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INGESTION OF PLASTIC POLLUTANTS BY MARINE BIRDS

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ABSTRACT

To date, ingestion of plastic pollutants has been recorded in 50 species of marine birds from around the world. Procellariiform birds ingest plastic most frequently, and phalaropes and some alcids also have relatively high rates of ingestion. Penguins, pelecaniform birds, larids, and most alcids ingest little or no plastic. Species feeding primarily by surface-seizing or pursuit-diving have the highest frequencies of plastic ingestion. Species feeding primarily on crustaceans or. cephalopods have the highest frequencies of plastic ingestion; secondary ingestion of plastics via fish appears to be unimportant. Although some species ingest plastic randomly, most exhibit selective preferences for certain types of plastic. Monomorphic seabird species show no sexual differences in rates of plastic ingestion. Subadult seabirds ingest more pieces of plastic than do adult seabirds. Geographic and seasonal variations in plastic ingestion have been recorded. Plastic ingestion has increased since it began in the early 1960's: Limited detrimental effects of ingested plastic on the physical condition of seabirds have been documented, although red phalaropes, Laysan albatrosses, and northern fulmars show evidence of some physical impairment and parakeet auklets show evidence of decreased reproductive performance.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

INTRODUCTION

The presence of plastic pollution in marine waters was first recorded from marine birds in the northwestern Atlantic Ocean in 1962 (Rothstein 1973). Since then, a series of papers on plastic pollutants in the ocean has reported on the qualitative and quantitative distributions of floating plastic (Carpenter et al. 1972; Carpenter and Smith 1972; Cundell 1973; Kartar et al. 1973; Venrick et al. 1973; Colton et al. 1974; Hays and Cormons 1974; Morris and Hamilton 1974; Wong et al. 1974; Gregory 1977, 1978, 1983; Shaw 1977; Shaw and Mapes 1979; Shiber 1979, 1982; Merrell 1980; Morris 1980a, 1980b; Van Dolah et al. 1980), the occurrence of plastic in the benthos (Kartar et al. 1973, 1976 ; Hays and Cormons 1974; Morris and Hamilton 1974; Jewett 1976; Feder et al. 1978), and the mechanisms that disperse or concentrate plastic and other marine pollutants (Colton et al. 1974; Wong et al. 1974, 1976; Shaw and Mapes 1979; Van Dolah et al. 1980).

Although most of the early work documented the distribution and abundance of plastic pollution at sea, it is clear that plastic pollutants were entering food webs quite soonafter their appearance in the oceans (Kenyon and Kridler 1969; Rothstein 1973). A survey of work in the last decade, however, shows that the ingestion of plastic pollutants by marine birds is being recorded with greater frequency and that our impression of the problem is changing from one of a series of interesting observations to recognition of a pollution problem facing seabirds worldwide (Coleman and' Wehle 1984). Concern over this problem culminated in a recent study by the senior author (Day 1980) of the dynamics of plastic pollution in a suite of 37 species of marine birds in Alaska, a relatively pristine environment remote from source areas of plastic. In that study, plastic was recorded in 15 (40.5%) of the 37 species and 448 (22.8%) of the 1,968 birds examined, illustrating how extensive plastic pollution had become in the 16 years since it was first recognized in seabirds.

In this paper, we attempt to synthesize all information available on global patterns of plastic ingestion in marine birds and we discuss the dynamics and characteristics of plastic pollutants ingested. The emphasis is on the North Pacific, for which the most complete data exist. We do not discuss the interactions of marine birds with gill net fisheries (i.e., Tull et al. 1972; Ainley et al. 1981; Coleman and Wehle 1983; Carter and Sealy 1984; Piatt et al. 1984; Piatt and Reddin 1984), the entanglement of marine birds in other marine debris (e.g., Gochfeld 1973; Bourne 1976; Coleman and Wehle 1984; Conant 1984), or the mortality of marine birds from oil or heavy-metal pollution (e.g., Bourne 1976; Ohlendorf et al. 1978).

RESULTS

General Aspects of Plastic Ingestion in Marine Birds

All ingested plastic found has been in the gizzards and (occasionally) proventriculi of the birds examined. Plastic has not been found in intestinal tracts or feces (Rothstein 1973; Day 1980; Pettit et al. 1981), indicating that passage through the intestines is minimal. This lack of passage is surprising, inasmuch as some particles are too small to handle for measurements (Day 1980).

Raw polyethylene pellets (= "'nibs" of Colton et al. 1974) appear to be the major form of plastic ingested (Rothstein 1973; Baltz and Morejohn 1976 ; Day 1980; Anonymous 1981; Bourne and Imber 1982; Van Franeker 1983; M. J. Imber, Wildlife Service, Wellington, New Zealand pers. commun.). Asymmetrical fragments, generally broken from larger polyethylene pieces, are commonly eaten by marine birds (Rothstein 1973; Day 1980; Furness 1983; Van Franeker 1983), whereas polystyrene spherules and Styrofoam (i.e., foamed polystyrene spherules) appear to be much less common (Hays and Cormons 1974; Connors and Smith 1982; Furness 1983; Van Franeker 1983; T. J. Dixon, Nature Conservancy Council, Aberdeen, Scotland pers. commun.) The presence of unfoamed polystyrene in marine birds was unexpected, because this synthetic material is neutrally or negatively buoyant (Hays and Cormons 1974; Morris and Hamilton 1974). Many other types and shapes of plastic have been recorded, including toys, polyethylene bottle caps, clear plastic sheets, and nylon, monofilament, and polypropylene line (Kenyon and Kridler 1969; Baltz and Morejohn 1976; Bourne 1976; Day 1980; Pettit et al. 1981; Harrison et al. 1983; Conant 1984).

Eleven recognized colors of plastic were ingested by seabirds in Alaska (Day 1980). Eighty-five percent of these colors were in the "light brown" color range (white, yellow, tan, and brown). Another 8% were in the 'other "light" shades ('light blue, green, and red-pink), making over 93% of the total 833 particles ingested light in color or shade. The remaining 7% of the particles were dark in color or shade: black-gray and darker shades of blue, green, and red-pink.

The individual weight of 830 particles ingested by seabirds in Alaska averaged about 0.02 g for most species; this figure includes raw polyethylene pellets and variably sized asymmetrical fragments after post-ingestion wear (Day 1980). Mean volumes of individual particles from Alaska averaged 0.03-0.04 ml after post-ingestion wear. The mean dimensions of particles from seabirds in Alaska were 4.2 x 3.5 x 2.0 mm, again including some large plastic fragments. Unworn raw polyethylene pellets range from 3 to 5 mm indiameter (Carpenter and Smith 1972; Colton 1974; Colton et al. 1974; Gregory 1977, 1978, 1983 ; Shiber 1982) and average 0.014 g each in the Atlantic (Colton et al. 1974) and 0.026 g in New Zealand (Gregory 1978), Nova Scotia, and Bermuda (Gregory 1983).

Nearly all plastic particles ingested by seabirds float at the water's surface (Kenyon and Kridler 1969; Day 1980); the specific gravity of polyethylene , excluding air vacuoles, is about 0.9 (Carpenter 1976). The few negatively buoyant particles recorded are assumed to have been broken from larger floating objects or to contain air vacuoles; thereby decreasing their densities and allowing them to float.

Ingestion of Plastic Pollutants by Marine Birds: A Global Perspective

As of November 1984, ingestion of plastic pollutants had been recorded in 50 species of marine birds from around the world (Table 1). In this total, we do not include three bird species in which plastic has been recorded because they represent instances of secondary ingestion via predation of plastic-contaminated seabirds: bald eagle, Haliaeetus leucocenhalus, preying on parakeet auklets in Alaska (Day unpubl. data),

Table 1.--List of seabird species that have been recorded ingesting plastic as of November 1984. Phylogenetic sequence for procellariiform birds and pelecaniform birds follows Mayr and Cottrell (1979), and for all other species follows the American Ornithologists' Union (1983).

