities of plastic (for example, the fibers and small fragments ingested by both adult and juvenile birds in this study) exposes animals at all stages of the breeding cycle to plastic-associated copollutants (e.g., metals and flame retardants; Lavers and Bond 2016a; Lavers et al. 2014; Tanaka et al. 2013; Tanaka et al. 2015).

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