PREVALENCE AND CHARACTERISTICS OF PLASTIC INGESTED BY HAWAIIAN SEABIRDS

Louis Sileo, Paul R. Sievert,* Michael D. Samuel
National Wildlife Health Research Center
U.S. Fish and Wildlife Service
Madison, Wisconsin 53711, U.S.A.

and

Stewart I. Fefer**
Hawaiian and Pacific Complex National Wildlife Refuge
U.S. Fish and Wildlife Service
Honolulu, Hawaii 96850, U.S.A.

*Present address: Department of Biology, University of Pennsylvania, Philadelphia, Pennsylvania 19104.

**Present address: U.S. Fish and Wildlife Service, 1 Gateway Center, Suite 700, Newton Corner, Massachusetts 02158.

ABSTRACT

The prevalence of plastic in 18 species of seabirds at seven study sites in the Hawaiian Islands and Johnston Atoll was studied during 1986 and 1987. Stomach samples were collected by induced emesis from 1,803 live birds of 15 species and during necropsy of 277 dead birds of 5 species. The prevalence of ingested plastic varied greatly among species; age, year of collection, and location of the study site had less pronounced but significant effects. Ingested plastic was absent or uncommon in terns and noddies. Plastic was not found at all in samples from gray-backed terns, *Sterna lunata*, or white terns, *Gygis alba*. The prevalence was low in sooty terns, *Sterna fuscata* (0 to 8%), and brown, *Anous stolidus*, and black noddies, *A. minutus* (0 to 3%). Plastic was much more prevalent (67 to 100%) in chicks of black-footed, *Diomedea nigripes*, and Laysan albatrosses, *D. immutabilis*. In the 11 other species prevalence ranged from 0 to 44% depending on the age, year of collection, and location. The mean volume of plastic in samples collected at necropsy from Laysan albatross chicks was higher in 1986 (46 cc) than in 1987 (5 cc). Prevalence was generally higher in seabirds which fed at the surface. Fragments of manufactured articles were the most common type of plastic found. Other plastics included pellets, Styrofoam, bottle caps, bags, and sponges. The largest individual item (200 cc) and the greatest diversity of plastic items were found in albatross chicks.

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INTRODUCTION

Production of plastic products and dumping of plastic garbage in the ocean have increased dramatically in the past 25 years. From 1960 to 1985 the United States increased plastic production from 2.9 to 20.7 billion kg (6.3 to 47.9 billion lb) per year (Iudicello and O'Hara 1986). The prevalence of plastic ingestion by seabirds also has increased. Plastic was first reported in the stomachs of seabirds in 1960, when it was discovered in broad-billed prions, *Pachyptila vittata*, that were killed during storms on New Zealand (Harper and Fowler 1987). By 1985, at least 70 species of seabirds from all the world's oceans were known to ingest plastic (Day et al. 1985; Ryan 1987a).

Seabirds ingest a wide variety of plastic types, but 2- to 5-mm diameter plastic pellets and fragments of manufactured plastic products are most common (Day et al. 1985; Ryan 1987a). Other types of plastic found in seabird stomachs include Styrofoam, fibers, bags, bottle caps, and toys (Kenyon and Kridler 1969; Harrison et al. 1983; Dickerman and Goelet 1987; Ryan 1987a). Plastic particles may be eaten intentionally, accidentally mistaken for prey, or ingested secondarily when hidden within a food item (Day et al. 1985). For example, small plastic particles may be confused with fish eggs or small invertebrates, while larger pieces can be mistaken for squid, jellyfish, fish, or other large prey. Flyingfish often deposit their egg masses on floating debris such as plastic, which may then be ingested by albatrosses (Pettit et al. 1981; Harrison et al. 1983).

Plastic ingestion has not been reported as a significant health problem in seabird populations, but several studies have indicated negative effects on individual birds. Ingested plastic may distend or block the proventriculus or intestine, causing erosions or ulcers (Pettit et al. 1981; Sileo and Fefer 1987) or possibly starvation (Dickerman and Goelet 1987). The presence of ingested plastic was correlated with elevated (but nonthreatening) concentrations of polychlorinated biphenyls in great shearwaters, *Puffinus gravis* (Ryan et al. 1988), and with reduced body weight in red phalaropes, *Phalaropus fulicarius* (Connors and Smith 1982) and domestic chickens, *Gallus domesticus* (Ryan 1988a). Other studies have shown no correlation between body weight and plastic presence (Day et al. 1985; Ryan 1987b). Ryan and Jackson (1987) found no reduction in assimilation efficiency in white-chinned petrels, *Procellaria aequinoctialis*, artificially fed large quantities of plastic particles.