Species	Scientific name
Wandering albatross	Diomedea exulans
Royal albatross	Diomedea epomophora
Black-footed albatross	Diomedea nigripes
Laysan albatross	Diomedea immutabilis
Gray-headed albatross	Diomedea chrysostoma
Northern fulmar	Fulmarus glacialis
Great-winged petrel	Pterodroma macroptera
Kerguelen petrel	Pterodroma brevirostris
Bonin petrel	Pterodroma hypoleuca
Cook's petrel	Pterodroma cookii
Blue petrel	Halobaena caerulea
Broad-billed prion	Pachyptila vittata
Salvin's prion	Pachyptila salvini
Antarctic prion	Pachyptila desolata
Fairy prion	Pachyptila turtur
Bulwer's petrel	Bulweria bulwerii
White-chinned petrel	Procellaria aequinoctialis
Parkinson's petrel	Procellaria parkinsoni
Pink-footed shearwater	Puffinis creatopus
Greater shearwater	Puffinis gravis
Sooty shearwater	Puffinis griseus
Short-tailed shearwater	Puffinis tenuirostris
Manx shearwater	Puffinis puffinis
White-faced storm-petrel	Pelagodroma marina
British storm-petrel	Hydrobates pelagicus
Leach's storm-petrel	Oceanodroma leucorhoa
Sooty storm-petrel	Oceanodroma tristrami
Fork-tailed storm-petrel	Oceanodroma furcata
Blue-footed booby	Sula nebouxii
Red-necked phalarope	Phalaropus lobatus
Red phalarope	Phalaropus fulicaria
Laughing gull	Larus atricilla
Heermann's gull	Larus heermanii
Mew gull	Larus canus
Herring gull	Larus argentatus
Western gull	Larus occidentalis
Glaucous-winged gull	Larus glaucescens
Glaucous gull	Larus hyperboreus
Great black-backed gull	Larus marinus
Black-legged kittiwake	Rissa tridactyla
Red-legged kittiwake	Rissa brevirostris
"Terns"	Sterna spp.
Dovekie	Alle alle
Thick-billed murre	Uria lomvia
Cassin's auklet	Ptychoramphus aleuticus
Parakeet auklet	Cyclorrhynchus psittacula
Least auklet	Aethia pusilla
Rhinoceros auklet	Cerorhinca monocerata
Tufted puffin	Fratercula cirrhata
Horned puffin	Fratercula corniculata

Antarctic skua, Catharacta antarctica, preying on broad-billed prions in the South Atlantic (Bourne and Imber 1982), and short-eared owl, Asio flammeus, preying on blue-footed boobies in the Galgpagos Islands- (Anonymous 1981). We also omit the Antarctic fulmar, Fulmarus glacialoides, and the Atlantic puffin, Fratercula arctica, which have been reported to ingest elastic threads but not plastic (Parslow and Jefferies 1972; Crockett and Reed 1976). In addition, great frigatebird, Fregata minor, may pick up pieces of marine debris, but do not appear to ingest them (Conant 1984).

All seabird species that have. been examined for plastic ingestion, and their rates of ingestion, are listed in Table 2. Twenty-eight (56%) of the species ingesting plastic are procellariiform birds, 1 (2%) is a pelecaniform bird, 2 (4%) are phalaropes, 11 (22%) are gulls and terns, and 8 (16%) are alcids.

The highest frequencies of plastic ingestion are recorded in procellariiform species and in the parakeet auklet, an alcid breeding in the North Pacific. The highest mean number of particles ingested, 21.7 particles per bird, was found in short-tailed shearwaters from California (Baltz and Morejohn 1976). Greater shearwaters from South Africa (Furness 1983) and parakeet auklets from Alaska (Day 1980) exhibited the second and third highest amounts of plastic ingestion, respectively. Of the 50 species containing plastic, only 12 have been recorded ingesting a mean of one or more particles per bird (Table 2).

We have summarized the data from Table 2 in terms of frequencies of ingestion in families and in groups of similar species (Table 3). To determine the approximate mean frequency of occurrence of plastic per species within a particular taxon, we: (1) estimated the frequency of occurrence of plastic for each species from Table 2, where possible; and (2) calculated mean frequencies of occurrence from these estimates. These mean values are approximate and should only be viewed as indicating trends among taxa.

Procellariiform birds exhibit high overall rates-of ingestion; 28 (90%) of 31 species examined contained plastic. This group also has a relatively high mean frequency of occurrence per species, indicating that many individuals of many species have ingested plastic. Penguins and sea ducks have not yet been recorded with plastic. Pelecaniform birds contain little or no plastic, and have a very low mean frequency of occurrence per species. Among the charadriiform birds, phalaropes and some alcids (auklets-dovekie and puffins) have both high rates of ingestion and relatively high frequencies of occurrence per species. In contrast, larids have a high overall rate of ingestion but a low frequency of occurrence per species, indicating that only a few individuals of many species in this taxon have ingested plastic.

Effects of Feeding Ecology on Variation in Plastic Ingestion

The only analysis of the relationships between feeding ecology and plastic ingestion is from Day (1980). Twenty-six percent of the birds from Alaska classified as primarily pursuit-divers contained plastic, the highest incidence among all feeding methods; 16% of those seabirds feeding

Table 2.--A list of all species of seabirds that have been examined for plastic ingestion and their rates of ingestion. Phylogenetic sequence for procellariiform birds and pelecaniform birds follows Mayr and Cottrell (1979), and for all other species follows the American Ornithologists' Union (1983).

