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Selectivity of flesh-footed shearwaters for plastic colour: Evidence for differential provisioning in adults and fledglings

Jennifer L. Lavers [a, *], Alexander L. Bond [b]

[a] Institute for Marine and Antarctic Studies, University of Tasmania, 20 Castray Esplanade, Sandy Bay, Tasmania, 7004, Australia
[b] RSPB Centre for Conservation Science, Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire, SG19 2DL, United Kingdom

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ABSTRACT

The ingestion of plastic by seabirds has been used as an indicator of population and ocean health. However, few studies have examined adults and juveniles of the same species concurrent with the availability of plastic in the local marine environment. In King George Sound (KGS), Western Australia, 13% of adult flesh-footed shearwaters (*Ardenna carneipes*) and 90% of fledglings contained plastic items in their digestive tract. On Lord Howe Island (LHI), New South Wales, 75% of adult shearwaters and 100% of fledglings contained plastic.

Ingested items were assessed using Jaccard's Index (where $J = 0$ indicates complete dissimilarity and $J = 1$ complete similarity). The colour of items ingested by self- and chick-provisioning shearwaters from KGS exhibited broad overlap with plastic available in the local environment ($J = 0.78–0.80$), and plastic in adults and fledglings from LHI were less similar to those available ($J = 0.31–0.58$). Additional data on seabird colour selection would improve our understanding of the factors influencing the behaviour of ingesting plastic, and its contribution to the decline of some species.

1. Introduction

Since the introduction of plastic into the industrialized world more than a century ago, the accumulation of plastic waste has become a growing concern, accounting for up to 80% of the pollution found in the marine environment (UNEP, 2014; Woodall et al., 2014). The presence of plastics in the world's oceans has increased greatly due in part to poor waste management, illegal dumping of litter, ineffective or insufficient legislation, and increasing demand for, and production of, plastic products (Rochman et al., 2013; Thompson et al., 2009). Society's awareness of this global problem is increasing, largely due to the visible and confronting impacts of plastic pollution on marine wildlife (Newman et al., 2015; Tudor and Williams, 2003).

The ingestion of plastic debris by marine birds was first reported in Laysan albatross (*Phoebastria immutabilis*) fledglings in the early 1960s (Kenyon and Kridler, 1969). In the mid-1990s an estimated 35% of the world's seabird species were known to ingest or become entangled in plastic (Laist, 1997), a number which grew to 56% of seabird species in 2014 (Gall and Thompson, 2015). Ingested plastic has been linked to a variety of negative health effects in seabirds, including nutritional deprivation (i.e., starvation; Pierce et al., 2004) and reduced body mass and growth rates (Lavers et al., 2014; Sievert and Sileo, 1993). Once ingested, contaminants absorbed to the surface of plastic from the surrounding sea water may be introduced into an animal's tissues and contribute to a range of physiological effects (Browne et al., 2013; Lavers and Bond, in press; Lavers et al., 2014; Tanaka et al., 2013).

In Australia, 90% of flesh-footed shearwater (*Ardenna carneipes*) fledglings contain considerable quantities of plastic (Lavers et al., 2014), fed to chicks by their parents, who presumably mistake floating plastic items for prey. Ingested plastic has been implicated in reduced fledgling body condition, increased pollutant concentrations in tissues, and the decline of this species on Lord Howe Island (Hutton et al., 2008; Lavers et al., 2014; Priddel et al., 2006). Whether adult flesh-footed shearwaters are similarly affected by ingested plastic is unclear, but this information is critical to linking trends in seabird populations with increasing densities of plastic in the world's oceans (Gregory, 2009).

It has long been hypothesized that birds exhibit a preference for different colours of plastic, and that this varies by species and location (Lavers et al., 2014; Ryan, 1987), but testing this relationship has been hampered by a lack of information on the type or

* Corresponding author.
E-mail address: Jennifer.Lavers@utas.edu.au (J.L. Lavers).

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colour of plastic available in the local environment, thereby confounding any analysis of preference with availability. Most plastic is found at the ocean surface (Reisser et al., 2015), which is similar to that on nearby beaches (Dahlberg and Day, 1985; Davis and Murphy, 2015; Day et al., 1985), and could therefore act as a proxy for the proportions of colours available to foraging birds.