Studies of the prevalence of plastic ingestion in seabird communities, based on examination of regurgitations or carcasses, have been conducted in the North Pacific (Day et al. 1985) and South Atlantic Oceans (Furness 1985; Ryan 1987a). Reports of plastic in Laysan and black-footed albatrosses have shown that these birds ingest the widest variety of plastic items (Kenyon and Kridler 1969) and ingest the largest volumes of plastic more frequently than other seabirds (Fry et al. 1987; Sileo and Fefer 1987). Harrison et al. (1983) reported cursory data for other Hawaiian seabirds, but systematic study of the prevalence of plastic ingestion in the Hawaiian avifauna has not been done. Our objective was to determine the prevalence of ingested plastic in three orders of Hawaiian seabirds (Procellariiformes, Pelecaniformes, and Charadriiformes) from different islands by examining stomach contents. We evaluated the prevalence of ingested plastic for associations with species, location of study site, year of collection, and ages of birds sampled.

STUDY AREA AND METHODS

Stomach samples were collected from 18 species of seabirds on Kauai, Maui, Nihoa, Tern, and Laysan Islands, Pearl and Hermes Reef, and Midway in the Hawaiian Islands. Approximately 5 million seabirds of 22 species nest on these islands (Harrison et al. 1984). Samples were also collected on Johnston Atoll, 1,400 km southwest of Honolulu. Seabirds from remote, uninhabitated islands were sampled by the authors or other biologists as travel circumstances permitted. One of us (Sievert) spent 4 months in 1986 and 6 months in 1987 on Midway.

To avoid killing large numbers of seabirds, a stomach pumping method was used to recover the proventricular contents (Wilson 1984; Ryan and Jackson 1986). The method reportedly recovers 89 to 100% of the proventricular contents, although Ryan and Jackson (1986) found that the proportion (by mass) of food recovered by a single pumping was negatively correlated with total stomach content in white-chinned petrels. Seawater was pumped through a 10-mm (outside diameter) plastic tube into the proventriculus of larger species with a manual pump (Black and Decker Model No. JSO-1500). Smaller species, such as terns and petrels, were given seawater using a 6-mm (outside diameter) plastic tube attached to a 140-cc syringe. Seawater was pumped into the proventriculus until water became visible in the esophagus. The tube then was quickly removed and the bird inverted over a container. The bill was held open with one hand and large objects were massaged through the esophagus if the bird was having difficulty regurgitating. A 1-mm diameter mesh net was used to skim plastic items from the surface of the regurgitant for later characterization.

The samples were collected from April 1986 to November 1987 by induced emesis from live seabirds or during necropsy of carcasses. Necropsy samples were obtained from carcasses found dead of natural causes and from six euthanized Laysan albatross chicks. All necropsies were performed by the authors. Dehydration was the most common natural cause of death in 1987 (Sileo et al. 1990). Seabird stomach samples were collected by different biologists in different locations, which resulted in statistical confounding of investigator effect with location. The confounding was unavoidable because the remoteness and inaccessibility of the study sites precluded replicative sampling by different biologists. Investigator effect was minimized by having each biologist complete a training session for the stomach pumping method. For most species, stomach samples were collected from chicks because they were more accessible and more easily captured. All live birds were approached on foot and captured by hand. Age of the seabirds was determined by plumage characters. When it was not possible to differentiate between free-flying juveniles and adults, all were assigned to an arbitrary "either" category. Birds were sampled once and banded with a U.S. Fish and Wildlife Service leg band to prevent repetitive sampling.

We tested the effectiveness of the sampling technique by pumping the stomachs of six Laysan albatross chicks, then euthanizing and examining them. The volume of proventricular content not removed by the stomach pump was determined. We necropsied birds that were found dead and inspected their digestive tracts for the presence of plastic. This was the only method used for 58 Bonin petrels, *Pterodroma hypoleuca*, 3 dark-rumped petrels, *Pterodroma phaeopygia*, and 18 Newell's shearwaters, *Puffinus auricularis* (newelli). The proventriculus and ventriculus of all necropsied birds were examined, and the intestines also were examined for a sample of 39 black-footed albatrosses, 57 Laysan albatrosses, and 12 Bonin petrels. Contents of the entire intestine from pyloris to cloaca were stripped. All plastic was separated from the stomach content by fresh water flotation and saved for later characterization.