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Wandering albatross	?	1-5	"Low"	Subantarctic (Chatham Islands)	?	Manufactured pieces, usually red.	M. J. Imber pers. commun.
	?	Present	?	South Atlantic (Gough Island)	?	From chick regurgitations.	Furness 1983.
Royal albatross	?	1-5	"Low"	Chatham Islands	?	Manufactured pieces, usually red.	M. J. Imber pers. commun.
Black-footed albatross	172	Present	?	Hawaiian Islands	1978-81	One adult died from choking on toy; broken fragments, manufactured pieces, cellophane, styrofoam, thermal underwear.	Harrison et al. 1983; M. Naughton pers. commun.
	?	Present	?	Hawaiian Islands	1981	From chick found dead; plastic bags, bottle caps, plastic fragments.	Conant 1984.
Laysan albatross	100	76	2.4	Hawaiian Islands	1966	From chicks found dead.	Kenyon and Kridler 1969.
	1	0	0	Alaska	1969-77	--	Day 1980.
	183	Present	?	Hawaiian Islands	1978-81	Plastic chips, styrofoam, monofilament line.	Harrison et al. 1983.
	4	100	?	Hawaiian Islands	1979-80	From chicks found dead; intestinal blockage, ulceration of proventriculus.	Pettit et al. 1981.
	50	90	?	Hawaiian Islands	1982-83	From chicks found dead; three chicks with plastic impaction and ulcerative lesions.	S. I. Fefer pers. commun.
	4	50	?	Hawaiian Islands	1982-83	From adults.	S. I. Fefer pers. commun.
Gray-headed albatross	?	Present	?	Subantarctic (Marion Island)	?	--	Furness 1983.
Antarctic fulmar	26	0	0	New Zealand	1973-75	Birds found dead.	Crockett and Reed 1976.
Northern fulmar	38	58	2.8	Alaska	1969-77	Both raw plastic and fragments; primarly light-colored.	Day 1980.
	36	3-33	?	Scotland	?	Nylon threads and plastic combined; some plastics causing stomach ulcerations; much other man-made debris.	Bourne 1976.
	3	100	11.3	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	214	40	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Northern fulmar	?	<10	?	Scotland/North Sea	?	Foamed polystyrene.	T. J. Dixon pers. commun.
	88	80	5	Netherlands	1981-82	From birds found dead; raw plastic, other plastic types.	Van Franeker 1983.
	29	76	4	Jan Mayen Island	1983	Also reported large nail embedded in thick layer of fatlike tissue in distal part of gut of one bird.	Van Franeker and Camphuijsen 1984.
Great-winged petrel	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
Kerguelen petrel	26	4	<0.1	New Zealand	1981	From dead birds; raw plastic.	Reed 1981.
Bonin petrel	144	Probably present	?	Hawaiian Islands	1978-81	Regurgitation; presence of plastic not confirmed.	Harrison et al. 1983; C. S. Harrison pers. commun.
Cook's petrel	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
Blue petrel	?	20	?	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
	27	100	?	New Zealand	1981	From dead birds.	Reed 1981.
Broad-billed prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
	?	Present	?	Chatham Islands	?	Raw plastic.	Bourne and Imber 1982.
	?	Present	?	Gough Island	1979	Recorded in only one of a few birds examined; the one contained 33 pieces of raw plastic.	Bourne and Imber 1982.
Salvin's prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Antarctic prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Fairy prion	?	10	"Low"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Bulwer's petrel	100	Present	?	Hawaiian Islands	1978-81	Regurgitation.	Harrison et al. 1983.
White-chinned petrel	20	5	0.5	South Africa	1981	Fragments.	Furness 1983.
Parkinson's petrel	?	10	"Low"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Pink-footed shearwater	5	20-40	2.4	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
Greater shearwater	1	100	?	Scotland	?	Nylon threads.	Bourne 1976.
	98	40	?	Eastern Canada	1974-78	Raw plastic.	Brown et al. 1981.
	?	"Low"	?	Massachusetts	1977	Regurgitations	Powers and Van Os 1979.
	2	100	22	Gough Island	1980	Primarily polyethylene; also polyolefin and nylon.	Randall et al. 1983.
	?	Present	?	Eastern Canada	1981	--	M. S. W. Bradstreet pers. commun.
	10	90	20.6	South Africa	1981	Raw plastic and polystyrene spheres.	Furness 1983.
Wedge-tailed shearwater	233	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Sooty shearwater	76	43	1.1	Alaska	1969-77	Both raw plastic and fragments; primarily light-colored.	Day 1980.
	21	43-67	6.9	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	35	17	?	Eastern Canada	1974-78	Raw plastic.	Brown et al. 1981.
	1	100	?	Scotland	?	Nylon threads.	Bourne 1976.
	37	51	?	California	1977	Both raw plastic and fragments; white, red, blue, and brown.	E. W. Chu pers. commun.
	154	49	?	California	1978-79	Both raw plastic and fragments; white, red, blue, and brown.	E. W. Chu pers. commun.
	?	Present	?	Eastern Canada	1981	--	M. S. W. Bradstreet pers. commun.
	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
	13	0	0	South Africa	1981	--	Furness 1983.
Short-tailed shearwater	200	84	5.4	Alaska	1969-77	Both raw plastic and fragments; great diversity of colors.	Day 1980.
	6	100	21.7	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	189	47	1.0	Australia/Tasmania	1979-80	--	I. J. Skira pers. commun.
Christmas shearwater	182	0	0	Hawaiian Islands	1978-81	From regurgitations	Harrison et al. 1983.
Manx shearwater	?	Present	?	?	?	--	Van Franeker 1983.
Gray-backed storm-petrel	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
White-faced storm-petrel	?	50	"Low-high"	Chatham Islands	?	Raw plastic.	M. J. Imber pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particlea per bird	Location	Year(s)	Comment a	Source
British storm-petrel	?	Present	?	?	?	--	Van Franeker 1983.
Leach's storm-petrel	7	14	0.3	Eastern Canada	1962	From adults.	Rothstein 1973.
	7	57	1.0	Eastern Canada	1964	From adults.	Rothstein 1973.
	8	25	0.2	Eastern canada	1964	From chicks.	Rothstein 1973.
	4	25	3.0	Alaska	1969-77	Primarily broken fragments; light-colored; very small pieces.	Day 1980.
Sooty storm-petrel	10	10	0.1	Hawaiian Islands	1978-81	From regurgitations; broken fragments.	Harrison et al. 1983; M. Naughton pers. commun.
Fork-tailed storm-petrel	8	100	6.2	Alaska	1969-77	Primarily broken fragments; light-colored; very small pieces.	Day 1980.
	?	Present	?	Alaska	?	--	Ohlendorf et al. 1978.
Common diving petrel	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
Emperor penguin	?	0	0	Antarctic	?	--	M. J. Imber pers. commun.
Little blue penguin	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
Red-tailed tropicbird	270	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Great frigate-bird	284	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Double-crested cormorant	4	0	0	Alaska	1969-77	--	Day 1980.
Shag	2	0	0	Scotland	?	--	Bourne 1976.
Red-faced cormorant	2	0	0	Alaska	1969-77	--	Day 1980.
Pelagic cormorant	3	0	0	Alaska	1969-77	--	Day 1980.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Gannet	3	0	0	Scotland	?	--	Bourne 1976.
Masked booby	305	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Blue-footed booby	?	Present	?	Galapagos Islands	?	Raw plastic; secondarily via fish.	Anonymous 1981.
Red-footed booby	360	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Brown booby	244	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Greater scaup	3	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Harlequin duck	6	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Oldsquaw	11	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Surf scoter	11	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
White-winged scoter	5	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Barrow's goldeneye	17	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Red-necked phalarope	3	67	1.0	Alaska	1969-77	All light-colored pieces.	Day 1980.
	2	0	0	California	1981	Northbound migrants.	Connors and Smith 1982.
Red phalarope	20	"Most"	?	California	1969	From starving birds; up to 36 particles per bird.	Bond 1971.
	4	25	0.2	California	1979	Southbound migrants.	Connors and Smith 1982.
	7	86	5.9	California	1980	Northbound migrants; primarily polyethylene; a few pieces of styrofoam.	Connors and Smith 1982.
"Skuas"	3	0	0	Scotland	?	--	Bourne 1976.
Pomarine jaeger	1	0	0	Alaska	1969-77	--	Day 1980.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Parasitic jaeger	1	0	0	Alaska	1969-77	--	Day 1980.
"Gulls"	?	Present	?	New York	1971	Probably herring gull.	Hays and Cormons 1974.
"Large gulls"	13	0	0	Scotland	?	--	Bourne 1976.
Laughing gull	?	Present	?	Florida	1975-78	From regurgitated casts; plastic occasionally present.	Below 1979.
Bonaparte's gull	4	0	0	Alaska	1969-77	--	Day 1980.
Heermann's gull	15	7-13	0.1	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
Mew gull	10	0	0	Alaska	1969-77	--	Day 1980.
	4	25	0.3	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
	?	Present	?	Germany	?	--	Vauk-Hentzelt and Schumann 1980 cited in Vauk-Hentzelt 1982.
Herring gull	?	Present	?	Germany	1967	--	Vauk and Lohmer 1969 cited in Vauk-Hentzelt 1982.
	5	0	0	Alaska	1969-77	--	Day 1980.
	?	Present	?	Maine	1979-82	Plastic bags, styrofoam, cellophane.	D. H. S. Wehle pers. observ.
Western gull	?	Present	?	North Pacific	?	--	H. Ogi pers. commun.
Glaucous-winged gull	63	0	0	Alaska	1969-77	--	Day 1980.
	8	13	0.1	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
	?	Present	?	Alaska	1984	Small plastic toy in regurgitated cast, western Aleutian Islands.	R. S. Wood and A. W. DeGange pers. commun.
Glaucous gull	33	3	0.0	Alaska	1969-77	--	Day 1980.
Great black-backed gull	?	Present	?	Maine	1979-82	Plastic bags, styrofoam cellophane.	D. H. S. Wehle pers. observ.
Black-legged kittiwake	188	5	0.1	Alaska	1969-77	Primarily broken fragments; light-colored.	Day 1980.
	8	13-25	0.5	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	50	12	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.
	28	4-7	?	Scotland	?	Nylon threads and plastic combined.	Bourne 1976.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Red-legged kittiwake	46	13	0.2	Alaska	1969-77	Raw plastic; primarily light-colored.	Day 1980.
Sabine's gull	1	0	0	Alaska	1969-77	--	Day 1980.
Ivory gull	1	0	0	Alaska	1969-77	--	Day 1980.
"Terns"	?	"A few"	?	New York	1971	Regurgitated casts; common and roseate terns breed here.	Hays and Cormons 1974.
Arctic tern	21	0	0	Alaska	1969-77	--	Day 1980.
Aleutian tern	8	0	0	Alaska	1969-77	--	Day 1980.
Gray-backed tern	272	0	0	Hawaiian Islands	1979-81	From regurgitations.	Harrison et al. 1983.
Sooty tern	356	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Brown noddy	354	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Black noddy	494	0	0	Hawaiian Islands	1979-81	From regurgitations.	Harrison et al. 1983.
Blue-gray noddy	111	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
White tern	241	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
"Auks"	37	3-5	?	Scotland	?	Nylon threads and plastic combined.	Bourne 1976.
Dovekie	303	Present	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.
	?	4	?	North Atlantic	?	--	Van Franeker 1983.
Common murre	191	0	0	Alaska	1969-77	--	Day 1980.
Thick-billed murre	138	1	0.0	Alaska	1969-77	Raw plastic; light-colored.	Day 1980.
	283	1	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.
Pigeon guillemot	18	0	0	Alaska	1969-77	--	Day 1980.
Marbled murrelet	61	0	0	Alaska	1969-77	--	Day 1980.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Kittlitz' murrelet	5	0	0	Alaska	1969-77	--	Day 1980.
Ancient murrelet	16	0	0	Alaska	1969-77	--	Day 1980.
Cassin's auklet	10	40	3.8	Alaska	1969-77	Both raw plastic and fragments; light-colored; very small pieces.	Day 1980.
Parakeet auklet	?	Present	?	Alaska	?	Raw plastic; light-colored.	Olhendorf et al. 1978.
	116	75	13.7	Alaska	1969-77	Raw plastic; light-colored.	Day 1980.
	1	100	8	Hawaiian Islands	1980	Found dead; all particles black.	Pettit et al. 1981.
Least auklet	89	1	0.0	Alaska	1969-77	--	Day 1980.
Whiskered auklet	5	0	0	Alaska	1969-77	--	Day 1980.
Crested auklet	85	0	0	Alaska	1969-77	--	Day 1980.
Rhinoceros auklet	20	0	0	Alaska	1969-77	--	Day 1980.
	26	4	0.1	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
Tufted puffin	348	15	0.5	Alaska	1969-77	Primarily raw plastic; light-colored; diversity of colors.	Day 1980.
Atlantic puffin	6	0	0	United Kingdom	1969-71	Birds found dead; elastic threads, but no plastic.	Parslow and Jefferies 1972.
Horned puffin	?	Present	?	Alaska	?	--	Ohlendorf et al. 1978.
	148	37	0.9	Alaska	1969-77	Primarily raw plastic; light-colored; diversity of colors.	Day 1980.

