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Intergenerational transfer of plastic debris by Short-tailed Shearwaters (*Ardenna tenuirostris*)

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Abstract. Pollution of the world's oceans affects a wide variety of marine organisms and raises major conservation concerns. Ingestion of plastic debris has increased since the 1970s, particularly among the Procellariiformes, resulting in a range of lethal and sub-lethal side effects. Plastic loads (grams of plastic per bird) of adult Short-tailed Shearwaters (*Ardenna tenuirostris*) are well known from research in the northern hemisphere, but the amount of plastic ingested by their offspring has yet to be quantified. In this study, the stomach contents of fledgling Short-tailed Shearwaters on Phillip Island, Victoria, were analysed for plastic particles. All birds sampled contained plastic, averaging 7.6 particles per bird. The mean mass of plastic per bird was 113 mg. The most common type of plastic was user plastic, followed by industrial pellets. The birds contained a small proportion of other refuse, such as polystyrene and plastic bag. Plastics were primarily light in colour, though red and grey-black materials were also recorded. Despite a weak trend, no clear influence of ingested plastic on body condition could be demonstrated, although there was some evidence of physical damage to the gizzard. Accumulation of plastic objects in the digestive tract over time may indirectly affect the life cycle of species and their reproductive success, with long-term harm caused to populations. Data suggests that an assessment of the effect of this type of pollution on seabird welfare is urgently required.

Additional keywords: plastic pollution, marine debris, seabirds, shearwater.

Introduction

Marine pollution affects all the world's major oceans and coastlines and is a serious conservation concern (Derraik 2002). Marine debris can affect a wide range of wildlife species, including marine mammals (Arnould and Croxall 1995; Baird and Hooker 2000), sea turtles (Barreiros and Barcelos 2001; Bugoni *et al*. 2001; Tomás *et al*. 2002; Mascarenhas *et al*. 2004) and seabirds (Cadée 2002; Hartwig *et al*. 2007; Colabuono *et al*. 2009), either through entanglement, contaminants or ingestion (Moore *et al*. 2009). Plastic debris, once swallowed, can cause damage, impairment or blockage to the digestive tract, reducing stomach volume and leading to reduced growth and even starvation (Ryan 1988*a*; Auman *et al*. 1997; Hutton *et al*. 2008). Toxic chemicals, such as polychlorinated biphenyls (PCBs), can be released from plastic debris and, when consumed, can cause subtle effects that are evident only over long periods of time (Ryan *et al*. 1988; Mato *et al*. 2001; Burger and Gochfeld 2004; Colabuono *et al*. 2010).

Procellariids (petrels and shearwaters) have the highest incidence of plastic ingestion of any seabird family (Robards *et al*. 1995; Blight and Burger 1997; Ryan 2008; Colabuono *et al*. 2009). Their unique proventriculus, which is connected to the small gizzard by a narrow passage, restricts their ability to regurgitate indigestible items (Furness 1985; Warham 1990). The Northern Fulmar (*Fulmarus glacialis*), a medium-sized petrel, has been a useful indicator of trends in marine debris in both the North Atlantic and North Pacific Oceans since the 1980s (van Franeker 1985; Robards *et al*. 1995; Mallory *et al*. 2006; Mallory 2008). Similarly, the Short-tailed Shearwater (*Ardenna tenuirostris*), the dominant species in the Bering Sea during the austral winter, has been used to identify long-term trends of plastic pollution in that region since the early 1970s (Vlietstra and Parga 2002). Disturbingly, levels of plastic ingestion in this species have increased over the past three decades to a point where >80% of adults ingest plastic material (Ogi 1990; Vlietstra and Parga 2002).

The problem of plastic ingestion may affect many Australian breeding seabirds, and not solely Procellariformes, probably without being observed or documented (Copley 1996; Baker *et al*. 2002). It is not clear whether adults are accumulating plastic in the non-breeding season, at their breeding grounds or both. At Australian colonies, Shy Albatross (*Thalassarche cauta*), Short-tailed, Flesh-footed (*A. carneipes*) and Wedge-tailed (*A. pacifica*) Shearwaters, prions (*Pachyptila* spp.), Common Diving-Petrels (*Pelecanoides urinatrix*) and the skuas (*Catharacta* spp.) have all been recorded as having ingested plastic to varying degrees (Skira 1986; Norman and Brown 1987; Hedd and Gales 2001; Auman *et al*. 2004; Hutton *et al*. 2008). Chicks appear to be at greater risk of plastic accumulation than adults because their rates of ingestion are higher and they regurgitate boli at only low

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frequency. When chicks ingest plastic particles, those particles accumulate in the gut during the nestling period. The subsequent physical blockage, ulceration and perforation that can occur are likely to lower survival (Sievert and Sileo 1993; Auman *et al*. 1997; Hutton *et al*. 2008). Large quantities of plastic result in less capacity for food and therefore satiation before sufficient food ingested (Ryan 1988*a*), thus lowering growth rate and increasing the probability of death (Sievert and Sileo 1993). Intergenerational transfer of plastic particles has been suggested as an important pathway for plastic flow in species that accumulate plastic particles and feed their chicks by regurgitation (Ryan 1988*b*).