Here we report on the frequency, number, and mass of plastic items ingested by adult and fledgling flesh-footed shearwaters in Western Australia and Lord Howe Island, and compare the colour of ingested plastic with samples taken from nearby beaches to determine whether flesh-footed shearwaters exhibit any colour preference for ingested plastic.

2. Methods

2.1. Ingested plastic

In King George Sound (KGS), Western Australia (35.03°S, 117.93°E; Fig. 1), freshly dead adult shearwaters taken as bycatch in a purse seine fishery were collected during September–April 2009–2014. Beach-washed fledglings were collected from nearby Barker's Bay (35.05°S, 117.92°E; Fig. 1) in late-April 2013.

On Lord Howe Island (LHI), New South Wales (31.55°S, 159.08°E; Fig. 1), freshly dead adult shearwaters (primarily road kill) were collected in January 2012–2013. Fledglings from LHI were collected in April 2011 (additional data on these birds is reported in Lavers et al. (2014)). Ingested plastic was collected from the proventriculus and gizzard by necropsy (van Franeker et al., 2004). Plastic items were dried, weighed to the nearest 0.001 g using an electronic balance, and sorted by colour and type following Lavers et al. (2014) and van Franeker et al. (2004).

2.2. Beach-washed plastic

All plastic items >5 mm located on the surface of the beach from the high-water mark up to the landward berm (approx. 5 m) were recorded from Ned's Beach on LHI (Fig. 1) in April 2011 and three beaches (Goode, Middleton, and Perkins; Fig. 1) in KGS in March 2015. Transects extended along the majority of the length of the beach (minimum distance 500 m). Sites were mostly sandy, and were chosen based on proximity to breeding sites and accessibility.

2.3. Statistical approach

We compared the proportion of colours of ingested plastic with the proportion found on nearby beaches using two metrics. At a broad scale, we looked at the overall similarity in the proportions of colours 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 colours overall. Values of $J \geq 0.60$ are considered to represent significant overlap (Bond et al., 2012; Catry et al., 2009). We then examined preference or avoidance of individual colours using Ivlev's Electivity Index (E_i):

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

where r_i is the proportion of colour i ingested by the shearwaters, and P_i is the proportion of colour i in the environment relative to the total available plastic. A value of -1 indicates a prey item that was totally ignored, and a value of $+1$ describes a food item that was highly favoured (Ivlev, 1961).

3. Results

3.1. Adult shearwaters

Fifteen (12.9%) of 136 adult birds from KGS contained an average of 1.667 ± 1.113 pieces of plastic weighing 0.061 ± 0.056 g (Table 1). Twenty-six pieces of ingested plastic were identified, the majority of which were hard plastic fragments (53.8%; n = 14), followed by