Table 3.--Rates of plastic ingestion in families of birds and in groups of similar species, calculated from the data in Table 2. The approximate mean frequency of occurrence of plastic per species was calculated by: (1) estimating the frequency of occurrence of plastic for each species from Table 2, where possible; and (2) calculating a mean frequency of occurrence for these estimates. These mean values are approximate and should only be viewed as indicating trends among taxa.

Taxon	No. of species examined for plastic in taxon	Frequency of occurrence of plastic in taxon (%)	Approximate mean frequency of occurrence of plastic per species (%)
PROCELLARIIFORMES			
Diomedeidae	5	100	28
Procellariidae	21	86	24
Gadfly petrels	4	100	8
Prions	4	100	40
Shearwaters-fulmars	9	67	31
Other	4	100	32
Hydrobatidae	6	83	38
Pelecanoididae	1	0	0
SPHENISCIFORMES			
Spheniscidae	2	0	0
PELECANIFORMES			
Phaethontidae	1	0	0
Fregatidae	1	0	0
Phalacrocoracidae	4	0	0
Sulidae	5	20	? (low)
ANSERIFORMES			
Anatidae	6	0	0
CHARADRIIFORMES			
Scolopacidae (phalaropes)	2	100	45
Laridae	≥26	≤47	≤3
Skuas-jaegers	3	0	0
Gulls	14	71	6
Terns	≥9	≤11	? (very low)
Alcidae	≥16	≤50	≤11
Murres-guillemots-murrelets	≥6	≤17	<1
Auklets-dovekie	6	67	18
Puffins	4	75	14

by surface-seizing, 9% of 'those feeding by dipping, and none of those feeding by plunging or piracy contained plastic (Table 4). Some bias is present in these results, however, because shearwaters, which were classified as primarily pursuit-divers, also feed extensively by surface-seizing. If the data for sheawaters are combined with those for surface-seizers, as many as 52% of the surface-seizers and as few as 16% of the pursuit-divers contained plastic. This bias notwithstanding, a significant number of species previously considered to be exclusively subsurface-feeding contained plastic found only at the surface of the water, suggesting that many pursuit-divers exhibit a greater range of feeding behaviors than was believed previously.

Table 4.--Frequency of occurrence of plastic in seabirds from Alaska with respect to primary feeding method (from Day 1980). Feeding method classifications are from Ashmole (1971) and Day (1980).

Feeding method	No. examined (n)	No. with plastic	Frequency of occurrence (%)
Pursuit-diving	1,532	399	26.0
Surface-seizing	157	25	15.9
Dipping	256	24	9.4
Plunging	21	0	0
Piracy	2	0	0

Birds feeding by plunging or piracy show no evidence of plastic ingestion. Plungers generally sight individual prey items below the surface of the water (Ashmole 1971), where floating plastic is not found, and they probably cannot distinguish objects as small as plastic particles from the air. Those birds feeding by piracy take food dropped by other birds ; such food is primarily fish (Ashmole 1971) and appears to contain little or no plastic.

Birds feeding by hydroplaning, a method not used by Alaska's seabirds, also exhibit high rates of plastic ingestion (Tables 2 and 3). The prions use this method to filter surface water, where the plastic occurs, through their bill lamellae (Ashmole 1971). Approximately 50% of the prions examined by M. J. Imber (pers. commun.) contained plastic (Table 2).

Another feeding method, scavenging at the sea's surface, is used to varying degrees by seabirds throughout the world (Ashmole 1971). Unfortunately, its importance relative to other feeding methods is often difficult to quantify. Scavenging is common in many procellariiform birds and in gulls (Ashmole 1971); interspecies variation in degree of scavenging probably accounts for some of the variation in ingestion frequencies seen in these groups.

Plastic ingestion also can be correlated with a given species' preferred prey (Table 5). Generally, those species of seabirds from Alaska relying primarily on crustaceans or cephalopods had a higher frequency of, plastic ingestion than did those relying primarily on fishes (Day 1980): species feeding primarily on crustaceans had a significantly higher frequency of ingestion than did fish-feeders (X^2 = 305.6; 1 df; $P < 0.001$; chi-square R x C test; Conover 1971), as did cephalopod-feeders when compared with fish-feeders (X^2 = 68.2; 1 df; $P < 0.001$). Thus, secondary. ingestion of plastic via fish is evidently low, although it has been proposed for blue-footed boobies in the Galapagos Islands (Anonymous 1981). Cephalopod- and crustacean-feeding seabirds showed no significant difference in the frequency of plastic ingestion (x^2 = 1.1; 1 df; $P >$ 0.051, indicating that both were important in effecting plastic ingestion.

Table 5.--Frequency of occurrence of plastic in seabirds from Alaska with respect to primary prey type (adapted from Day 1980). Prey type classifications are from Ashmole (1971) and Day (1980).

Prey type	No. examined (n)	No. with plastic	Frequency of occurrence (%)
Crustaceans	566	270	47.8
Cephalopods	39	22	56.4
Fishes	1,363	156	11.4

Prey type was a better predictor of plastic occurrence in seabirds than was feeding method, probably because of the particles' similarities (location in the water column and in physical attributes) to known and probable prey items. A number of known and probable prey items occur regularly in surface waters, where plastic might be mistaken for, or ingested, along with these prey. In Alaska, squid larvae live primarily within the upper 0.5 m of the sea's surface; in addition, the adults undergo a circadian pattern of vertical migration and are found at the sea's surface at night (Clarke 1966; C. G. Bublitz, Institute of Marine Science, University of Alaska, Fairbanks, Alaska pers. commun.). The planktonic larvae and adults of many pelagic crustaceans (e.g., copepods, euphausiids) , which many of the light-brown particles of raw plastic eaten by seabirds resemble (Table 2), are also found at or near the water's surface (Mauchline 1980; Raymont 1983).

The eggs of many fishes are also found at the surface of the ocean (Hart 1973). These pelagic eggs are rarely recorded in seabirds, probably because they are rapidly digested in the birds' stomachs. Flyingfish (Exocoetidae) eggs attached to plastic have been found in Laysan and black-footed albatrosses (Pettit et al. 1981; Harrison et al. 1983), and some sea ducks and gulls eat the benthic eggs of some nearshore fishes (Outram 1958; Gjosaeter and Saetre 1974). Colton (1974) originally mistook the light-brown pellets of raw plastic that he had caught in neuston tows for pelagic fish eggs, and several scientists at the University of Alaska mistook the samples of Day (1980) for fish eggs. The small, round pellets could also be mistaken by the birds for the eyes of squids or fishes or for the bodies of larval fishes. Thus, it is not surprising that those seabirds feeding primarily on crustaceans or cephalopods exhibit a higher occurrence of plastic than do those species feeding primarily on fish.

Interspecific Variation in Plastic Ingestion

An obvious question to be asked is whether seabirds actively select specific kinds of plastic or randomly eat any plastic that they encounter at sea. Examination of two data sets from the North Pacific suggests that the former hypothesis is correct.