Plastic was characterized by type, volume, and color. Types were fiber, pellet, Styrofoam, fragment, bottle cap, bag, sponge, and other. Fiber included fishing line, net fragments, and rope. Pellets were 2 to 5 mm diameter spherical polyethylene particles primarily used as the raw material for manufacturing plastic products (Carpenter et al. 1972). Bottle caps included all types of plastic lids, and bags were defined as plastic film less than 1 mm thick in the form of a bag or sheet. Other included children's toys, cigarette lighters, hair combs, balloons, gloves, condoms, tubing, sandals, wrappers, and bandages. The number of plastic items of each type per bird was counted except for fiber, which was recorded as present or absent. Plastic fragments were assigned to one of five color groups: white, which included white, yellow, tan, and brown; black, which included gray and black; blue, which included purple and blue; green, which included all shades of green; and red, which included pink and red. One of us (Sievert) was studying growth rates of a marked population of albatross chicks at a study site on Midway. Albatross carcasses found dead at this study site were dissected and the total volume of recovered plastic was determined by water displacement. The buoyant contents were placed in a wire screen bag (1.5-mm diameter mesh) and immersed in a 2,000-ml beaker filled with tap water. The volume of water displaced was measured. In 1986, all measurements were made in 1-cc increments, and in 1987, in 5-cc increments. The volume of the largest plastic fragment from each bird was calculated from the linear dimensions of the fragment.

Statistical analysis of the plastic prevalence data followed the general recommendations of Freeman (1987). Chi-square tests for association were used for 2 × 2 tables of plastic prevalence and other independent variables. Fisher's exact test was used when cell expectations were small (<5). Several 2 × 2 tables were combined using the Cochran-Mantel-Haenszel procedure to test hypotheses of an overall association between plastic prevalence and the independent variables. This procedure provided a means for stratifying the plastic prevalence data from each unique combination of island, age, species, and year so that there was only a single independent variable in each test. Hypothesis tests were considered significant at the 0.05 level, however, P values for each test are also reported. Samples from wedge-tailed shearwaters, *Puffinus pacificus*, and red-tailed tropicbirds, *Phaethon rubricauda*, from different islands permitted assessment of the effect of geographic location on plastic ingestion. The influence of year of collection was determined by comparing prevalence in 1986 and 1987 in 11 combinations of species, location, and age. The prevalence in chicks was compared to adults in nine combinations of year, species, and location. If the prevalences of two or more closely related species were not significantly different, data from the species were combined to make comparisons with broader taxonomic groups.

RESULTS

In 1987 stomach pumping removed at least 50% of the proventricular plastic from five (83%) of six Laysan albatross chicks, each of which contained 5 to 10 cc of plastic (Table 1). Stomach pumping failed to remove any plastic from the remaining chick, which contained 5 cc of plastic as well as 100 cc of rock. The rock was primarily buoyant volcanic pumice. Induced emesis recovered half of the proventricular plastic as long as the pumice content was less than 55% of the total proventricular content. For comparison, the prevalence of proventricular plastic in the carcasses of Laysan albatross chicks examined by dissection at Midway was 94% in 1986 and 98% in 1987 (Table 2).

Stomach-pumped samples from both 1986 and 1987 were collected from 11 unique combinations of species, location, and age (Table 2). Significant differences between years of collection were found for red-tailed tropicbird chicks at Midway and adult wedge-tailed shearwaters at Kauai; however, the overall test for a significant association between year of collection and plastic prevalence was not quite significant ($P = 0.053$). To remove potential investigator effect, combinations where all the birds were sampled by only one of us (Sievert) were analyzed. These included the five combinations sampled at Midway, and the overall P value (0.029)

Table 1.--Rock, plastic, and other proventricular contents removed by stomach pumping from six Laysan albatross chicks that were then euthanized and necropsied.

Bird No.	Total content: Volume present[a] (cc)	Total content: Percent removed	Rock content: Volume present[a] (cc)	Rock content: Percent removed	Plastic content: Volume present[a] (cc)	Plastic content: Percent removed
1	140	3	100	5	5	0
2	100	20	55	18	10	50
3	60	17	20	25	10	50
4	45	44	15	67	5	100
5	20	50	10	50	10	50
6	20	50	5	100	10	50

[a]Volumes were measured in 5 cc increments.