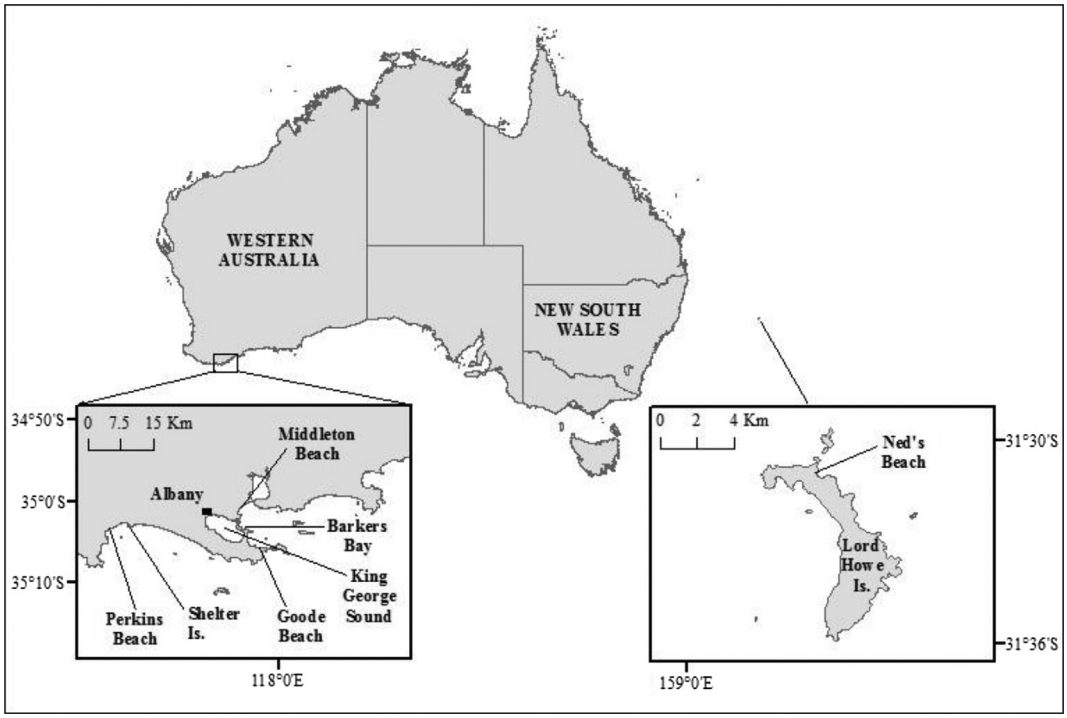

Fig. 1. Location of flesh-footed shearwater breeding islands and key sites mentioned in the text.

Table 1
Frequency of occurrence (FO), mean number, and mass (g) of plastic items ingested by adult and fledgling flesh-footed shearwater from King George Sound (KGS), Western Australia and Lord Howe Island (LHI; Lavers et al., 2014).

Age class	Site	n	FO	Mean number	Mass (g)	Reference
Adult	KGS	136	0.129 ± 0.092	1.733 ± 1.223	0.061 ± 0.056	This study
Adult	LHI	4	0.750	2.250 ± 2.217	0.390 ± 0.772	This study
Fledgling	KGS	7	1.000	18.833 ± 34.452	1.367 ± 3.113	This study
Fledgling	LHI	38	0.897	17.474 ± 44.860	2.697 ± 10.600	Lavers et al. (2014)

rope fragments (34.6%; n = 9), and industrial pellets (nurdles; 11.5%; n = 3; Table 2). Black (34.6%, n = 9) and white (30.8%, n = 8) plastic were the most commonly ingested, followed by red/pink (15.4%, n = 4), yellow/orange (7.7%, n = 3), blue (3.8%, n = 1), and green (3.8%, n = 1; Table 2).

Three (75%) of four adult shearwaters from LHI contained an average of 2.25 ± 2.21 pieces of plastic weighing 0.39 ± 0.77 g (Table 1). In total, nine pieces of plastic were ingested by the birds, the majority of which were hard white fragments (88.9%; Table 2).

3.2. Fledgling shearwaters

All fledglings (n = 6) from KGS contained an average of 18.83 ± 34.45 pieces of plastic weighing 1.37 ± 3.11 g (Table 1). Eighty-nine pieces of ingested plastic were identified, all of which were hard plastic fragments (Table 2). White (56.2%, n = 50) and green (23.6%, n = 21) plastic were the most commonly ingested, followed by blue (16.9%, n = 15), red/pink (2.2%, n = 2), and black (1.1%, n = 1; Table 2).

Ninety percent of fledglings (n = 38) from LHI contained and average of 17.474 ± 44.860 pieces of plastic weighing 2.967 ± 10.600 g (Table 1; Lavers et al., 2014). We identified 848 pieces of ingested plastic, the majority (63.7%; n = 580) of which were hard plastic fragments (Table 2). White (68.5%, n = 581) and blue (10.2%, n = 87) plastic were the most commonly ingested, followed by green (16.9%, n = 15), black (2.2%, n = 2), red/pink (2.5%, n = 21), and yellow/orange (1.5%, n = 13; Table 2).