This study is the first to evaluate the prevalence of plastic ingestion by immature Short-tailed Shearwaters. Comparisons of plastic ingestion between fledglings from the southern hemisphere and adults studied in the northern hemisphere (Vlietstra and Parga 2002) are presented. In addition, if plastic loads adversely affect body condition, fledglings with higher loads of plastic are more likely to exhibit negative outcomes, such as lower levels of fat deposition or starvation.

Methods

Data were collected during eight surveys between April and May 2010 coinciding with the peak departure period of fledglings. Four surveys were conducted on a 2-km section of sandy beach at Cape Woolamai Surf Beach, Phillip Island, Victoria (38°31′S, 145°06′E), and four 8 km-long surveys were conducted through the Cape Woolamai Fauna Reserve. All dead beachcast Short-tailed Shearwaters were counted, and when decomposition was not extensive (i.e. the body wall was intact), a bird's proventriculus and gizzard were removed and retained. Stomachs were fixed in 70% alcohol for later analysis. For all birds, subcutaneous fat was estimated visually using the following scores: 0 = no fat, 1 = low fat, 2 = moderate fat and 3 = high fat (following Auman *et al*. 1997).

In the laboratory, stomach contents were examined for plastic material and noted for the presence or absence of plastic in the proventriculus and gizzard of each bird. Plastic particles were removed from the stomach contents, washed, air-dried and weighed (mg) using a digital balance (±0.001 g). Other stomach content items were also recorded, including nematode parasites, crustaceans, squid beaks and rock fragments. The lining of the emptied proventriculus was examined for lacerations, ulcerations and punctures.

Following Ogi (1990) and Vlietstra and Parga (2002) each plastic particle was categorised as one of three types: industrial pellets (polyethylene beads that are used for moulding into plastic products and in cargo packaging and transport), user plastic (usually particles from larger plastic items such as bottles) and other (such as polystyrene, rubber, plastic bag or sheet). Again, following Vlietstra and Parga (2002), each particle was then classified by colour as being light (white, yellow, yellow-brown), medium hued (brown, blue, green, red) or dark (dark blue, dark green, dark red, grey-black).

Statistical analyses were performed using SPSS version 17.0 (SPSS Inc., Chicago, IL). Data for adults were taken from Vlietstra and Parga (2002) and compared statistically with data on chicks from the present study using a *t*-test and $r \times c$ contingency table. The significance criterion for all tests was set at $P \leq 0.05$. All data are presented as means ± standard deviation (s.d.).

Results

During sampling, 415 beachcast Short-tailed Shearwaters were found. From that total, only 67 were in sufficiently good condition for collection and analysis. The remaining birds had been scavenged by Pacific Gulls (*Larus pacificus*), Little Ravens (*Corvus mellori*) and Australian Ravens (*C. coronoides*). Most (83%) of the birds were found along the sandy Cape Woolamai Surf Beach. All of the birds collected were fledglings based on the occurrence of down and plumage colouration.

All of the birds collected contained plastic particles. In total, 513 plastic particles were recovered (Fig. 1). The mean number of particles per bird was 7.6 (±5.4), significantly more than found in adults in the Bering Sea (5.8 ± 0.4; Vlietstra and Parga 2002) ($t_{66} = 2.7$, $P < 0.01$). Most birds (89%) had plastic in their gizzards, whereas fewer had plastic in the proventriculus (44%). Significantly more plastic particles were found in the gizzard than in the proventriculus (gizzard mean 6.1 ± 5.2 particles, $n = 67$; proventriculus mean 1.5 ± 3.1 particles, $n = 67$; Mann–Whitney test, $Z = 6.94$, $P < 0.001$). The mean mass of plastic per bird was 113 (±8.2 mg). The mean mass of particles per bird was similar between fledglings from Phillip Island and adults from the

Fig. 1. Plastic items found in the proventriculus and gizzard of four Short-tailed Shearwater fledglings.

Bering Sea (114 ± 7.8 mg; Vlietstra and Parga 2002) (t_{91} = 0.92, P = 0.36). Total mass of plastic ingested was significantly related to the number of particles found (r_{67} = 0.48, P < 0.001). Neither total mass of plastic or number of plastic particles were related to fledgling fat score ($F_{3,66}$ = 2.68, P = 0.06; $F_{3,66}$ = 1.81, P = 0.15 respectively). In two cases a sharp piece of plastic had perforated the gizzard wall, although it was not clear whether that had been the cause of death. Both birds recorded fat scores of 1 (low fat). No scars or inflammation were observed in any other specimen.