Table 2.--Statistical comparisons of the prevalence of plastic in stomach samples collected from Pacific seabirds.[a]

							P Values				
Method[b]	Year	Species[c]	Site[d]	Age[e]	N	%	1986-87	Age	Islands		Species
N	1986	BFAL	M	C	28	89	--	--	--	--	ab 0.433
N	1986	LAAL	M	A	31	35	--	i 0.000	--	--	--
N	1986	LAAL	M	C	78	94	--	i 0.000	--	--	ab 0.433
N	1986	BOPE	M	B	58	29	--	--	--	--	--
N	1987	BFAL	M	C	18	100	--	--	--	--	ac 1.00
N	1987	LAAL	M	C	43	98	--	--	--	--	ac 1.00
N	1987	NESH	K	I	18	11	--	--	--	--	--
P	1986	BFAL	L	C	56	79	a 0.097	--	--	--	--
P	1986	BFAL	T	C	1	0	--	--	--	--	--
P	1986	LAAL	L	C	24	92	c 0.161	--	--	--	--
P	1986	LAAL	T	C	12	92	d 0.245	--	--	--	--
P	1986	WTSH	K	A	150	18	i 0.024	--	ba 1.00	ca 0.452	--
P	1986	WTSH	M	A	15	13	j 0.304	h 0.620	ba 1.00	da 0.716	dc 1.000
P	1986	WTSH	M	C	11	27	--	h 0.620	--	--	--
P	1986	WTSH	T	A	48	23	k 0.272	--	ca 0.452	da 0.716	--
P	1986	CHSH	M	A	1	0	--	--	--	--	dc 1.000
P	1986	RTTB	M	A	8	0	--	c 0.054	--	--	--
P	1986	RTTB	M	C	16	44	g 0.001	c 0.054	--	--	--
P	1986	RFBO	L	A	34	0	--	--	--	--	--
P	1986	RFBO	L	C	7	0	e 1.00	--	gb 1.00	--	--
P	1986	RFBO	M	A	4	0	--	b 1.00	--	--	--
P	1986	RFBO	M	C	19	11	f 0.119	b 1.00	gb 1.00	--	--
P	1986	SOTE	M	A	26	8	--	f 0.172	--	--	ba 1.00
P	1986	SOTE	M	C	36	0	h 0.493	f 0.172	--	--	bb 1.00
P	1986	GBTE	M	A	7	0	--	--	--	--	ba 1.00
P	1986	GBTE	M	C	29	0	--	--	--	--	bb 1.00
P	1986	BRNO	M	A	17	0	--	a 1.00	--	--	--
P	1986	BRNO	M	C	86	1	b 1.00	a 1.00	--	--	--
P	1986	BLNO	L	A	18	0	--	--	--	--	--

Table 2.--Continued.

							P Values				
Method[b]	Year	Species[c]	Site[d]	Age[e]	N	%	1986-87	Age	Islands		Species
P	1987	BFAL	L	C	36	92	a 0.097	--	eb 0.710	--	aa 0.239
P	1987	BFAL	N	C	21	86	--	--	fb 1.00	--	--
P	1987	BFAL	P	C	35	97	--	--	--	--	ad 0.614
P	1987	BFAL	T	C	35	89	--	--	eb 0.710	fb 1.00	ae 0.206
P	1987	LAAL	L	C	35	100	c 0.161	--	--	--	aa 0.239
P	1987	LAAL	P	C	35	91	--	--	--	--	ad 0.614
P	1987	LAAL	T	C	6	67	d 0.245	--	--	--	ae 0.206
P	1987	BUPE	N	A	38	5	--	--	--	--	--
P	1987	WTSH	J	A	60	5	--	--	ab 0.004	--	--
P	1987	WTSH	K	A	35	3	i 0.024	g 0.067	bb 0.003	cb 0.064	--
P	1987	WTSH	K	C	7	29	--	g 0.067	--	--	--
P	1987	WTSH	L	A	35	14	--	--	ga 0.145	ea 0.888	da 0.782
P	1987	WTSH	M	A	35	29	j 0.304	--	ab 0.004	dd 0.093	--
							--	--	bb 0.003	ga 0.145	--
P	1987	WTSH	N	A	60	3	--	--	fa 0.033	--	db 0.522
P	1987	WTSH	T	A	85	15	k 0.272	--	cb 0.064	fa 0.033	--
							--	--	db 0.093	ea 0.888	--
P	1987	CHSH	L	A	36	17	--	--	--	--	da 0.782
P	1987	CHSH	N	A	2	50	--	--	--	--	db 0.522
P	1987	SOSP	L	A	18	33	--	e 0.903	--	--	--
P	1987	SOSP	L	C	17	35	--	e 0.903	--	--	--
P	1987	RTTB	J	C	50	4	--	--	aa 1.00	--	--
P	1987	RTTB	M	A	39	5	--	d 1.00	--	--	--
P	1987	RTTB	M	C	48	2	g 0.0001	d 1.00	aa 1.00	--	--
P	1987	RTTB	T	C	50	14	--	--	--	--	--
P	1987	MABO	L	C	20	5	--	--	--	--	--
P	1987	RFBO	L	C	35	3	e 1.00	--	ec 1.00	gc 1.00	--
P	1987	RFBO	M	C	35	0	f 0.119	--	dc 1.00	gc 1.00	--
P	1987	RFBO	T	C	35	0	--	--	dc 1.00	ec 1.00	--
P	1987	GRFR	M	C	45	18	--	--	--	--	--

Table 2.--Continued.

