THE INCIDENCE OF PLASTIC IN THE DIETS OF PELAGIC SEABIRDS IN THE EASTERN EQUATORIAL PACIFIC REGION

David G. Ainley, Larry B. Spear
Point Reyes Bird Observatory
Stinson Beach, California 94970, U.S.A.

and

Christine A. Ribic*
Center for Quantitative Science in Forestry, Fisheries and Wildlife
University of Washington
Seattle, Washington 98195, U.S.A.

*Present address: U.S. EPA Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333, U.S.A.

ABSTRACT

Between 1984 and 1988, 921 seabirds of 39 species were collected during cruises in the eastern equatorial Pacific. Cruises were centered in the areas of the South Equatorial Current, Equatorial Countercurrent, and the northern Peru Current. The majority of species, mostly gadfly petrels and storm-petrels, had not previously been checked for plastic ingestion. Ingestion was a function of feeding behavior, area of the ocean frequented, and the amount of time passed since birds frequented polluted areas. Species that resided year-round in the equatorial region had eaten little plastic, but those species or populations that had recently come from the area of the southern Peru Current (off Chile), the North Pacific (off Japan or California), or the Tasman Sea/northern New Zealand area, had high plastic loads in their digestive tracts. Results suggest that the residency time of plastic in the digestive tract of petrels is less than 1 year.

INTRODUCTION

On the basis of research and literature reviews by Day (1980; Day et al. 1985), who worked mostly in the northern Pacific, and by Ryan (1987a, 1987b, 1988a, 1988b; Ryan and Jackson 1987) in the southern Atlantic, we now recognize that the ingestion of plastic is a pervasive phenomenon in seabirds. At present, 69 seabird species are known to ingest plastic while feeding at sea, and the incidence of ingestion has risen steadily since the

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1960's. The species most likely to eat plastic are members of the order Procellariiformes. The factors that make these species so susceptible are 1) their feeding behavior (many feed at the surface, are omnivorous, and scavenge frequently); 2) their morphology (petrels have muscular gizzards in which indigestible items become trapped, whereas most other seabirds do not); and 3) their inability (albatrosses are an exception) to eject indigestible matter through the formation of pellets. It is believed that seabirds eat the plastic, usually in the form of industrial pellets and fragments of larger items, either because they mistake it for food or because edible organisms are attached to the plastic.

Geographic variation in the incidence of plastic indicates that seabirds feeding near to industrialized areas are the most likely to eat it. The plastic remains in digestive tracts until it degrades from abrasion and digestive processes or until adult birds feed it to their chicks. Day et al. (1985) estimated that the degradation process for an individual plastic pellet requires on the order of 6 months, but Ryan and Jackson (1987) proposed a time scale of 1 to 2 years. Ryan (1988b) further proposed that it is through feeding plastic to chicks that adults rid themselves of most of the plastic that has accumulated in their gut.

As yet, little work has been done on the incidence of ingestion in seabirds that forage far at sea, i.e., away from pollution sources. (See Ainley et al. 1990, who looked at plastic in the diets of Antarctic seabirds.) In this paper we present information on the incidence of plastic in the diets of seabirds that frequent Pacific equatorial waters. The sampling efforts closest spatially to ours were those by Harrison et al. (1983) and Sileo et al. (1990), who noted plastic in the diets of several species breeding in the Northwestern Hawaiian Islands, in the North Pacific a few thousand kilometers away from our study area. A number of species pass through our study area from various directions, and the incidence of plastic in them offers some clues as to where they are encountering it, and, on the basis of the time passed since visiting polluted areas, whether or not the degradation process and that of off-loading through chick feeding are important processes by which birds relieve themselves of plastic. In addition, several of the species we sampled had not been inspected before for evidence of plastic ingestion.

