THE INCIDENCE OF PLASTIC IN THE DIETS OF ANTARCTIC SEABIRDS

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ABSTRACT

We investigated the diets of seabirds at sea in the Antarctic from 1976 to 1988. During the study period, on eight cruises in the Ross, southern Scotia, and Weddell Seas and Drake Passage, we collected or pumped the stomachs of 1,223 seabirds of 23 species. The stomach contents of species that feed below the sea surface contained little plastic, as expected; these birds live entirely on live prey. Among species that feed at the surface, most of which eat both live and dead organisms, incidence of plastic was highest among the smaller ones and those that are omnivores, or feed on zooplankton and micronekton. This includes the majority of Southern Ocean flighted birds. Incidence of plastic among them was a function of the degree to which their populations frequented waters outside of the Antarctic during the winter. Among those species that live south of the Antarctic Convergence year-round there was little evidence of plastic ingestion. Among those species that are summer visitors to the Antarctic, incidence of plastic in the diet decreased with increased latitude. These results indicate either that the Antarctic Convergence blocks plastic debris, which is commonly found at the sea surface in the north, from entering the Southern Ocean, or that other factors such as the northward movement of pack ice sweeps the sea clear of plastic. Results also suggest that floating plastic debris is not yet the problem in the Antarctic that it is in more northern waters.

INTRODUCTION

Much has been learned recently about the ingestion of plastic by seabirds, mainly through the efforts of Day (1980; Day et al. 1985) in the northern Pacific, and of Ryan (1987a, 1987b, 1988a, 1988b, 1988c; Ryan and Jackson 1987) in the southern Atlantic. At present, 69 seabird species are known to ingest plastic while feeding at sea; 37 of these species frequent oceans of the Southern Hemisphere (see reviews in Day et al. 1985; Ryan 1987b). The incidence of ingested plastic in seabirds has been rising steadily since the 1960's, with the earliest records from procellariiform birds (Harper and Fowler 1987). The large majority of species now known to

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eat and retain plastic in their alimentary tracts are members of the order Procellariiformes.

Geographic variation in the incidence of plastic ingestion among seabirds is a function of proximity to areas of industrialization and human population centers. Among the 100 or so species investigated to date and for which sample sizes are greater than 30, in the following, about 80% of individuals carry plastic loads (see summaries in Day et al. 1985; Ryan 1987b; Sileo et al. 1990): Laysan and black-footed albatross, *Diomedea immutabilis* and *D. nigripes*, short-tailed shearwater, *Puffinus tenuirostris*, and parakeet auklet, *Cychlorrhynchus psittacula*, which frequent polluted waters of the North Pacific Rim; northern fulmar, *Fulmarus glacialis*, in the polluted northeastern Atlantic and the North Sea; greater shearwater, *Puffinus gravis*, which ranges between southern Africa and the polluted northwestern Atlantic; white-faced storm-petrel, *Pelagodroma marina*, and cape petrel, *Daption capense*, in waters off southern Africa; and blue petrels, *Halobaena caerulea*, in waters off southern Africa and the southwestern Pacific. High incidences of plastic also have been detected in seabirds of various species sampled off the U.S. west coast (Balz and Morejohn 1976).

In this paper we present information on the incidence of plastic in the diets of Antarctic seabirds, and compare our findings with the background of information just reviewed. The only samples collected previously in the Antarctic were reported by Ryan (1987b) and van Franeker and Bell 1988), and included small samples of five species.

METHODS

Birds were collected at sea off the Antarctic Peninsula and in the Ross Sea (Fig. 1) during investigations of their diets and marine ecology (Ainley et al. 1984, 1988, in press; Fraser and Ainley 1986). One sample of 60 Adélie penguins, *Pygoscelis adeliae*, was obtained by pumping stomachs at Palmer Station, Anvers Island (lat. 64°S, long. 64°W), in the Drake Passage; other penguin samples, except those from the Ross Sea, were obtained at sea also by stomach pumping. A sample of 75 castings was obtained from blue-eyed shags, *Phalacrocorax atriceps*, also at Palmer Station. All other birds were shot and contents of the proventriculus and ventriculus were obtained by dissection, collecting areas in the Ross Sea, December-January 1977-80, are summarized in Ainley et al. (1984); those in the southern Scotia Sea (Weddel Confluence region), November 1983 and August 1988, are summarized in Ainley and Sullivan (1984); those in the Weddell Sea, March 1986, are in Sullivan and Ainley (1988); and those in the Drake Passage and adjacent areas, July-August 1985-87, are in Pietz and Strong (1987).