Method[b]	Year	Species[c]	Site[d]	Age[e]	N	%	P Values				
							1986-87	Age	Islands		Species
P	1987	SOTE	M	C	35	3	h 0.493	--	--	--	bc 1.00
P	1987	GBTE	M	A	10	0	--	--	--	--	--
P	1987	GBTE	M	C	25	0	--	--	--	--	bc 1.00
P	1987	BRNO	M	C	35	0	b 1.00	--	--	--	--
P	1987	BRNO	T	C	15	0	--	--	--	--	ca 1.00
P	1987	BLNO	T	C	35	3	--	--	--	--	ca 1.00
P	1987	WHTE	M	C	35	0	--	--	--	--	--

[a]Rows having the same letter codes and the same P value were compared by the Cochran-Mantel-Haenszel procedure (Freeman 1987). The first letter of a double letter P value code indicates a species group comparison; the second letter of a double letter code indicates the two members of a paired comparison within the designated group.

[b]N - sample collected at necropsy, P - sample collected by stomach pumping.

[c]BFAL - black-footed albatross, BLNO - black noddy, BRNO - brown noddy, BOPE - Bonin's petrel, BUPE - Bulwer's petrel, CHSH - Christmas shearwater, GBTE - gray-backed tern, GRFR - great frigatebird, LAAL - Laysan albatross, NESH - Newell's shearwater, MABO - masked booby, RFBO - red-footed booby, RTTB - red-tailed tropicbird, SOSP - sooty storm petrel, SOTE - sooty tern, WHTE - white tern, WTSH - wedge-tailed shearwater.

[d]J - Johnston Atoll, K - Kauai, L - Laysan Island, M - Midway, N - Nihoa Island, P - Pearl and Hermes Reef, T - Tern Island.

[e]A - adult, C - chick, B - both adults and free-flying immatures, and I - free-flying immatures.

indicated a significantly higher prevalence in 1986. Thus year of collection had a significant effect in species and age combinations from Midway.

To test age, prevalence data based on stomach-pumped samples collected from both adults and chicks of eight combinations of species, location, and year of collection were compared (Table 2). None of the individual results were significantly different; however, in all species except the sooty tern, the trend was for higher prevalence among chicks. This caused a significant overall association between age and prevalence ($P = 0.05$). A second analysis of age was done which included the 1986 necropsy samples from the Laysan albatrosses at Midway. There was a significant difference between the Laysan albatross chicks and adults ($P < 0.00$), and the overall association between age and prevalence was again significant ($P < 0.00$).

In 1987 the adult wedge-tailed shearwaters of Johnston Atoll had significantly lower prevalence (5%) of plastic in pumped stomach samples than at Midway (29%) in individual tests (Table 2), and the overall test of association also showed a significantly ($P = 0.01$) lower prevalence at Johnston. In 1987, adult wedge-tailed shearwaters had higher prevalence (29%) at Midway than at Kauai (3%), and at Tern Island (15%) than at Nihoa (3%). The individual tests for these particular combinations were significant (Table 2), but the overall tests of association were not ($P = 0.064$, and $P = 0.078$, respectively), suggesting the absence of a consistent pattern in differences in prevalence among these island pairs. No other significant differences were detected between locations.

It was possible to compare prevalence between black-footed and Laysan albatrosses using both stomach-pumped and necropsy samples for five combinations of location, age, and year of collection (Table 2). Neither the individual results nor the overall test of association ($P = 0.98$) were significant. Consequently, data from both species of albatrosses were combined for later comparisons with other taxa. Stomach pumped samples from three combinations of location, age, and year were used to compare gray-backed terns and sooty terns. Again, neither individual nor overall ($P = 0.264$) tests of association were significant, and both species of terns were combined for comparison with other taxa. Brown noddies and black noddies were also not significantly different ($P = 1.00$) and were combined. Finally, the combined terns were compared to the combined noddies, and again neither individual ($P = 0.542$, 1.00, or 1.00) nor the overall ($P = 0.519$) tests of association were significant, so that all tern and noddy species were combined for comparisons with other taxa. Stomach-pumped samples from Christmas shearwaters, *Puffinus nativitatis*, and wedge-tailed shearwaters were compared for three combinations of location, age, and year (Table 2). There were no significant individual or overall ($P = 0.69$) association, and data from these two species of shearwaters were combined for comparisons with other taxa. In comparisons between taxonomic groups, the albatrosses had significantly higher prevalences, the terns and noddies the lowest, and the shearwaters, tropicbirds, and boobies were intermediate (Table 3).