METHODS

In conjunction with the Equatorial Pacific Ocean Climate Study (EPOCS) of the National Oceanic and Atmospheric Administration (NOAA), we have been characterizing the community structure of open-ocean seabirds using the eastern equatorial Pacific as our study area. Included in our studies are the analyses of prey items. On six cruises (boreal autumn 1984, spring 1986, spring and autumn 1987, and spring and autumn 1988) we collected 921 seabirds of 39 species using a shotgun (Table 1). During each collection, we attempted to obtain up to five individuals of each species present. We noted which individuals had ingested plastic and, except for autumn 1984, counted the number of plastic pieces. Based on necropsy, we determined whether individuals were adults or subadults. The study area is between lat. 15°N and 15°S and long. 170° and 85°W (Fig. 1). Collections were made

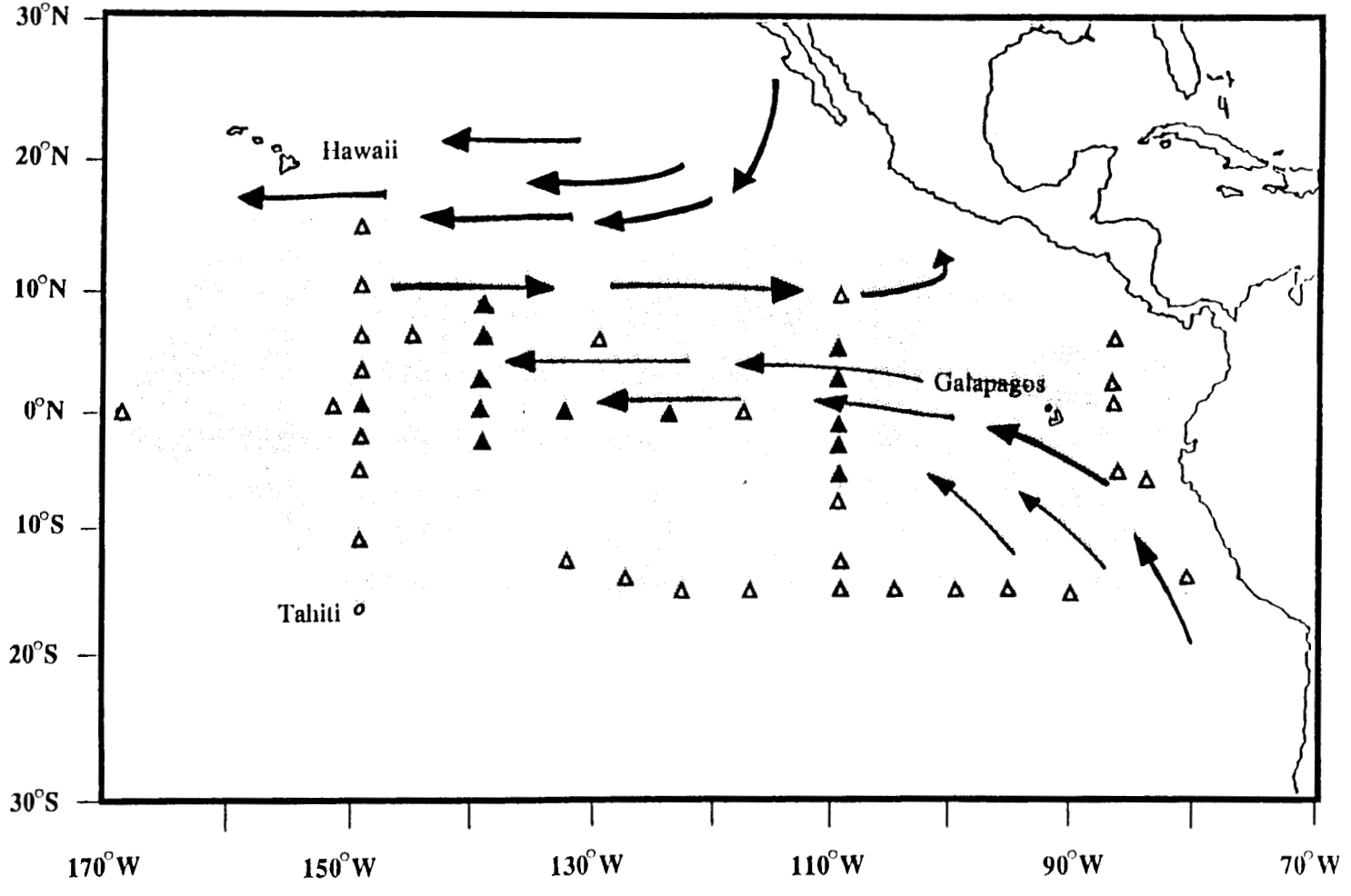

Figure 1.--The study area in the eastern equatorial Pacific (shading), and sites where seabirds were collected (open symbols, on one cruise only; closed symbols, on four or more cruises); arrows indicate ocean currents.