Unlike Day (1980), Ryan (1987a, 1987b, 1988a, 1988b, 1988c; Ryan and Jackson 1987), and others (e.g., Furness 1985) who actually were attempting to directly characterize plastic ingestion in seabirds, we collected information incidental to other work. Therefore, except for the most recent sampling in August 1988, we did not quantify the number, size, and color of the particles found in digestive tracts.

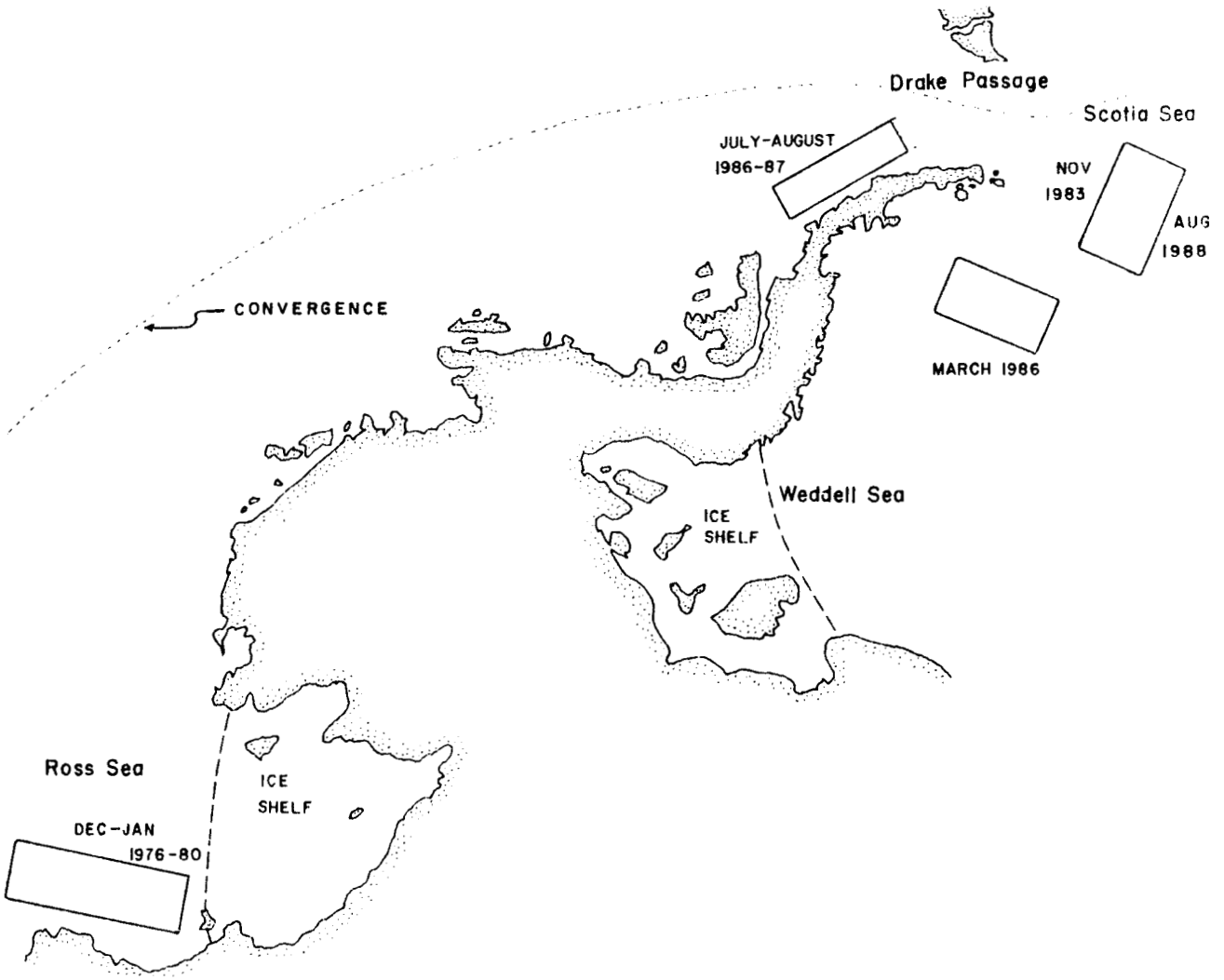

Figure 1.--The areas and time periods in which seabird stomach samples were collected.

RESULTS

We observed no large accumulations of plastic in any of the birds inspected. The greatest number of pieces was 22 in a blue petrel, but usually it was much smaller (the next largest quantity was 8, also in a blue petrel). The birds that contained plastic in August 1988 averaged (±SD) the following numbers per bird; blue petrel, 5.1 + 5.4 (n = 14); cape petrel, 1 (n = 4); and snow petrel, *Pagodroma nivea*, 1 (n = 4). As observed in other studies, most of the plastic consisted of small (3-6 mm diameter) fragments and "pellets." Styrofoam occurred rarely (1 of 74 pieces of plastic in 1988). One Antarctic petrel, *Thalassoica antarctica*, had eaten a piece of rubber from a (meteorological?) balloon; and a snow petrel had eaten threads of polypropylene rope.

No plastic was observed in any species that feed by diving beneath the sea surface (penguins, *Aptenodytes* and *Pygoscelis* spp.; the shag; and the diving petrel, *Pelecanoides urinatrix*), all of which feed on live micronekton (Croxall 1987, and papers therein; Table 1). Neither did we find plastic in any species that lack a well-developed gizzard or regularly regurgitate castings of indigestible material (albatrosses, *Diomedea* spp.; shags; skuas, *Catharacta* spp.; gulls, *Larus* spp.; and