The most common type of plastic found in Short-tailed Shearwaters was user plastic, followed by industrial pellets. The stomachs contained a small proportion of other refuse such as polystyrene and plastic bag (Table 1). The type of plastic found in fledglings was significantly different to that of adults (Vlietstra and Parga 2002) (χ^2_2 = 13.3, P < 0.01).

Stomachs contained plastics that were primarily light in colour. However, plastics that were medium in hue such as red, blue and brown were also frequently present. Dark colours were seen less frequently, and were predominantly grey-black particles, which made up almost 20% of the sample (Table 2). Colour composition was significantly different between fledglings on Phillip Island and the Bering Sea (Vlietstra and Parga 2002) (χ^2_2 = 94.6, P < 0.01).

Cephalopod remains were present in 85% of samples (Table 3). The presence of cephalopods was determined primarily by beaks. Most beaks were fragments and eroded owing to digestion. Low frequencies of other food items were recorded (Table 3). Parasitic nematodes were present in 6% of stomachs. Rock fragments and pumice were also recorded in the stomachs of some birds (Table 3).

Discussion

The extent of plastic accumulation in marine ecosystems is a source of major concern. This study confirms the transgenerational transfer of synthetic material by Short-tailed Shearwaters at Australian colonies. All sampled fledglings contained plastic particles. This finding is in accord with other studies that indicate Short-tailed Shearwaters have a high prevalence of plastic debris in their systems. The 100% incidence of plastic in the present sample is higher than that reported for adults in the subarctic Pacific and Bering Sea (84%; Vlietstra and Parga 2002) and

Table 1. Type of plastic found in Short-tailed Shearwaters collected in the subarctic Pacific Ocean (Day 1980; Ogi 1990), Bering Sea (Vlietstra and Parga 2002) and on Phillip Island, Victoria (this study)

Plastic type	Percentage of plastic particles			
	Subarctic Pacific Ocean		Bering Sea	Phillip Island
	1969–77 (Day 1980)	1970–79 (Ogi 1990)	1997–99, 2001 (Vlietstra and Parga 2002)	2010 (this study)
Industrial pellets	72.5	67.2	32.9	28.6
User plastic	25.6	16.3	63.9	70.8
Other	1.9	16.7	3.2	0.6

Table 2. Percentage of plastic particles of various colours found in the proventriculus and gizzards of Short-tailed Shearwaters collected in the subarctic Pacific Ocean (Day 1980; Ogi 1990), Bering Sea (Vlietstra and Parga 2002) and on Phillip Island, Victoria

Colour	Percentage of plastic particles			
	Subarctic Pacific Ocean		Bering Sea	Phillip Island
	1969–77 (Day 1980)	1970–79 (Ogi 1990)	1997–99, 2001 (Vlietstra and Parga 2002)	2010 (this study)
Light				
White	18.3	27.4	33.8	37.2
Yellow	1.2	2.5	11.5	3.8
Yellow-brown	53.7	35.4	19.7	3.1
Total	73.2	65.3	65.0	44.1
Medium				
Brown	12.2	16.9	13.9	6.1
Blue	2.4	2.4	2.9	5.1
Green	4.9	5.4	7.2	4.8
Red	1.8	3.0	4.1	20.2
Total	21.3	27.7	28.1	36.4
Dark				
Dark blue	1.2	0.3	0.4	0.2
Dark green	1.2	0.5	0.4	0.2
Dark red	1.8	0.3	1.5	0
Grey-black	0.7	6.0	4.7	18.9
Total	4.9	7.1	7.0	19.4

Table 3. Frequency of occurrence (FO%) of dietary and non-food items identified from 67 Short-tailed Shearwater proventriculi and gizzards from Phillip Island, Victoria

Taxa	FO%	Kind of material
Cephalopoda		Beaks
Teuthida	85.1	
Malacostraca		Fragments, whole specimen
Euphausiacea	1.5	
Insecta		Fragments, elytra, whole specimen
Siphonaptera	2.9	
Phthiraptera	1.5	
Coleoptera	2.9	
Arachnida		Whole specimen
Acari	1.5	
Use plastic	95.5	
Industrial pellets	55.2	
Polystyrene	1.5	
Plastic bag	2.9	
Rock fragments	49.2	Pumice
Nematode parasite	6.0	