Table 1.--The incidence of plastic in the diets of Pacific equatorial seabirds, and a comparison to other studies.

Species[b]	Cruise[a]						Total[a]		Other studies	
	A84[c]	S86	S87	A87	S88	A88	No.	%	%	Source[d]
Petrels										
Bulweria bulwerii			0 (7)		0 (10)	0 (2)	19	0	0	3
*Daption capense**			88 (8)				8	88	14-57	1,5
*Pachyptilla belcheri**			83 (6)				6	83	0-57	5
*Procellaria aequinoctialis**			67 (3)				3	67	0-57	1,5
Pterodroma alba			0 (2)			0 (9)	11	0		
Pterodroma arminjoniana			0 (8)			0 (3)	11	0		
*Pterodroma cookii defilippiana**		0 (3)	67 (6)				9	44	10	4
*Pterodroma e. externa**	0 (3)	0 (5)	0 (27)	0 (21)	0 (13)	0 (35)	104	1		
Pterodroma e. cervicalis		100 (1)	0 (2)		0 (7)		10	10		
Pterodroma inexpectata						0 (1)	1	0	0	1
Pterodroma leucoptera	0 (6)	75 (4)	20 (15)	7 (28)	26 (19)	5 (20)	92	15		
*Pterodroma l. longirostris**		100 (1)	50 (6)	33 (6)	50 (10)	100 (2)	25	52		
Pterodroma l. pycrofti					50 (2)		2	50		
Pterodroma neglecta				0 (2)	0 (5)	0 (1)	8	0		
Pterodroma nigripennis		0 (1)	0 (4)	0 (3)	0 (14)	7 (15)	37	3		
Pterodroma rostrata	0 (2)		0 (21)	0 (13)	7 (15)	0 (16)	67	2		
Pterodroma ultima			0 (1)			0 (4)	5	0		
Puffinus bulleri					100 (1)		1	100		
Puffinus griseus			50 (2)		0 (6)	100 (17)	25	72	10-67	2,5
Puffinus nativitatus			50 (2)			0 (1)	3	33	0	3
Puffinus pacificus			0 (15)		0 (7)	8 (13)	35	3	0	2
Puffinus tenuirostris						100 (1)	1	100	47-100	2

Table 1.--Continued.

Species[b]	Cruise[a]						Total[a]		Other studies	
	A84[c]	S86	S87	A87	S88	A88	No.	%	%	Source[d]
Storm-Petrels										
Fregetta grallaria		0 (2)	0 (3)		0 (1)	0 (2)	8	0		
Nesofregetta fuliginosa	0 (2)	0 (1)	0 (1)	0 (3)	0 (1)		8	0		
Oceanites gracilis			0 (2)				2	0		
*Oceanites oceanicus**			0 (8)				8	0	19-75	1,5
Oceanodroma castro			0 (2)		0 (3)	0 (2)	7	0		
*Oceanodroma hornbyi**		0 (1)					1	0		
Oceanodroma leucorhoa	6 (18)	0 (1)	9 (22)	13 (45)	0 (16)	16 (49)	151	11	25	2
*Oceanodroma markhami**		0 (3)	0 (7)		50 (2)		12	8		
Oceanodroma melania			0 (2)				2	0		
Oceanodroma tethys	7 (29)	0 (12)	0 (32)	0 (45)	0 (29)	0 (29)	176	1		
Pelagodroma marina		0 (1)	88 (8)		50 (4)		13	69	50-88	4,5
Other										
Fregata minor			0 (3)				3	0		
Gygis alba			0 (2)				2	0	0	3
Phaethon lepturus			0 (1)				1	0		
Phaethon rubricauda			0 (2)				2	0	0	3
Stercorarius parasiticus					50 (2)		2	0	0-50	2,5
Sterna fuscata			0 (19)	0 (2)	0 (5)	0 (9)	35	0	0	3
Sterna lunata			0 (4)		0 (1)		5	0	0	3

[a]In each column is given the number of seabirds with plastic followed by the total number inspected.
[b]Species marked by an asterisk (*) were collected at the outer edge of the Peru Current, or breed in that area; see text.
[c]The cruises are designated as A (autumn) or S (spring) by year (e.g., A84 = autumn 1984).
[d]Source: 1, Ainley et al. 1990; 2, Day et al. 1985; 3, Harrison et al. 1983; 4, Imber *in* Day et al. 1985; 5, Ryan 1987b.

while the ship tended permanently moored oceanographic buoys, and thus were mostly from the same sites on each cruise. During spring 1987, however, the ship worked in the outer reaches of the Peru Current off Peru, and birds were collected there as well.