terns, *Sterna* spp.). Among those birds whose stomachs or gizzards did contain plastic (petrels, Procellariidae, only), incidence was higher in the smaller species. Such patterns are consistent with previously published information (Day et al. 1985; Ryan 1987b; but see Sileo et al. 1990, for the exception presented by the large albatrosses); these species tend to eat zooplankton or micronekton, and also scavenge dead organisms.

The frequency of occurrence of plastic decreased with increasing latitude in each of the four areas sampled, except to some extent in the Ross Sea (Table 2). The same pattern also emerged for only those species having a relatively high frequency of plastic ingestion. For example, in the Scotia Sea, the frequencies of plastic in blue petrels, cape petrels, Antarctic prions, and Wilson's storm-petrels combined, were 17, 6, 0, and 0% at lat. 56°-58°S (n = 60), 59°S (n = 51), 60°S (n = 50), and 61°-62°S (n = 17), respectively.

A pattern seemingly inconsistent with the latter finding is evident in a comparison between frequencies of occurrence of plastic in Scotia Sea and Weddell Sea samples (Table 1). Within a species, the frequency of plastic is much higher in birds from the more southerly Weddell Sea than in birds from the Scotia Sea. The Weddell Sea sample, which was from autumn, however, contained a much higher proportion of subadult nonbreeders, which would be expected to contain larger plastic loads (Ryan 1988c). Indeed the frequency of plastic in blue petrels in this sample was 88%, and in winter samples it was 90%, which were rates similar to those reported for this species off the coast of Africa. In spring, when there were many more adults in the sample, frequency was 21%.