Table 6 compares the numbers and frequencies of colors of 833 plastic particles ingested by Alaska seabirds (Day 1980) with numbers and frequencies of colors of 250 pieces of floating plastic sighted from the deck of a ship during a cruise in the subtropical North Pacific from Honolulu, Hawaii, to Hakodate, Japan, between 10 and 22 August 1984 (Dahlberg and Day 1985; Day unpubl. data).

We make two assumptions about this latter data set: (1) We assume that the frequencies of plastic colors in the subtropical North Pacific are representative of the frequencies of colors of plastic in the subarctic North Pacific, where the seabirds were collected; and (2) since about 73% of the plastic particles ingested by these seabirds are raw polyethylene pellets rather than plastic fragments, we assume that the frequencies of raw polyethylene pellets in the ocean are reflected in the frequencies of colors of these larger plastic objects. We see no reason why there should be geographic variation in frequencies of colors of plastic in the ocean; Dahlberg and Day (1985) found no geographic variation in frequencies of types of marine debris. No data are available for determining the accuracy of the second assumption.

There is a significant difference between frequencies of colors of plastic objects in the stomachs of seabirds from Alaska and frequencies of colors of floating plastic objects (X^2 = 1,280.4; 7 df; $P < 0.001$; chi-square goodness-of-fit test; Zar 1984). In this test, we omitted the color columns "orange" and "transparent" (Table 6), since they could not be adequately compared; although both colors were recorded in short-tailed shearwaters, they were not recorded in subsamples examined. Hence, the adjusted sample size for the subtropical North Pacific is 229. White, ye l low, and blue occurred significantly less frequently in the birds than they did in the ocean (partial chi-square value for cells = 214.5, 21.8, and 34.5, respectively), whereas tan and brown occurred more frequently in birds than they did in the ocean (partial chi-square value for cells = 78.9 and 225.6, respectively). Yellow, brown, blue, red, green, and black-gray did not occur in proportions significantly different from that in the ocean (partial chi-square values for each cell did not exceed 1.91, suggesting that seabirds randomly ingest particles of these colors. There was some selection for the "light brown" colors (white,' yellow, tan, brown; see following paragraph) as a group, however, for they constituted 79.0% of the plastic in the ocean but formed 85.0% of the plastic in the birds' stomachs.

Table 6.--Numbers and percentages of colors of plastic ingested by seabirds in Alaska (from Day 1980) and numbers and percentages of colors of floating plastic objects recorded in the subtropical North Pacific, 10-22 August 1984 (Day unpubl. data). Chi-square contributions are for deviations from expected values, which are calculated from frequencies seen in the North Pacific; total chi-square from goodness-of-fit test = 1,280.4 (7 df; Zar 1984).

	Sample size (n)	Color[1]							
		White	Yellow	Tan	Brown	Blue	Red	Green	Black-gray
Alaska seabirds	833	152	6	459	92	40	20	40	24
Frequency (%)		18.2	0.7	55.1	11.0	4.8	2.4	4.8	2.9
Expected values[2]		469.2	32.7	134.6	21.8	98.2	18.2	40.0	18.2
χ^2 contribution[3]		214.5	21.8	781.9	225.6	34.5	0.2	0.0	1.9
Subtropical North Pacific	229	129	9	37	6	27	5	11	5
Frequency (%)		56.3	3.9	16.2	2.6	11.8	2.2	4.8	2.2

[1]The colors orange and transparent were recorded in the North Pacific (n = 15 and n = 6, respectively) and in Alaska seabirds (short-tailed shearwaters; Day pers. observ.), but not in subsamples of plastic examined. Because no estimates of frequencies in seabirds were available for these two colors, they were omitted from the table and the test.

[2]Expected number of particles in each color category, based on the frequency of each color in the environment (i.e., the North Pacific).

[3]Chi-squared for P = 0.05 is 14.067; for P = 0.01 is 18.475; for P = 0.001 is 24.322 (all for 7 df).

An analysis of color-shape combinations of plastic particles ingested by seabirds from Alaska (Day 1980) also provides evidence of selective ingestion. To determine preferences for certain combinations of colors and shapes of particles, the particles ingested by each species were classified into four color-shape categories ("light brown-regular," "light brown-irregular," "other color-regular)" and "other color-irregular") , and deviations of frequencies of each particle type from the combined frequencies of all species were determined with a chi-square test for independence (Zar 1984). "Light brown" colors, which resemble the colors of many natural prey items, were white, yellow, tan, and brown, and the "other" color category included the remaining colors. "Regular" shapes were pill, cylinder, sphere, and box-cube (as classified in Day 1980). All regularly shaped particles were roughly similar in size and shape, in contrast to the highly variable "irregular" particles.

The total X^2 of 108.3 shows a significant dependence between the species of seabird and the type of plastic eaten (Table 7). Only sooty shearwaters, short-t ailed shearwaters, and tufted puffins appeared to ingest plastic at random, whereas the others showed strong affinities for or avoidances of certain color-shape combinations. The parakeet auklet, which feeds primarily on zooplanktonic crustaceans (Bedard 1969), was the most extreme in preferences: 94% of its plastic were in the light brown-regular category. These preferences support the hypothesis that at least some species mistake many particles for food items.

Other evidence for selective ingestion comes from the extreme interspecific variation in ingestion frequencies seen in Table 2. Also, some seabirds (e.g., Leach's storm-petrel, fork-tailed storm-petrel, Cassin's auklet) selectively ingest very small plastic particles (Day 1980), indicating selectivity for size of particles rather than for color or shape. Hence, although some species may ingest plastic randomly, most are quite specific in the types of plastic that they eat.

Sex and Age-Related Variation in Plastic Ingestion

No significant differences in the number of plastic particles ingested were found between sexes in any of the six seabird species examined from Alaska (Table 8). This observation compares well with data on feeding habits of monomorphic seabird species (most have monomorphic bills), in which there is almost 100% overlap in intersexual food habits (Tuck 1960; Bedard 1969; Sealy 1975; Wehle 1982).

Significantly more plastic particles were found in subadult parakeet auklets and tufted puffins from Alaska than in adults (Table 8). No significant differences between subadult and adult horned puffins were found, although the relatively small sample size of subadults may have affected the validity of the statistical test. Age-related differences in food habits have been found in ancient murrelets (Sealy 1975) and tufted and horned puffins (Wehle 1982), but not in marbled murrelets (Sealy 1975).

Subadult birds of many species are less efficient at foraging than are adults (Orians 1969; Recher and Recher-1969; Dunn 1972; Morrison et al. 1978; Searcy 1978). Hence, there should be selective pressures on subadults to compensate for poorer foraging efficiency by broadening their feeding' niches, possibly increasing the amount of nonfood items eaten. The

Table 7.--Numbers 'and percentages of color-shape combinations of plastic particles ingested by six seabird species in Alaska (data reanalyzed from Day 1980). Also included are chi-square values for deviations from expectation, using a chi-square R x C test for independence (Zar 1984); total X^2 of 108.3 shows a significant ($P < 0.001$; df = 15) dependence between the species of seabird and the type of plastic eaten.

	Sample size (n)	"Light brown" colors[1]		"Other" colors[1]		Total species χ^2 value
		"Regular" shapes[2]	"Irregular" shapes[2]	"Regular" shapes	"Irregular" shapes	
Northern fulmar	97	56	34	3	4	
Frequency (%)		57.8	35.1	3.0	4.1	
χ^2 contribution[3]		2.6	29.6	0.9	2.5	35.6
Sooty shearwater	77	50	10	6	11	
Frequency (%)		64.9	13.0	7.8	14.3	
χ^2 contribution		0.5	0.1	0.9	2.6	4.1
Short-tailed shearwater	164	114	24	10	16	
Frequency (%)		69.5	14.6	6.1	19.8	
χ^2 contribution		0.1	0.0	0.2	0.2	0.5
Parakeet auklet	120	113	0	4	3	
Frequency (%)		94.2	0	3.3	2.5	
χ^2 contribution		8.6	17.1	1.0	5.4	32.1
Tufted puffin	139	117	10	6	6	
Frequency (%)		84.2	7.2	4.3	4.3	
χ^2 contribution		3.1	4.9	0.3	3.2	11.5
Horned puffin	127	68	25	10	24	
Frequency (%)		53.5	19.7	7.9	18.9	
χ^2 contribution		5.8	2.6	1.5	14.6	24.5
Combined total	724	518	103	39	64	108.3
Frequency (%)		71.5	14.2	5.4	8.8	

[1]"Light brown" = white, tan, yellow, brown; "other" = dark blue, medium-light blue, dark red, medium-light red, dark green, medium-light green, black-gray.