3.3. Beach plastic

A total of 1440 and 477 plastic items were recorded on LHI and in KGS beaches, respectively. In KGS, blue (42.1%, n = 201) and green (32.1%, n = 153) plastics were the most numerically abundant, followed by white (9.8%, n = 47), black (6.5%, n = 31), yellow/orange (5.2%, n = 25), red/pink (3.8%, n = 18), and purple (0.4%, n = 2). In contrast, white (29.4%, n = 423) and yellow/orange (17.5%, n = 252) were the most common colours of beach plastic recorded on LHI, followed by black (13.1%, n = 189), purple (12.5%, n = 180), green (9.7%, n = 140), and red/pink (8.8%, n = 126).

3.4. Colour preference

We found a low degree of similarity between ingested and beach-cast plastic colours in adult shearwaters from LHI ($J = 0.31$), though based on only nine pieces of ingested plastic (Table 2). Ingested plastic from adults from KGS, however, showed much higher overlap ($J = 0.80$) with beach plastic items from KGS, though again based on relatively small sample of 26 pieces. The colour of plastics ingested by LHI fledglings were also broadly similar to those found on beaches at LHI ($J = 0.58$), notably higher than that of LHI adults. Plastic ingested by fledglings in KGS had high overlap ($J = 0.78$) with beach plastic from KGS, similar to adults from the region. Adults from LHI and KGS had high overlap in the colour of their ingested plastic ($J = 0.79$), while fledglings from the two sites had ingested plastic of differing colour compositions ($J = 0.29$).

Adults on LHI showed little preference for any colour, though they selected green slightly more than random ($E_i = 0.36$). Adults in KGS selected black ($E_i = 0.66$) and white ($E_i = 0.52$) with greater frequency than they were available in the environment (Table 3). Adults had a mild preference for delivering white plastic to their chicks in both locations (LHI $E_i = 0.40$, KGS $E_i = 0.76$) and a strong aversion to yellow/orange (LHI $E_i = -0.84$, KGS $E_i = -1.00$), purple (E_i −1.00 at both sites), and red/pink on LHI only (LHI $E_i = -0.56$, KGS $E_i = -0.12$). Blue and green were found in similar proportions in chicks as on beach surveys on LHI, while both were generally avoided (green completely so) in KGS (Table 3).

Table 2
Type and colour of plastic items ingested by adult (2009–2014; n = 136) and fledgling (2013; n = 7) flesh-footed shearwaters in King George Sound (KGS), Western Australia and on Lord Howe Island (LHI; n = 4 adults in 2009–2012; n = 38 fledglings in 2011, from Lavers et al. (2014)).

Plastic type	Black	White	Red/Pink	Yellow/Orange	Blue	Green	Total	Proportion
Adults – KGS								
Fragment	3	5	3	3	0	0	14	0.538
Rope	6	0	1	0	1	1	9	0.346
Pellet	0	3	0	0	0	0	3	0.115
Fledglings – KGS								
Fragment	1	49	2	0	15	0	67	0.991
Pellet	0	1	0	0	0	0	1	0.009
Adults – LHI								
Fragment	0	8	0	0	0	1	9	1.000
Fledglings – LHI								
Fragment	65	580	21	13	87	80	848	0.998
Pellet	1	1	0	0	0	0	2	0.002

Table 3
Values of Ivlev's Electivity Index (E_i) for plastic colour between adult and fledgling flesh-footed shearwaters on Lord Howe Island (LHI) and in King George Sound (KGS), Western Australia and plastic from nearby beaches. Values show complete avoidance ($E_i = -1$), or complete preference ($E_i = 1$).

Colour	LHI adults	LHI fledglings	KGS adults	KGS fledglings
Blue	0.06	0.40	−0.84	−0.31
Green	−1.00	0.07	−0.79	−1.00
Red/pink	0.36	−0.01	0.61	−0.12
Orange/yellow	−1.00	−0.84	0.45	−1.00
Black	−1.00	−0.56	0.66	−0.65
Purple	−1.00	−0.25	−1.00	−1.00
White/clear	−1.00	−1.00	0.52	0.76

4. Discussion

The frequency of occurrence, mean mass, and number of plastic items ingested by fledgling flesh-footed shearwaters in KGS were comparable to that reported for fledglings on LHI (Table 1; Lavers et al., 2014). The type and colour of plastic items recovered from fledglings was differed between locations, though hard white fragments the most commonly ingested item (Table 2). Adult birds from LHI appeared to avoid black plastic items ($E_i = -1.0$; Table 2), while it was found in greater proportion in birds from KGS than available in the local environment ($E_i = 0.65$). Overall, the mean mass of plastic ingested by adult birds was low (KGS: 0.061 ± 0.056 g; LHI: 0.390 ± 0.772 g) compared to fledglings (Table 1).