Table 1.--The frequency of occurrence of plastic in the digestive tracts of seabirds collected in various sectors of the Southern Ocean.[a]

Species	Ross Sea	Drake Passage	Scotia Sea	Weddell Sea	Total
Aptenodytes forsteri			0 (8)	0 (17)	0 (25)
Pygoscelis adeliae	0 (5)	0 (60)	0 (29)	0 (10)	0 (104)
Pygoscelis papua		0 (5)			0 (5)
Phalacrocorax atriceps		0 (1)[b]			0 (1)
Diomedea palpebrata[c]	0 (2)				0 (2)
Macronectes giganteus[c]	0 (2)	0 (5)	0 (4)	0 (2)	0 (13)
Procellaria aequinoctialis[c]			0 (10)		0 (10)
Fulmarus glacialoides[c]	0 (13)	0 (4)	2 (49)	6 (18)	2 (84)
Thalassoica antarctica[c]	2 (40)	0 (25)	0 (66)	0 (53)	<1 (184)
Pagodroma nivea[c]	0 (108)	0 (77)	3 (139)	0 (39)	1 (363)
Daption capense[c]	50 (4)	5 (20)	11 (63)	31 (16)	14 (105)
Pterodroma inexpectata[c]	0 (4)				0 (4)
Pterodroma brevirostris[c]			0 (5)	9 (23)	7 (28)
Halobaena caerulea[c]			44 (45)	88 (17)	56 (62)
Pachyptila vittata[c]	67 (3)		4 (51)	20 (15)	10 (69)
Pelecanoides urinatrix[c]			0 (4)		0 (4)
Oceanites oceanicus[c]	37 (27)		4 (49)	33 (15)	19 (91)
Fregetta tropica[c]			0 (6)		0 (6)
Catharacta maccormicki	0 (25)				0 (25)
Larus dominicanus		0 (15)			0 (15)
Sterna paradisaea			0 (10)	0 (14)	0 (24)
Sterna vittata	0 (12)			0 (5)	0 (17)
Chionis alba	0 (2)				0 (2)

[a]Percentage with sample sizes in parenthesis.
[b]Samples of 30 pellets in 1977 and 45 in 1987 contained no plastic.
[c]Birds of the order Procellariiformes; see Table 2.

DISCUSSION

Plastic was found in 36% of the 23 species examined, a percentage much lower than that of most other regional studies: 100% of 10 species in California (Balz and Morejohn 1976), 76% of 15 at Gough Island (Furness 1985), 71% of 14 in New Zealand (Imber *in* Day et al. 1985), 56% of 95 in a world survey (Day et al. 1985), 60% of 60 from the Southern Hemisphere (Ryan 1987b), and 98% of 22 in Hawaii (Sileo et al. 1990). In another study of seabirds in the equatorial Pacific, Ainley et al. (1990) found plastic in 59% of petrel species. Thus, an unusually low incidence of contamination is evident in the Antarctic as compared to other areas of the world ocean (see also van Franeker and Bell 1988).

Table 2.--Frequency of occurrence of plastic in procellariiform birds, by latitude and sampling sector in the Southern Ocean.[a]

Latitude N	Ross Sea	Drake Passage	Scotia Sea	Weddell Sea
56°-58°			15 (183)	
59°			7 (119)[b]	
60°			1 (93)	
61°-62°		3 (37)	0 (97)	
63°-64°		0 (60)[b]		25 (60)
65°-66°		0 (34)		9 (137)
67°-69°	11 (35)			(b)
70°-75°	18 (63)[b]			
76°-78°	0 (46)			

[a]Percentages, with sample size in parenthesis, are given; see Table 1 for procellariiform species.
[b]Approximate northern edge of the pack ice.

The greatest frequency of occurrence found by us was in blue petrels, but the 56% rate was much lower than the 90% reported for this species by Ryan 1987b). A relatively high incidence was also evident in our Antarctic samples of the cape petrel (14%), Antaractic prion, *Pachyptila desolata* (10%), Kerguelen petrel, *Pterodroma brevirostris* (7%), and Wilson's storm-petrel, *Oceanites oceanicus* (19%). For these species, however, rates were much lower than those reported by Ryan (1987b), van Franeker and Bell (1988), Ainley et al. (1990), and Sileo et al. (1990) for other areas. Harper and Fowler (1987) reported a rate equivalent to ours for Antarctic prions found dead on beaches in New Zealand. In the present study, frequencies of plastic occurrence for the Antarctic fulmar, *Fulmarus glacialoides*, white-chinned petrel, *Procellaria aequinoctialis*, and Antarctic petrel were negligible, as also noted by van Franeker and Bell (1988) for the Indian Ocean sector of Antarctia. Ryan (1987b) found a similarly low rate for this sample of Antarctic petrels from the Antarctic, but higher rates of 11% in fulmars found dead on beaches in southern Africa and of 57% in white-chinned petrels from southern African waters. Ainley et al. (1990) found a rate of 67% for the latter species in the Peru Current. Not the present, nor Ryan's, nor van Franeker and Bell's studies detected much plastic in snow petrels, which are restricted to the Antarctic. Thus, a low incidence of plastic contamination is again indicated for Antarctic waters.