[2]"Regular" = pill, cylinder, sphere, box-cube; "irregular" = string, cone, asymmetrical, other.

[3]Chi-squared for P = 0.005 is 24.996; for P = 0.01 is 30.578; for P = 0.001 is 32.801 (all for 15 df).

Table 8.--Results of tests for sexual (A) and age-related (B) differences in the number of plastic particles ingested by Alaska seabirds (from Day 1980). Parakeet auklets were tested with a Mann-Whitney test; all other species were tested with a median test (Conover 1971).

Species	Sample sizes (n)[1]	df	Test statistic	Significance
(A) Male versus female (all two-tailed tests)				
Northern fulmar	17/12	1	1.129	NS[2]
Sooty shearwater	37/26	1	1.397	NS
Short-tailed shearwater	101/73	1	0.590	NS
Parakeet auklet	49/36	1	[3]1,034.5	NS
Tufted puffin	43/38	1	0.294	NS
Horned puffin	23/45	1	0.008	NS
(B) Adult versus immature (all one-tailed tests)				
Parakeet auklet	32/10	1	[4]231.5	$0.01<P<0.05$
Tufted puffin	81/17	1	17.080	$P<0.001$
Horned puffin	68/8	1	0.349	NS

[1]Sample sizes for the two classes tested are separated by a slash.

[2]NS = not significant at $\alpha = 0.05$.

[3]$W_{0.95} = 1,067.0$.

[4]$W_{0.95} = 2.5.7$; $W_{0.99} = 238.7$.

increased amount of plastic ingested by subadults also may be due to a poorer perception of what constitutes a “good” food item, or to the possibility that subadults naturally ingest a wide range of food items to learn differences among them.

Geographic Variation in Plastic Ingestion

Day (1980) analyzed geographic variation in plastic ingestion in seabirds from Alaska, dividing the marine waters of the state into three regions : the Gulf of Alaska, the Aleutian Islands, and the Bering and Chukchi Seas (Fig. 1). Five species of birds provided reasonable sample sizes from each of these three regions. Two of these species (black-legged kittiwake and thick-billed murre) had frequencies of plastic ingestion too low for meaningful intraspecies comparisons, and thus, were not tested. In the remaining three species (parakeet auklet, tufted puffin, and horned puffin), the highest frequencies of ingestion and mean numbers of particles per bird occurred in Aleutian Islands waters (Table 9; chi-square R x C test; Conover 1971).

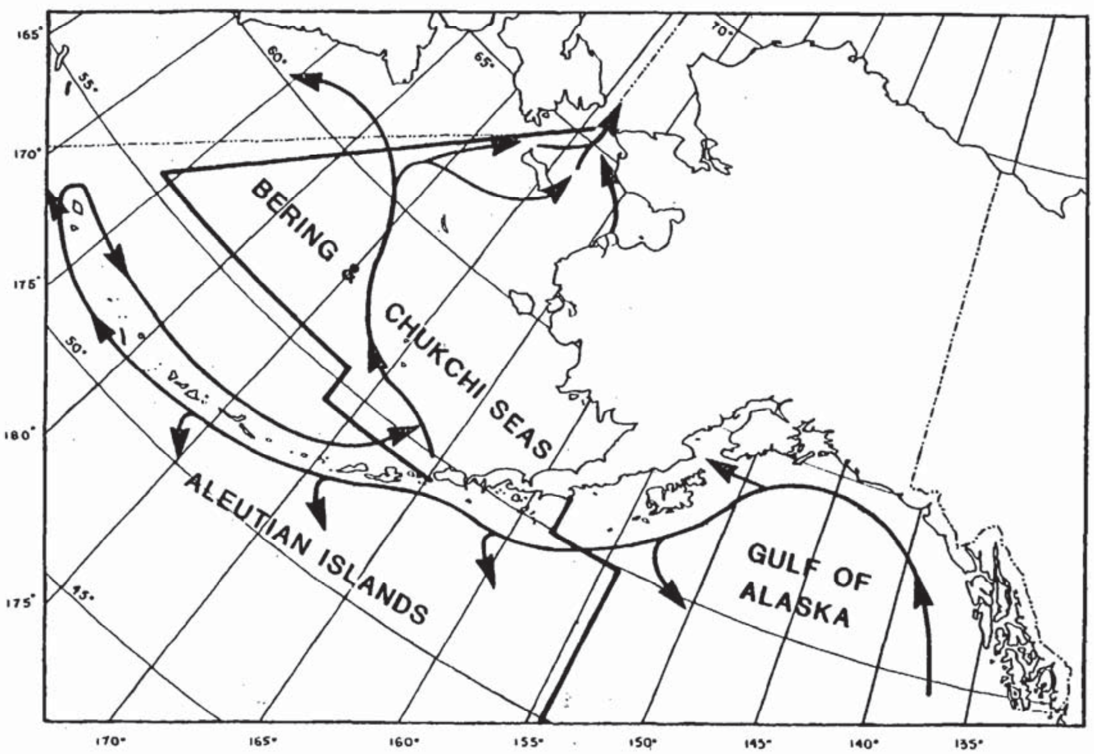

Figure 1.--Location of three geographic regions of Alaska in which differences in rates of plastic ingestion were tested (from Day 1980). The approximate locations of major currents are adapted from Coachman et al. (1975), Tabata (1975); Favorite et al. (1976), and T. C. Royer (pers. commun.).

Table 9.--Geographic variation in the frequency of occurrence of plastic (A) and in the mean number of plastic particles per bird (B) in the parakeet auklet, tufted puffin, and horned puffin in Alaska (from Day 1980).

(A) Frequency of occurrence of plastic

Species	Gulf of Alaska (n)	Gulf of Alaska No. with plastic	Gulf of Alaska Frequency (%)	Aleutian Islands (n)	Aleutian Islands No. with plastic	Aleutian Islands Frequency (%)	Bering and Chukchi Seas (n)	Bering and Chukchi Seas No. with plastic	Bering and Chukchi Seas Frequency (%)
Parakeet auklet	13	11	84.6	55	50	90.9	45	24	53.3
Tufted puffin	190	20	10.5	122	35	20.5	35	5	14.3
Horned puffin	41	11	26.8	74	37	50.0	20	6	30.0

(B) Mean number of plastic particles per bird

Species	Gulf of Alaska (n)	Gulf of Alaska Mean ± SD	Aleutian Islands (n)	Aleutian Islands Mean ± SD	Bering and Chukchi Seas (n)	Bering and Chukchi Seas Mean ± SD
Parakeet auklet	14	21.1 ± 22.6	55	21.3 ± 22.8	46	2.6 ± 4.0
Tufted puffin	190	0.2 ± 0.8	122	0.7 ± 2.1	36	0.6 ± 2.9
Horned puffin	41	0.8 ± 1.7	87	1.0 ± 1.5	20	0.6 ± 1.2

Parakeet auklets in the Gulf of Alaska (X^2 = 4.3; 1 df; P < 0.05) and the Aleutian Islands (X^2 = 18.1; 1 df; P < 0.001) had higher frequencies of plastic ingestion than did birds in the Bering and Chukchi Seas. No significant difference in frequencies was found between birds in the Gulf of Alaska and the Aleutian Islands, although one of the expected values was too small for valid statistical testing.

Horned puffins in the Aleutian Islands had a higher frequency of plastic ingestion than did birds in the Gulf of Alaska (X^2 = 5.9; 1 df; P< 0,05); significant differences were not found in any other test for this species. Tufted puffins from the Aleutian Islands had a higher frequency of plastic ingestion than did birds from the Gulf of Alaska (X^2= 5.9; 1 df; P < 0.05), but no other significant differences were found for this species.

When the combined data for all birds of all species ingesting plastic were tested among the three regions, a similar pattern emerged. A Kruskal-Wallis test (BMDP program; Dixon and Brown 1979) showed significant differences (P = 0) in the number of particles ingested among the three regions. The birds in the Gulf of Alaska averaged 2.4 + 5.9 particles per bird (n = 634), about two-thirds that of birds in the Aleutian Islands (X = 3.8 + 11.3 particles per bird; n = 391). Birds in the Bering and Chukchi Seas averaged 0.6 + 2.2 particles per bird (n = 413), about one-seventh that of birds in the Aleutians and about one-fifth that of birds in the gulf. This geographic variation may be explained in terms of nonuniform geographic input of plastic and subsequent dispersal by currents.