Australian colonies (4–36%; Montague *et al*. 1986; Skira 1986). Short-tailed Shearwater fledglings in this study also had a higher incidence of plastic ingestion than did Flesh-footed and Wedge-tailed Shearwaters chicks on Lord Howe Island (79 and 43% respectively; Hutton *et al*. 2008). These differences between colonies could reflect different migratory patterns, foraging ranges or feeding behaviour between the species. The mean mass of particles per bird was similar between fledglings on Phillip Island and adults studied in the Bering Sea. The number of particles per bird, however, was higher in fledglings at Phillip Island and demonstrates how large quantities of plastic can accumulate in the gut during the nestling period. Skira (1986) suggested that plastic particles are common in adults at the beginning of the breeding season but gradually decrease in frequency as the season progressed. This may reflect a combination of processes of regurgitation of indigestible objects and the transfer of plastic items to chicks during provisioning. Ryan (1988*b*) was able to demonstrate that immature and non-breeding birds had higher plastic loads than did breeding birds, and the former were more likely to exhibit adverse effects from plastic pollution. Although the incidence of plastic differs between species and among individuals, there is growing evidence that the problem is increasing (Colabuono *et al*. 2009).

The incidence of plastic ingestion in the Short-tailed Shearwater's wintering range has been well described (Day 1980; Ogi 1990). Those studies show that >80% of adults are affected by plastic debris (Day 1980; Ogi 1990) and that, over the past decade, that proportion may have stabilised (Vlietstra and Parga 2002). There has, however, been a shift in the type of plastic found in Short-tailed Shearwaters over time, a pattern that may be linked to regional composition and availability. Shifts in composition have also occurred in seabirds in the Atlantic and south-western Indian Oceans where there has been a reduction in the ingestion of industrial pellets over the most recent three decades (Ryan 2008). On Phillip Island, Short-tailed Shearwater fledglings contained a slightly different composition of marine debris than did adults studied in the subarctic Pacific and Bering Sea (Vlietstra and Parga 2002), in which there were lower incidences of industrial pellets and polystyrene and plastic sheet. This may indicate further declines in the amount of industrial pellets in the ocean and an increase in user-plastic pollution. Conclusive evidence is missing, and more data are needed about the relationship between plastic composition and the density of plastic at sea in the foraging grounds of these sea birds (Ryan 2008).

Both Montague *et al*. (1986) and Skira (1986) found plastic items in breeding Short-tailed Shearwater adults in south-eastern Australia. Until now no study has quantified the amount of plastic debris found in Short-tailed Shearwater fledglings. On Phillip Island, beachcast fledglings most likely died of drowning or predation but there were at least two cases where the death of the chick could possibly be attributed at least in part, to the perforation of the gizzard by a sharp piece of plastic. Despite a weak correlation between total plastic mass and fledgling fat score, plastic loads are unlikely to cause direct mortality. Plastic particles can remain in the digestive system for at least 2 years (Ryan and Jackson 1987), and presumably plastic that passes through to the gizzard is broken down and excreted by Short-tailed Shearwaters. The long-term exposure to plastic and associated chemical accumulation requires attention, for example levels of trace elements, PCB and other organochlorine accumulation within the body (Ryan *et al*. 1988; Bond and Lavers 2010; Colabuono *et al*. 2010).

Colour preference of plastic material has been noted in several seabirds and is thought to reflect a resemblance to prey items. Day (1980) suggested the variation in plastic colour taken by shearwaters in the Bering Sea indicated little colour preference. Vlietstra and Parga (2002), however, analysed three decades of data and suggested that Short-tailed Shearwaters took each colour in the same proportion, but with a general preference for plastics that are light in colour. Skira (1986) noted that plastic particles were brightly coloured yellow, green and red, similar to prey items taken during the breeding season. Plastic particles found in fledglings on Phillip Island were dominated by light colours, with red and grey-black also recorded. Colour composition on Phillip Island was somewhat different to that in the long-term research of Vlietstra and Parga (2002) and may reflect local composition of plastic particles. However, without direct sampling of plastic availability in Bass Strait and the Southern Ocean, where these adults feed, it is not clear whether these birds have a colour preference as a result of mistaken selection of prey or whether colour is irrelevant and simply reflects regional availability.

Plastic material has now been collected from seabirds in all the world's major oceans ecosystems. The highest incidence of plastic ingestion is found in the procellariids, a group of birds already under threat from other factors such as long-line fishing and introduced predators (Baker *et al*. 2002). Rates of ingestion may still be increasing in some species (Robards *et al*. 1995; Provencher *et al*. 2009) whereas in others it may have stabilised (Vlietstra and Parga 2002). It is clear that even colonies located in the most remote places on Earth are affected (Mallory *et al*. 2006). Continued monitoring of plastic loads in seabirds and at sea is required to establish the source of material and its effects. Long-term biomonitoring in colonies across Australia should be established to determine trends of plastic pollution in seabird populations, and monitoring plastic loads of seabirds could be one way of monitoring plastic pollution in the oceans of the southern hemisphere (Ryan 2008; Ryan *et al*. 2009).

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