Our findings also indicate that the greater the distance south from the Antarctic Convergence the less likely birds are to have eaten plastic. More southerly individuals either have weaker ties to waters outside the Antarctic (where densities of plastic are greater, Morris 1980; Pruter 1987), or they have not frequented northern waters recently. If bird

residency time in pollution-free waters is a factor, such a pattern might also support the idea that over time there is a gradual attrition of plastic from digestive tracts (Day et al. 1985; Ryan and Jackson 1987; Ryan 1988a; van Franeker and Bell 1988; Ainley et al. 1990). Again, however, the pattern indicates that the density of plastic is very low in Antarctic waters. In other words, once south of the Antarctic Convergence, northern seabirds lose plastic from their digestive tracts faster than they gain it.

Both the patterns described above and other patterns indicate that at present there is little plastic floating on the surface of ocean waters south of the Antarctic Convergence. Antarctic surface waters flow northward away from the continent, and then sink beneath subantarctic waters at the Antarctic Convergence (Deacon 1964). Where the Antarctic Convergence is particularly well developed, flotsam (e.g., kelp fragments) is much in evidence along its northern edge (D. G. Ainley, pers. observ.; S. S. Jacobs, Lamont Doherty Geological Observatory, pers. commun.). Thus, the convergence may act to some degree as a barrier to flowing debris and pollutants from the north (though not an absolute barrier, because eddies are able to transport some northern waters across the convergence; Jacobs, pers. commun.). Because there is little human activity in the Antarctic, there is at present a relatively low rate of disposal of plastics. This helps to maintain the apparent low densities of floating plastic there, but few efforts to directly sample the abundance of floating plastic in Antarctic waters have been reported (Gregory et al. 1984; Pruter 1987). One additional factor that may help to sweep Antarctic waters clear of plastic is the seasonal, northward advance of the pack ice (Jacobs, pers. commun.). In that each of our samples was collected with respect to the pack ice edge (because we were comparing the diets of birds in and out of the ice), and the decreasing plastic loads we detected were not a function of absolute latitude south of the convergence (i.e., position of the pack ice edge differed for each sample), our results indicate that northward movement of ice would indeed help to clear any plastic from the sea surface in the Antarctic. In fact, a great deal of organic detritus (e.g., dead diatoms) is scoured from the water column by the freezing process, transport north, and released by melting at the ice pack edge, where a large amount of detrital material can be found (C. W. Sullivan, Department of Biological Sciences, University of Southern California, pers. commun.).

Assuming that most of the plastic found in the birds inspected in this study was ingested near to or north of the Antarctic Convergence, the frequency of occurrence of plastic in seabirds provides an index of how strongly certain petrel species are tied to Antarctic seas. Considering the dearth of ecological studies in Antarctic waters during the spring and winter, such an index is useful in characterizing the avifauna. Those seabird species with low frequencies of occurrence of plastic should exhibit the weakest tendencies to exit the Antarctic during the winter. These data, therefore, suggest that Antarctic and snow petrels, and a significant proportion of Antarctic fulmars, do not leave the Antarctic during winter, as do so many other "Antarctic" seabirds. In fact, the only plastic found in snow petrels was in individuals that had moved north with the pack ice during winter, and were thus close to the Antarctic Convergence. Along these same lines of reasoning, one might expect a large

amount of plastic to accumulate along the Antarctic Convergence, and the higher incidence of plastic in certain species, especially the blue and Kerguelen petrels, may indicate that these species frequent the convergence area more than most other species or that in general they frequent water mass convergences (cf. Bourne and Clark 1984). Census results support these distributional patterns (Ainley and Fraser, unpubl. data).

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