The synthesis of plastic requires large amounts of petrochemicals; southern California and Japan are the two major petrochemical and plastics manufacturing centers in the North Pacific (Guillet 1974; Wong et al. 1976). Any plastic entering the ocean in southern California probably moves southward (i.e., away from Alaska) in the California Current system. Any plastic entering the ocean in eastern Japan probably moves eastward in' the North Pacific Drift Current (see Tabata 1975 and Favorite et al. 1976; also see Wong et al. 1976, for information on "downstream" contamination of the North Pacific Drift Current east of Japan by tar balls), which splits to form the California Current and the Alaska Current. Of the plastic transported into the northern Gulf of Alaska by the Alaska Current, some apparently moves inshore and is eaten by seabirds; most of the water moves across the Gulf far offshore, however, far from where most of the seabirds examined by Day were feeding. Some plastic must also enter inshore waters there from the small population centers and fishing activities. Recent studies by Royer (1975, 1983) indicate that there is little surface divergence in this region, suggesting that most of the plastic should be carried far offshore past this region.

The Alaska Current-Aleutian Stream system flows closely along the southern edge of the Aleutian Islands (Fig. 1), and the proximity of plastic in this nearshore current to birds breeding and feeding there probably accounts for the high level of plastic ingestion observed there. Surface flow into the Bering Sea is concentrated in Near Island Pass and Commander Pass, and appears to be relatively small (Tabata 1975; Favorite-' et al. 1976), explaining the lover amount of plastic ingested by birds in the Bering and Chukchi Seas.

The availability of large quantities of plastic in regions of plastic production, which are more polluted than Alaska, may allow a much higher degree of ingestion than in areas remote from plastic production. A comparison of plastic ingestion between seabirds in California (Baltz and Morejohn 1976) and Alaska (Day 1980) illustrates this point (Table 10). Of seven species that were examined for plastic in both regions, all seven from California were found to ingest plastic, whereas only four from Alaska did. Of the four species that contained plastic in both regions, California birds averaged about four times as many particles per bird as did Alaska birds. Thus, we predict that seabirds foraging near areas of extensive plastic production or manufacturing will have a higher incidence of plastic and a higher mean number of particles per bird than will seabirds foraging in areas of minor plastic production or manufacturing.

Table 10.--A comparison of plastic ingestion in seven seabird species examined from Alaska and California. Data for Alaska birds are from Day (1980) and for California birds are from Baltz and Morejohn (1976).

Species	Sample size (n)		Frequency of occurrence (%)		Mean No. of particles per bird	
	Alaska	California	Alaska	California	Alaska	California
Northern fulmar	38	3	58	100	2.8	11.3
Sooty shearwater	76	21	43	43-67	1.1	6.9
Short-tailed shearwater	200	6	84	100	5.4	21.7
Mew gull	10	4	0	25	0	0.2
Glaucous-winged gull	63	8	0	13	0	0.1
Black-legged kittiwake	188	8	5	13-25	0.1	0.5
Rhinoceros auklet	20	26	0	4	0	0.1

Temporal Variation in Plastic Ingestion

Inter- and intra-annual variations in plastic ingestion have been 'examined by Day (1980). The primary species providing enough data to examine long-term variations in plastic ingestion is the short-tailed shearwater; samples examined by D. L. Serventy (CSIRO Wildlife Research, Helena Valley , W. A., Australia pers. commun.) and R. Mykytowycz (CSIRO Wildlife Research, Canberra, Australia, fide D. L. Serventy) range as far back as the 1950's. The general trend an an increase in all characteristics of plastic ingestion over time, especially in' the frequency of occurrence of plastic and in the mean volume of, plastic per bird (Fig. 2). Given that world plastic production is increasing by about 6% each year (Guillet 1974), and that plastic litter may also be increasing exponentially (Guillet 1974), these increases in ingestion rates probably reflect the continually increasing availability of plastic in the oceans.

Laysan albatrosses in the Hawaiian Islands have also shown an increase in frequency of occurrence of plastic over time. In 1966, 76% of 100 chicks found dead contained plastic (Kenyon and Kridler 1969), whereas. 90% of 50 chicks examined there in 1982-83 did (S. I. Fefer, U.S. Fish and

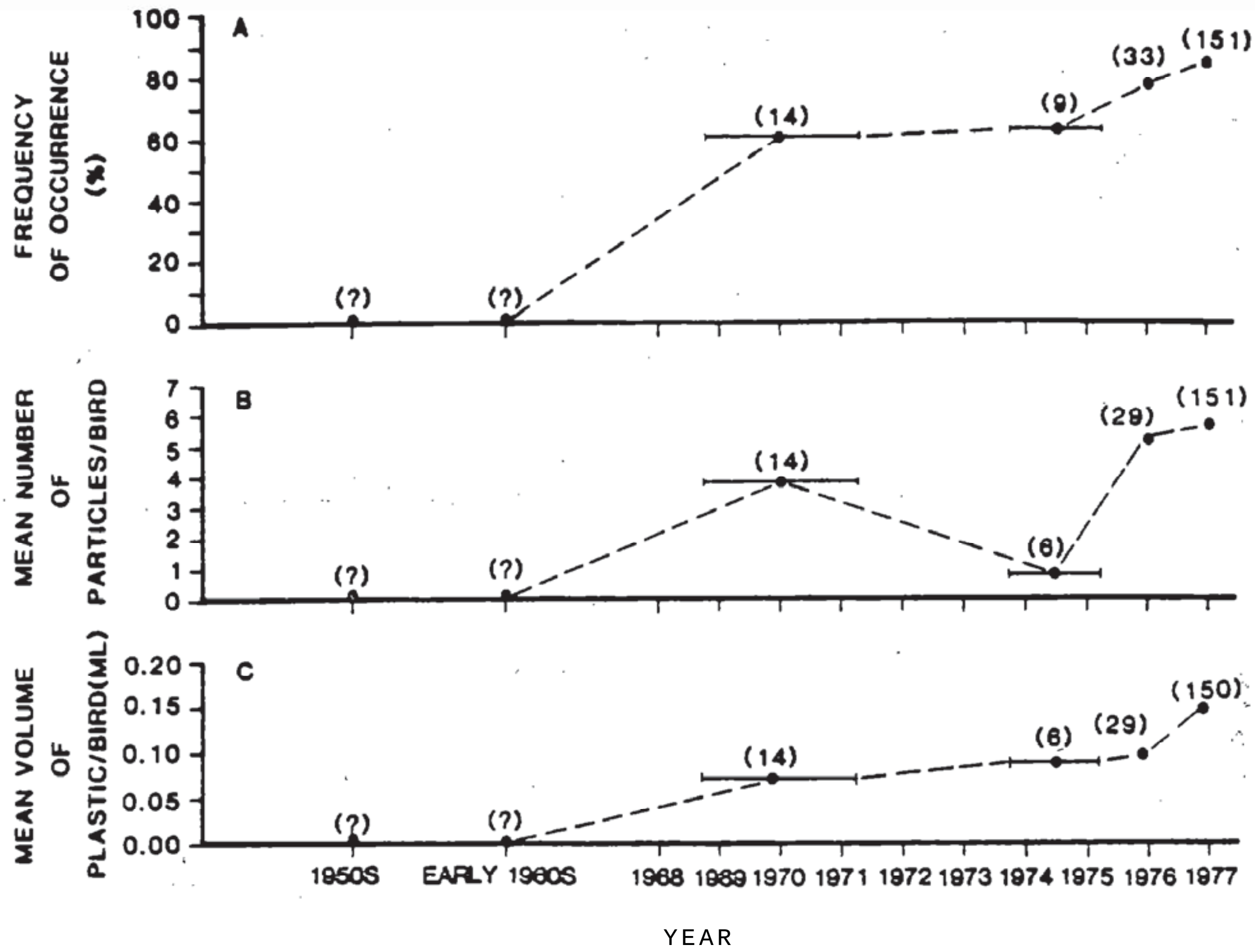

Figure 2.--Changes in plastic-ingestion in the short-tailed shearwater, 1950's to 1977 (adapted from Day 1980). Sample sizes are in parentheses, and horizontal bars represent combined data for the periods 1969-71 and 1974-75. Data from the 1950's and early 1960's are from D. L. Serventy (CSIRO Wildlife Research, Helena Valley, W. A., Australia pers. commun.) and R. Mykytowycz (CSIRO Wildlife Research, Canberra, Australia, fide D. L. Serventy); they examined hundreds of short-tailed shearwaters during the course of their studies.' Data from the period 1969-77 are from Alaska (Day 1980). (A) Frequency of occurrence of plastic; (B) mean number of plastic particles per bird; (C) mean volume (ml) of plastic per bird.