In our analyses, we statistically compared proportions using t-tests following angular transformations (Sokal and Rohlf 1969). Regressions were by Spearman rank correlation (r_s).

RESULTS

We looked for plastic in the stomachs of 39 species, 21 of which had not been previously inspected for this. Highest rates of plastic ingestion were evident in species that frequented the periphery of the study area or moved through it. Most obvious were the nine species that came from the edge of the Peru Current (Table 1). Plastic was found in all but one of these, and in seven the incidence equaled or exceeded 45% of the birds inspected. Incidence was very low in the Juan Fernandez petrel, *Pterodroma e. externa*, which nests on islands off Chile, but in the cape petrel, *Daption capense*, and the narrow-billed prion, *Pachyptila belcheri*, both of which only winter in the Peru Current, incidence exceeded 80%.

Various patterns of ingestion were apparent in several longer distance migrants that either pass through or spend the nonbreeding portion of their annual cycle in the study area. Incidence of plastic was very high in the sooty shearwater, *Puffinus griseus*, a species that migrates across the study area between its breeding islands in the southwestern Pacific (New Zealand) and its wintering grounds in the North Pacific. Incidence was 0% in shearwaters collected on their northward postbreeding journey during spring (n = 6) but was 95% among those individuals flying south in the autumn (n = 19). In the Leach's storm-petrel, *Oceanodroma leucorhoa*, which breeds on islands ringing the eastern and central North Pacific but which otherwise resides in the study area, frequency of plastic relative to its annual cycle was the opposite of the shearwater. Plastic occurred in 11% overall. During autumn, just after the breeding season, 13.4% contained plastic (n = 112) compared to 5.1% during spring (n = 39; t = 3.261, P = 002), after breeders had departed. The same relative seasonal pattern was also evident in the white-winged petrel, *Pterodroma leucoptera*, which breeds in the Tasman Sea but otherwise resides in the study area. Plastic occurred in 15% of these birds overall, with a seasonal breakdown of 5.6% (n = 54) during autumn, just before the nesting period, and 28.9% (n = 38) during spring, just after the nesting period (t = 3.104, P = 0.003). Finally, in the Stejneger's petrel, *Pt. l. longirostris*, which breeds off Chile and then migrates to North Pacific waters off Japan, plastic occurred in the same proportion of birds regardless of season (spring, coming from the nesting grounds off Chile: 52.9%, n = 17; autumn, coming from waters off Japan: 50.0%; n = 8).

Among species that reside in equatorial waters year-round, the incidence of plastic ingestion was very low, and in most it was nil. An instructive comparison is that between the migratory Leach's storm-petrel and the year-round resident wedge-rumped storm-petrel, *O. tethys*, two

species that are closely associated in the study area (unpubl. data). In Leach's, ingestion was 11%, but in wedge-rumped storm-petrel, it was only 1% ($t = 4.289$, $P < 0.001$).

Ingestion frequencies for each species were tracked by the number of plastic particles per bird. Individuals of species in which ingestion frequency was high also had large numbers of pieces in their gizzards and vice versa ($r_s = 0.7385$, df = 14, $P < 0.001$; for species where $n > 4$ individuals; Table 2). On the basis of that relationship, we might project for species in which samples were small, that if the one or two individuals inspected had eaten a large number of pieces, a larger sample should show a high proportion of individuals with plastic. For example, we inspected only one short-tailed shearwater, *Pu. tenuirostris*, but it contained 14 pieces of plastic. This species is known to eat large amounts of plastic (Day et al. 1985). The pattern should hold for the Buller's shearwater, *Pu. bulleri*, for which there are no other published data on plastic ingestion (the one individual in our sample contained seven pieces). One exception would be Juan Fernandez petrel, in which only 1 individual of 104 inspected contained plastic: 4 pieces, a relatively large number of pieces in our data set.