Table 3.--Comparisons of the prevalence of ingested plastic in stomach samples of five taxonomic groups of Hawaiian seabirds. A "-" means that the taxa in the row had significantly lower prevalence than the taxa in the column, "ns" means that there was no significant difference between the taxa in the row and column, "+" means that the taxa in the row had significantly higher prevalence than the taxa in the column, and "nc" means no comparison was done.

Taxa[a]	LAAL/BFAL	GBTE/SOTE BLNO/BRNO	RFBO	CHSH/WTSH	RTTB
LAAL/BFAL		+	+	nc	+
GBTE/SOTE BLNO/BRNO	-		ns	-	-
RFBO	-	ns		ns	-
CHSH/WTSH	nc	+	ns		+
RTTB	-	+	+	-	
Range of prevalence in chicks (%)	67-100	0-36	0-11	27-29	2-44
Range of prevalence in adults (%)	35	0-8	0-34	3-29	0-5

[a]BFAL - black-footed albatross, BLNO - black noddy, BRNO - brown noddy, CHSH - Christmas shearwater, GBTE - gray-backed tern, LAAL - Laysan albatross, RFBO - red-footed booby, RTTB - red-tailed tropicbird, SOTE - sooty tern, WTSH - wedge-tailed shearwater.

Necropsy examinations of carcasses revealed plastic in the intestines of many of the albatrosses (Table 4). While plastic was usually present in both the proventriculi and ventriculi of albatrosses, it was more common in the ventriculi of petrels and shearwaters (Table 4). The mean volume of plastic in the Laysan carcasses was about nine times greater in 1986 than 1987 (Table 5).

Albatrosses held the widest diversity of plastic types and were the only species to ingest bottle caps, bags, sponges, and a variety of other items. Styrofoam, fibers, sponges, bags, and bottle caps were more common in black-footed albatrosses than Laysan albatrosses, whereas plastic pellets were more common in the latter. Fragments were the most common type of plastic ingested by all the species except Bonin petrels, which contained fibers most frequently. Albatrosses ate the largest individual plastic items; the volume of the largest single item (plastic sheet) recovered was 200 cc. Albatrosses also ate the largest fragments (up to 25.2 cc); petrels, shearwaters, tropicbirds, boobies, and frigatebirds ingested moderate-sized ones; and storm-petrels and terns consumed the smallest (up to 2.0 cc, Table 6). Most of the fragments recovered were white regardless of the species of bird (Table 7). Samples from sooty storm-petrels, *Oceanodroma tristrami*, contained red fragments more frequently than samples from any of the other species. Great frigatebirds, *Fregata minor*, contained only white or black fragments.

DISCUSSION

Although we never recovered more than 50% of the volumes of plastic greater than 5 cc, or over 50% of the total stomach content of the euthanized albatross chicks, the reliability of stomach pumping seemed acceptable for simply detecting the presence of plastic in Laysan albatross chicks, and thus for prevalence information. Efficacy in the other species was not determined. Ryan and Jackson (1986) got higher (89-100%) yields of the total stomach content of petrels than we did for albatross chicks, although Ryan and Jackson were studying the removal of all dietary items and we were interested only in detecting the presence of plastic. Large volumes of proventricular rock seemed to interfere with removal of small volumes of plastic. Other reports also state that stomach pumping is less effective in birds that have full stomachs with tightly packed contents (Ryan and Jackson 1986). Stomach pumping removes only the proventricular content of petrels, and may or may not remove gizzard content from Pelecaniformes, Charadriiformes, and some Procellariiformes (Diomedeidae) (Ryan and Jackson 1986). Our stomach pumping results possibly underestimated prevalence in our study and this may have been more significant in individuals with small plastic loads. But stomach pumping precluded killing 1,803 seabirds, simply to learn what they were eating.