The colour of plastic items recovered from adult and fledgling shearwaters from LHI exhibited a low degree of overlap ($J < 0.60$) with items available on Ned's Beach (Table 3). In contrast, there was high overlap between the colour of plastic recovered from adult ($J = 0.80$) and fledgling ($J = 0.78$) shearwaters and beaches in KGS (Table 3). This suggests self- and chick-provisioning adults from LHI, but not KGS, exhibit a strong preference for plastic colour when foraging in nearby waters. Flesh-footed shearwaters in KGS (adults and fledglings) and on LHI (fledglings) appear to differ in their preference for plastic colour, particularly for black (Table 2; Lavers et al., 2014) and white plastic (adults: 21.7%; fledglings: 68%; Lavers et al., 2014). Plastic selection in seabirds is thought reflect similarity to potential prey or conspicuousness at sea (Blight and Burger, 1997; Lavers et al., 2014). Limited diet data for flesh-footed shearwaters suggests fledglings on LHI are provisioned mainly with squid (Lavers et al., 2014), which may resemble white plastic. Diet data for incubating birds from KGS and non-breeders in the North Pacific suggests adult birds prefer pilchards *Sardinops sagax neopilchardus* and small lanternfish (*Myctophidae*), respectively (Gould et al., 1997) which may explain their preference for darker coloured plastic.

Differences in the type of plastic ingested were also recorded between age classes. For example, adult flesh-footed shearwaters from KGS frequently ingested small rope fragments (34.8%) which were not recorded in any of the fledglings examined (Table 2). This suggests adult Flesh-footed Shearwaters, like many seabirds, provision chicks differently than themselves (Bond et al., 2012; Davoren and Burger, 1999; Fijn et al., 2012; Wilson et al., 2004) and this may confer differential exposure to plastic items through direct or secondary ingestion (i.e., plastic items consumed by the shearwater's prey; Ryan and Fraser, 1988). Among shearwaters, adults tend to make lengthy offshore trips for their own energetic needs, while using closer resources on short trips for chick provisioning (Cleeland et al., 2014; Congdon et al., 2005; Schultz and Klomp, 2000). Flesh-footed shearwaters in Western Australia, however, forage almost exclusively in coastal waters (Lavers and Bond, in press; Powell, 2009) therefore differential exposure to, or selection for, plastic type and colour is unlikely to be influenced by location.

Age and breeding status are thought to influence the likelihood of seabirds ingesting or retaining plastic, as adults of some species offload plastic to their chicks (Table 3; Bond and Lavers, 2013; Carey, 2011; Spear et al., 1995). The majority (96.6%) of adult flesh-footed shearwaters sampled in this study were provisioning chicks (February–April), therefore low plastic ingestion rates could be a consequence of this offloading behaviour. We would therefore expect an increase in the amount and frequency of plastic during the non-breeding season when this mechanism for eliminating

Table 4
Frequency of occurrence (FO) and mean number of plastic items ingested by adult (A) and fledgling (F) seabirds (N = sample size).