We compared the frequency of plastic as a function of age (subadult versus adult) in species where $n > 10$ birds. Compared to adults, a larger proportion of subadults should have ingested plastic (Day et al. 1985; Ryan 1987b). We found, though, that the proportion of breeding adults, nonbreeding adults, subadults, and unknowns that had ingested plastic (5.9, 35.6, 56.4, and 2.0%, respectively) did not differ from the proportion of these age classes in the total samples (7.9, 37.4, 51.8, and 3%, respectively; $\chi^2 = 8.78$, df = 3, $P > 0.05$). Plastic was not more prevalent in subadults.

DISCUSSION

We found little evidence that terns, tropicbirds, or frigatebirds ate plastic, as also noted by Harrison et al. (1983), Day et al. (1985), and Sileo et al. (1990). These species eat active prey, and even if they did ingest plastic, they lack a gizzard where, in Procellariiformes, plastic accumulates.

Among the petrels we sampled, ingestion was mainly a function of feeding behavior, what parts of the Pacific Ocean they frequented, and the amount of time passed since leaving polluted areas. Petrels such as Juan Fernandez petrel or wedge-tailed shearwater, *Pu. pacificus*, which chase airborne flyingfish and squid or prey being driven to the surface by predatory fish (i.e., very active prey), exhibited low rates of plastic ingestion. The majority of other petrel species are less specialized feeders, and they eat prey both live and dead. Some species, such as white-faced storm-petrel, *Pelagodroma marina*, and prions, genus *Pachyptila*, almost always contain very high loads of plastic (Day et al. 1985; Ryan 1987b). It is probable that their prey search-images (including particle size) and their propensity to associate with convergences account for their high susceptibility to plastic as food. On the other hand, some species

Table 2.--The average number of pieces of plastic, and standard error, in the gizzards of seabirds collected in the study area.

Species	Average number of pieces	SE	Number of birds
Daption capense	8.4	2.3	7
Pachyptila belcheri	8.2	3.4	5
Procellaria aequinoctialis	3.5	1.5	2
Pterodroma cooki defillipiana	9.8	4.8	4
Pterodroma e. externa	4		1
Pterodroma e. cervicallis	1		1
Pterodroma leucoptera	2.1	0.8	14
Pterodroma l. longirostris	3.1	0.6	14
Pterodroma l. pycrofti	2		1
Pterodroma nigripennis	1		1
Pterodroma rostrata	1		1
Puffinus bulleri	7		1
Puffinus nativitatus	1		1
Puffinus griseus	10.5	2.7	18
Puffinus tenuirostris	14		1
Puffinus pacificus	1		1
Oceanodroma leucorhoa	3.3	0.4	16
Oceanodroma markhami	2		1
Pelagodroma marina	12.2	3.5	9

that are obligate scavengers, such as Tahiti petrel, *Pt. rostrata*, do not eat much plastic (unpubl. data). They, too, might have a particular search-image.

Temporal and geographic aspects of plastic ingestion were also evident, and these patterns bear on the question of how long plastic is retained in seabird guts. Ryan (1988b) proposed that most of the observed seasonal change in plastic loads is a function of the transfer of plastic from breeding adults to chicks rather than degradation within the digestive tracts of adults. If this is correct, we should have found highest incidence in subadults (who have never bred and thus have never had an opportunity to disgorge plastic), lowest incidence in postbreeding adults, and intermediate values in nonbreeding adults. Our data do not indicate such a pattern. First, in species for which samples were sufficiently large to make comparisons, we found no indication that subadults had more or less plastic than adults. Second, the seasonal patterns we observed suggest that degradation is an important process, and that the time scale is on the order of 6 months or slightly longer. Ryan and Jackson (1987) assumed that degradation rate is constant throughout the time that plastic resides in a seabird digestive tract, and they based their extrapolation on plastic fed to birds and then inspected after retention for only 12 days.

However, plastic subjected constantly to digestive acids and abrasion could degrade at a faster rate as time passes, especially if its surface-to-volume ratio increases. Van Franeker and Bell (1988) found that the mass of plastic particles in cape petrels collected in the Antarctic (where there is no plastic to replenish ingested loads) decreased by 50% over a 3-month period. This rate supports a shorter degradation period than that proposed by Ryan and Jackson (1987; see Day et al. 1985).