There are several reports that the prevalence of ingested plastic in seabirds is increasing over the long term. Day et al. (1985) reported increases in short-tailed shearwaters, *Puffinis tenuirostris*, in the 1970's. Van Franeker (1985) noted an increase in the number of plastic particles in fulmars, *Fulmaris glacialis*, in the North Sea through the early 1980's. Harper and Fowler (1987) reported long-term interannual increases in plastic prevalence based on large samples of prions, *Pachyptila* spp., found dead on New Zealand beaches from <5% in 1960 to >20% in 1970. Fry et al. (1987) show that the prevalence (80-90%) in the Laysan albatrosses of the Northwestern Hawaiian Islands in the late 1980's was higher than the 74% reported by Kenyon and Kridler (1969), although the sampling methods were different. Frequency of occurrence increased in Antarctic prions, *P. desolata*, in the Southern Ocean during the early 1980's (Ryan 1988b). It is widely assumed that increasing prevalence in seabirds reflects increasing pollution of the marine environment, and this is probably correct; however, the marked short-term interannual difference we found (44% in red-tailed tropicbird chicks at Midway in 1986 versus 2% in 1987) in the same species at the same nesting colony examined by the same scientist suggests that long-term relationships must be interpreted carefully. Such interannual variation might be caused by changes in the amount of plastic dumped in the ocean, movement of floating plastic by winds and currents, seabird foraging areas, or feeding behavior. The volumes of plastic we recovered from the necropsied albatross chicks are 10 to 100 times greater than the volumes reported for other species (Day et al. 1985; Furness 1985; Ryan 1987a, Bayer and Olson 1988; van Franeker and Bell 1988). The mean 18.3 cc volume (estimated as 0.9053 × weight) recovered from Laysan albatross chicks by Kenyon and Kridler (1969) compares well with our data.

Table 4.--The prevalence of plastic in the gastrointestinal tracts of seabird carcasses examined by necropsy in the Hawaiian Islands in 1986 and 1987 [percent containing plastic (number examined)].

Species	Age[a]	Plastic location: Proventriculus	Ventriculus	Intestines
Black-footed albatross	Chick	95 (44)	93 (44)	30 (20)
Laysan albatross	Chick	100 (131)	95 (131)	39 (57)
Bonin petrel	Both	27 (99)	82 (99)	0 (12)
Dark-rumped petrel	Both	33 (3)	100 (3)	--
Newell's shearwater	Both	8 (36)	17 (36)	--

[a]Both = Juveniles plus adults.

Table 5.--Volume of plastic removed from the proventriculi of black-footed and Laysan albatross carcasses found dead of natural causes on Midway.

	Black-footed albatross			Laysan albatross		
Year	N	Range	Mean	N	Range	Mean
1986	25	0-198	39	45	1-186	46
1987	18	5-165	33	76	5-20	5

With the inclusion of the results from this study, 80 species, or approximately 25% of the world's seabird species, have been shown to ingest plastic. The pronounced differences in the prevalence of ingested plastic between different taxa of Hawaiian seabirds was expected. Seabird biologists have reported interspecific differences for seabird communities in the North Pacific and Southern Ocean and have attributed them primarily to differences in feeding behavior (Day et al. 1985; Ryan 1987a). Species feeding primarily at the ocean surface ingested more plastic, possibly because of increased exposure to it.

Geographic variations in prevalence in a given species are usually attributed to differences in the environmental availability of plastic, although no study has attempted to test this assumption (Day et al. 1985; Ryan 1988b). The mean density of plastic particles in Alaskan waters was 910 particles/km^2 (calculated from Day and Shaw 1987), in the South Atlantic it was 2,080 particles/km^2 (calculated from Morris 1980), and in the subtropical North Pacific (the Hawaiian Islands region) it was 96,100 particles/km^2 (Day and Shaw 1987). The corresponding percentages of

Table 6.--Mean volume (cc) of the largest plastic fragment[a] removed from the proventriculi and ventriculi of individual Hawaiian seabirds during 1986 and 1987.

Species	Proventriculus		Ventriculus	
	N	Mean volume	N	Mean volume
Black-footed albatross	51	2.056	16	0.089
Laysan albatross	47	0.649	63	0.073
Petrels (Bonin, Bulwer's, dark-rumped)	4	0.041	20	0.014
Shearwaters (wedge-tailed, Newell's, Christmas)	54	0.117	6	0.006
Sooty storm-petrel	30	0.017	--	--
Red-tailed tropicbird	14	0.051	--	--
Boobies (masked, red-footed)	2	0.054	--	--
Great frigatebird	5	0.329	--	--
Sooty tern	1	0.002	--	--

[a]Fragments were flat pieces of manufactured plastic, 1-3 mm thick, typically from broken plastic bottles or other containers.