Species	Age	N	FO	Mean plastic	Reference
Laysan albatross *Phoebastria immutabilis*	A	31	0.350		Sileo et al. (1990)
Laysan albatross *Phoebastria immutabilis*	F	233	0.906		Sileo et al. (1990)
Laysan albatross *Phoebastria immutabilis*	F	40	1.000	132.48	Lavers and Bond (in press)
Wedge-tailed shearwater *Ardenna pacificus*	A	18	0.280		Sileo et al. (1990)
Wedge-tailed shearwater *Ardenna pacificus*	F	247	0.137		Sileo et al. (1990)
Flesh-footed shearwater *Ardenna carneipes*	A[a]	136	0.129	1.667	This study
Flesh-footed shearwater *Ardenna carneipes*	F[a]	7	1.000	18.833	This study
Flesh-footed Shearwater *Ardenna carneipes*	A[b]	4	0.750	2.250	This study
Flesh-footed shearwater *Ardenna carneipes*	F[b]	38	0.897	17.474	Lavers et al. (2014)
Short-tailed shearwater *Ardenna tenuirostris*	A	102	0.627	4.50	Acampora et al. (2014)
Short-tailed shearwater *Ardenna tenuirostris*	F	27	0.850	7.14	Acampora et al. (2014)
Northern fulmar *Fulmarus glacialis*	A	49	0.820	5.3	Kühn and van Franeker (2012)
Northern fulmar *Fulmarus glacialis*	F	9	0.670	9.7	Kühn and van Franeker (2012)
Red-footed booby *Sula sula*	A	38	0.000		Sileo et al. (1990)
Red-footed booby *Sula sula*	F	131	0.047		Sileo et al. (1990)
Red-tailed tropicbird *Phaethon rubricauda*	A	8	0.000		Sileo et al. (1990)
Red-tailed tropicbird *Phaethon rubricauda*	F	16	0.440		Sileo et al. (1990)

[a] King George Sound, Western Australia.
[b] Lord Howe Island, New South Wales.

plastic is unavailable. Determining shearwaters' age class outside the breeding season can be challenging, which confounds inter-seasonal comparisons, as recently-fledged birds with large amounts of plastic may not be easily separated from adults, which have been eliminating ingested plastic for several months. In some other procellarids, there was no clear pattern in the frequency of plastic ingestion in adult birds across a range of studies (Bond et al., 2014). For example, Great Shearwater (*Puffinus gravis*) adults had a mean frequency of occurrence of 0.73 during the breeding season over seven studies, while the frequency dropped only to 0.65 in eight studies during the non-breeding period (Bond et al., 2014).

This pattern of higher incidences of plastic in adults rather than fledglings was not consistent among a variety of seabirds (Table 4). Adult wedge-tailed shearwaters (*Ardenna pacificus*) had twice the frequency of plastic than fledglings (Sileo et al., 1990). While adult short-tailed shearwaters (*Ardenna tenuirostris*) had a lower frequency of occurrence (0.63) than fledglings (0.85; Acampora et al., 2014), adults were clearly not offloading plastic to chicks in the same magnitude as we observed. Some species, however, do not offload any plastic to chicks. More than 90% of adult parakeet auklets (*Aethia psittacula*) contain ingested plastic (Robards et al., 1997), but plastic has not been recorded in chick meals (Bond et al., 2010). The reasons for the differences in how species manage their plastic burden merits further investigation, but require more data on ingestion by different age classes.

Our small samples of ingested plastics from adults from LHI ($n = 9$) and fledglings from KGS ($n = 26$) mean that some caution is warranted. The detection of rare or uncommon colours increases with sample size, which is similar to the challenges in species surveys where the probability of detection of rare species is a function of search effort. Low sample sizes can also increase the chance of "unseen pairs", the undetected presence of a rare species (or in our case, colour) in both samples (Chao et al., 2005), but as we had a defined set of categories *a priori*, this source of error is greatly reduced.

On LHI, small numbers of Flesh-footed Shearwater adults and fledglings die each year as a result of perforations to the stomach lining by large or sharp plastic items (Lavers et al., 2014). Based on the size and number of plastic items ingested by adult birds, mortality is likely rare. However, the occasional ingestion of small plastic items may still pose a hazard to flesh-footed shearwaters by exposing birds to contaminants adsorbed to the surface of plastic (Lavers et al., 2014; Tanaka et al., 2013). Adult flesh-footed shearwaters from Western Australia and LHI exhibit high concentrations of some trace metals, particularly mercury, cadmium, and lead (Bond and Lavers, 2011). The ingestion of plastic by Flesh-footed Shearwater adults and fledglings could therefore negatively influence all stages of the breeding cycle, which may partially explain the decline of this species across its range (Lavers, 2015; Reid et al., 2013; Waugh et al., 2013).

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