We interpret our seasonal and geographic data as follows. Those birds that reside year-round in the region of the South Equatorial Current and the Equatorial Countercurrent (Wyrtki 1967), i.e., our study area, exhibited only incidental ingestion of plastic. We observed little floating debris during our censuses, probably because there are few, if any, large industrial source areas in the central Pacific for plastic and there are no large human population centers except for Oahu. Among petrel species of the Northwestern Hawaiian Islands, which lie in the North Equatorial Current, Harrison et al. (1983) also found only low levels of plastic ingestion. We did not collect any samples in the Panamanian Bight, where we observed much floating plastic and other flotsam on our bird censuses.

Compared to year-round equatorial residents, results were much different for petrels that were either passing through the study area or that came a long way from polluted areas to spend their nonbreeding period there. Those species that had just come from areas where industrial plastic pellets are common, for example, off Japan and California (Day et al. 1985; Pruter 1987), had ingested significant amounts of pellets. Several of these species, including adults and subadults, had higher plastic loads after frequenting polluted waters (where adults bred). This suggests that loss of plastic while in plastic-free waters (because erosion outpaces ingestion) is important. Since the migrations are annual, degradation over a 6- to 12-month period would best fit the patterns. As examples, species or populations that had come from the eastern and central North Pacific had high plastic loads (i.e., Buller's, short-tailed, and sooty shearwater and Leach's storm-petrel). The first three were in the prebreeding portion of the annual cycle, and the last was postbreeding. This inconsistency is contrary to the off-loading through chick-feeding hypothesis. When specimens of these speciews have been inspected in California waters they contain much plastic (Balz and Morejohn 1976). The fact that sooty shearwaters migrating north from New Zealand or Leach's storm-petrel not newly arrived from the north have low plastic loads confirms that it is in the eastern North Pacific that these species are ingesting plastic. Sooty shearwaters, probably of the South American breeding population, also frequent the Peru Current, but we did not collect any. A portion of the New Zealand population of this species migrates to polluted waters off Japan, but the eastern Pacific position of our study area and the flight directions observed indicate that the birds we sampled were moving between New Zealand and the eastern North Pacific.

The incidence of plastic ingestion was also high in species collected at the periphery of the Peru Current or that came to the study area from waters off Chile (i.e., cape petrels, prions, white-chinned petrel,

Procellaria aequinoctialis, Cook's petrel, *Pt. cooki defilippiana*, and Stejneger's petrel). Cape and white-chinned petrels collected south of South America have much lower plastic loads than those inspected in this study (Ainley et al. 1990). This supports the suggestion that the specimens inspected in this study encountered the plastic in the Peru Current. Stejneger's petrel moves through the study area between Chilean waters and waters off Japan, and thus its plastic could have come from either area. Unlike the other migrants discussed above, these petrels had similar plastic loads regardless of whether they were moving south or north. This supports the suggestion that they were ingesting plastic off Chile and off Japan. Bourne and Clark (1984) noted specific areas of nearshore Chile where significant amounts of plastic had accumulated, but little information is available on a larger geographic scale. One species they observed in association with scum and flotsam lines was *Pa. belcheri*, which in our samples contained much plastic. Species from the northern part of the Peru Current (i.e., several species of the genus *Oceanodroma*) had low plastic loads.

Though not as high as in the birds noted above, the occurrence frequency of plastic was high in white-winged petrel, which as far as we know nests in the subtropical Tasman Sea area. The pattern of low plastic incidence before breeding and after wintering away from polluted areas, but high incidence after breeding, again is contrary to the chick off-loading hypothesis. Along the Equator, one of two individuals of Pycroft's petrel, *Pt. longirostris pycrofti*, which breeds in northern New Zealand, contained plastic, and four of six white-faced storm-petrels, that could also have come from northern New Zealand, contained much plastic. Imber (in Day et al. 1985) reported plastic in 50% of specimens of the latter species from Chatham Island (NZ); Harper and Fowler (1987) found that plastic was prevalent in prions washed ashore in northern New Zealand; van Franeker and Bell (1988) noted significant loads of plastic in Antarctic-breeding species that wintered in the Indian Ocean and Tasman Sea; and Gregory (1978) has noted significant amounts of plastic on most New Zealand beaches, north and south. Thus, it is not surprising that petrels that spend time in New Zealand waters show high plastic ingestion. It is surprising that those sooty shearwaters that were newly arrived to our study area from New Zealand had no plastic, although the large majority of sooty shearwaters nest away from and south of the main islands of New Zealand, and thus away from industrialized areas. This may account for the lower rates of plastic ingestion in these birds.

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