Table 7.--Prevalence (number of stomach samples containing the color/the total number of samples examined × 100) of different colors of plastic fragments[a] removed from the proventriculi of Hawaiian seabirds during 1986 and 1987. Stomach samples were obtained by stomach pumping.

Species	N	Plastic color (%)[b]				
		White	Black	Blue	Green	Red
Black-footed albatross	82	93	27	43	41	13
Laysan albatross	78	95	32	49	50	27
Wedge-tailed shearwater	51	84	8	24	29	8
Sooty storm-petrel	30	87	13	10	27	40
Red-tailed tropicbird	14	57	43	21	7	0
Great frigatebird	5	80	40	0	0	0

[a]Fragments were flat pieces of manufactured plastic, 1-3 mm thick, typically from broken bottles or other containers.

[b]Color groups were: white - white, yellow, tan and brown; black - gray and black; blue - purple and blue; green - green; red - pink and red.

seabird species that ingested plastic in these three regions were 41 (Day et al. 1985), 60 (Ryan 1987a), and 89 (this study), suggesting a positive relationship between plastic availability and the prevalence of ingestion. The same relationship may explain the lower prevalence of plastic in adult wedge-tailed shearwaters at Johnston Atoll compared with the same species at Midway. The beaches of Johnston Atoll have much less plastic refuse than those of the Northwestern Hawaiian Islands (S. I. Fefer, unpubl. observ.), suggesting a lower density of plastic in the surrounding waters used for feeding. Much of the plastic in these waters may be of Japanese origin as indicated by Pettit et al. (1981), who found that 108 of 109 identifiable plastic items in dead albatross carcasses at Midway were manufactured in Japan. Movement of floating plastic by ocean currents provides an explanation for the high prevalence of Japanese plastic in Hawaiian waters and the reduced amount of plastic on Johnston Atoll. The Kuroshio moves surface waters from near Japan southeast to the Hawaiian region, and may carry plastic with it (Fry et al. 1987). Johnston Atoll is affected primarily by the North Equatorial Current, which probably has less intense shipping and fishery activity and hence less plastic.

Day et al. (1985) found that subadult parakeet auklets, *Cyclorrhynchus psittacula*, and tufted puffins, *Lunda cirrhata*, contained more plastic than adults, and Ryan (1988b) found the same association for blue petrel, *Halobaena caerulea*, chicks. The high prevalence in albatross chicks, and probably chicks of other species in the Hawaiian Islands, was likely due to the regurgitational chick-feeding process and the inability of very young chicks to regurgitate indigestibles. All Hawaiian seabirds except white terns feed their chicks by regurgitation, and plastic items ingested by the parents are probably passed to the chicks. Ryan (1988b) proposed that this "intergenerational" transfer of plastic reduces occurrence in the adult populations while increasing it in the chick populations. Plastic is usually expelled from the proventriculus of albatross chicks by regurgitation late in the chick-rearing period (Clarke et al. 1981), and the volume of plastic in a given chick, and perhaps the prevalence in the chick population, are reduced at that time. Other seabirds (giant petrels, cormorants, skuas, gulls, and terns) also regurgitate indigestible matter. The presence of plastic in the intestines of some birds indicates that plastic is also removed by defecation. Interspecific differences in physiology, the ratios of proventricular to ventricular volume, or the total volume of plastic ingested may have influenced the interspecific differences in the distribution of plastic through the gastrointestinal tract.

It was not determined if the color composition of fragments from the stomach samples reflected the color distribution of floating fragments at sea or some feeding specificity by the birds. Day et al. (1985) found that some Alaskan seabirds selectively consume plastic particles similar to prey items.

Black-footed albatrosses ingest about 10 times the volume of fish eggs ingested by Laysan albatrosses (Harrison et al. 1983), and might be expected to ingest more plastic pellets if these are mistaken for fish eggs. However, we found pellets more often in Laysan (52%) than black-footed albatrosses (12%, P < 0.001). Black-footed albatrosses probably do not ingest single fish eggs, but instead consume large masses of eggs attached to floating objects, which may explain the higher (34%) prevalence of fibers in the proventriculi of black-footed albatrosses than Laysans (11%, P < 0.001).

The size of plastic particles relative to common food items may be important in explaining why albatrosses ingest much larger plastic pieces than other Hawaiian seabirds. Black-footed and Laysan albatrosses both ingest larger size classes of squid and other food items than most Hawaiian seabirds (Harrison et al. 1983). It is also possible that black-footed albatrosses have more frequent contact with large plastic items due to their habit of feeding on refuse dumped overboard by ships (Miller 1940).

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