Wildlife Service, Hawaiian and Pacific Islands National Wildlife 'Refuge pers. commun.); this increase in frequency of occurrence is significant ($\chi^2 = 4.2$; $P < 0$

No plastic was found in any of the parakeet auklets collected at St. Lawrence Island in the mid-1960's (J., Bedard, Universite Laval, Quebec, Canada pers. commun.), yet approximately 50% of the parakeet auklets from. the Bering and Chukchi Seas contained plastic in the period 1974-77 (Table 9). **Thus,** it appears that ingestion of plastic by marine birds first occurred in the early 1960's in the Pacific (Kenyon and Kridler 1969) and that plastic ingestion is increasing annually; plastic ingestion also appears to have begun in the Atlantic in the early 1960's (Rothstein 1973).

Marine birds in Alaska also show intra-annual variation in plastic ingestion (Day 1980). Figure 3 shows the mean number of plastic particles per bird and the frequency of occurrence of plastic in short-tailed shearwaters collected in Alaska and Australia and in tufted puffins collected in Alaska.

In May, the mean number of particles per short-tailed shearwater was relatively small, although about 80% of the birds contained plastic (Figs. 3A, 3B). The birds began ingesting plastic in large numbers in June (X = 6.5 particles per bird). By July, the mean number of particles per bird decreased slightly, so the rate of ingestion was not so high as the rate of loss through wear, The percentage of birds with plastic had risen slightly, to 84%, indicating that ingestion was still occurring. A second period of heavy plastic ingestion occurred in August, when the mean number of particles per bird again increased; 98% of the birds contained plastic at this time. The mean number of particles ingested again declined in September, although virtually 100% of the birds contained at least some plastic. During winter, the rate of ingestion was low, as indicated by the data from Bass Strait: only 47% of the birds contained plastic, and approximately 72% of these had two or fewer particles.

Essentially the same pattern is seen in tufted puffins (Figs. 3C, 3D): Low frequencies of occurrence and low mean numbers of particles per bird in May, high rates of plastic ingestion in midsummer, and decreased ingestion rates and subsequent loss through wear late in the summer. A similar pattern was also seen in parakeet auklets and horned puffins from Alaska (Day 1980).

The frequency distributions for the wear classes (a relative grade of how worn individual particles are) of individual particles support the evidence that most plastic in boreal birds is ingested during the summer (Fig. 4) . In May, only the more-worn wear classes were represented, indicating little ingestion during the winter and following the pattern predicted from the decreased ingestion rates seen in Australian birds. During June, the mean wear class decreased from 4.6 (worn-very worn> to 3.6 (relatively worn-worn), indicating that many less-worn particles were being ingested; 50% of the particles were in wear classes 1-3, the less-worn categories. The lack of wear-class 1 (fresh) particles is attributable to the likelihood that not all particles are in wear class 1 when ingested.

The frequency-distributions for July and August were similar, with those particles in the stomach wearing down. The bulk of the particles was concentrated in wear classes 4 and 5, the more-worn categories. Although "fresher" particles (wear classes l-3) were being ingested, the mean wear class increased (i.e., particles became more worn) because the newly added fresh particles constituted a proportionally smaller percentage of the number of particles than they had in May and June. The mean wear class again increased in September, and particles in the fresher wear classes only constituted 10% of the sample at this point, indicating that the rate of ingestion had decreased.

In summary, during the northern winter, the birds apparently eat little plastic. Consequently, that plastic remaining in the stomach wears down (mean wear class approaches 5) and some is lost (the mean number of

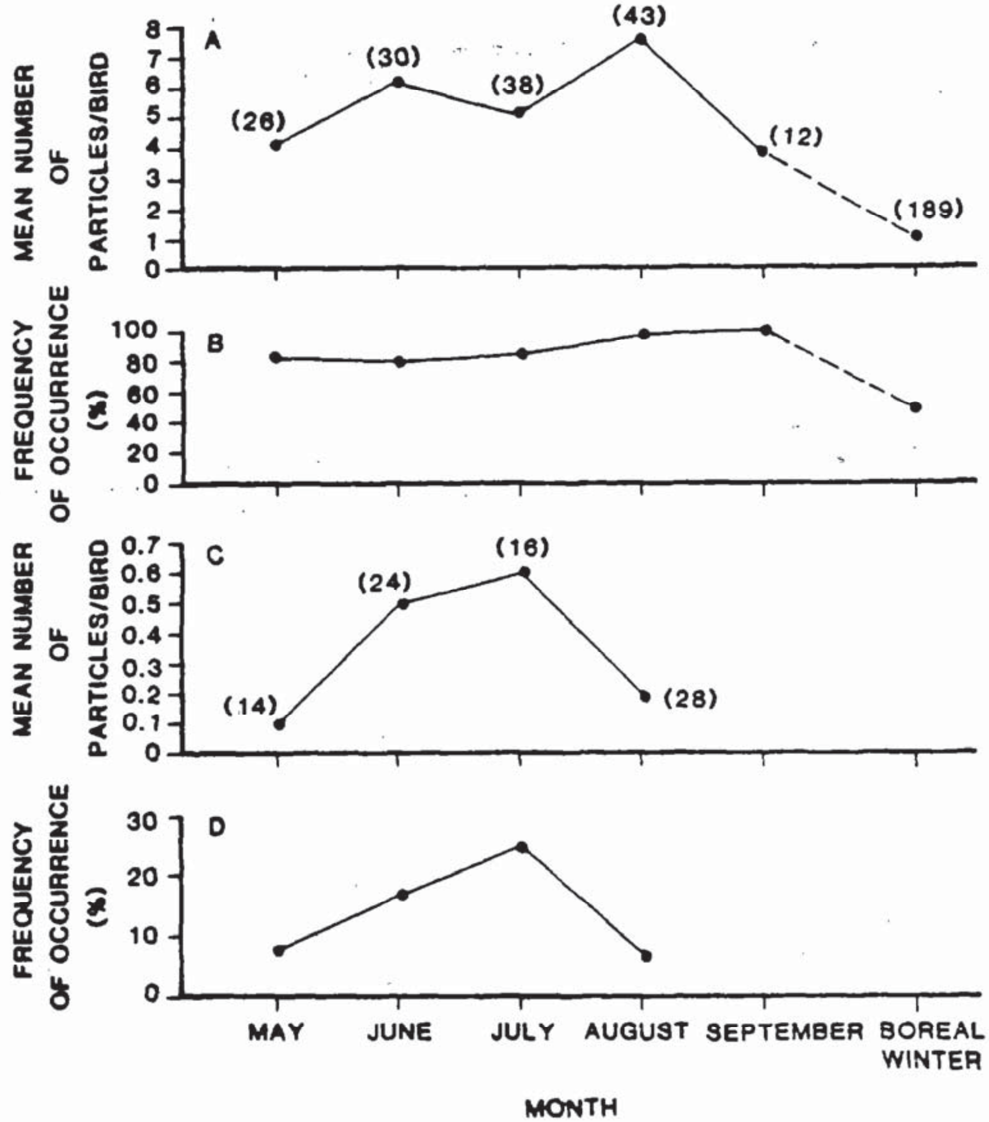

Figure 3.--Temporal variation in plastic ingestion in short-tailed shearwaters (A, B) and in tufted puffins (C, D) in Alaska (adapted from Day 1980 and Day unpubl. data). (A) Mean number of plastic particles per bird in short-tailed shearwaters of unknownage collected near Kodiak Island in 1977 and in Bass Strait, Australia, during the boreal winters of 1978 and 1979 (I. J. Skira, National Parks and Wildlife Service, Sandy Bay, Tasmania pers. commun.); sample sizes are indicated in parentheses. (B) Frequency of occurrence of plastic in short-tailed shearwaters, as above. (C) Mean number of plastic particles per bird in adult tufted puffins collected at Buldir Island in 1975; sample sizes are indicated in parentheses. (D) Frequency of occurrence of plastic in tufted puffins, as above.

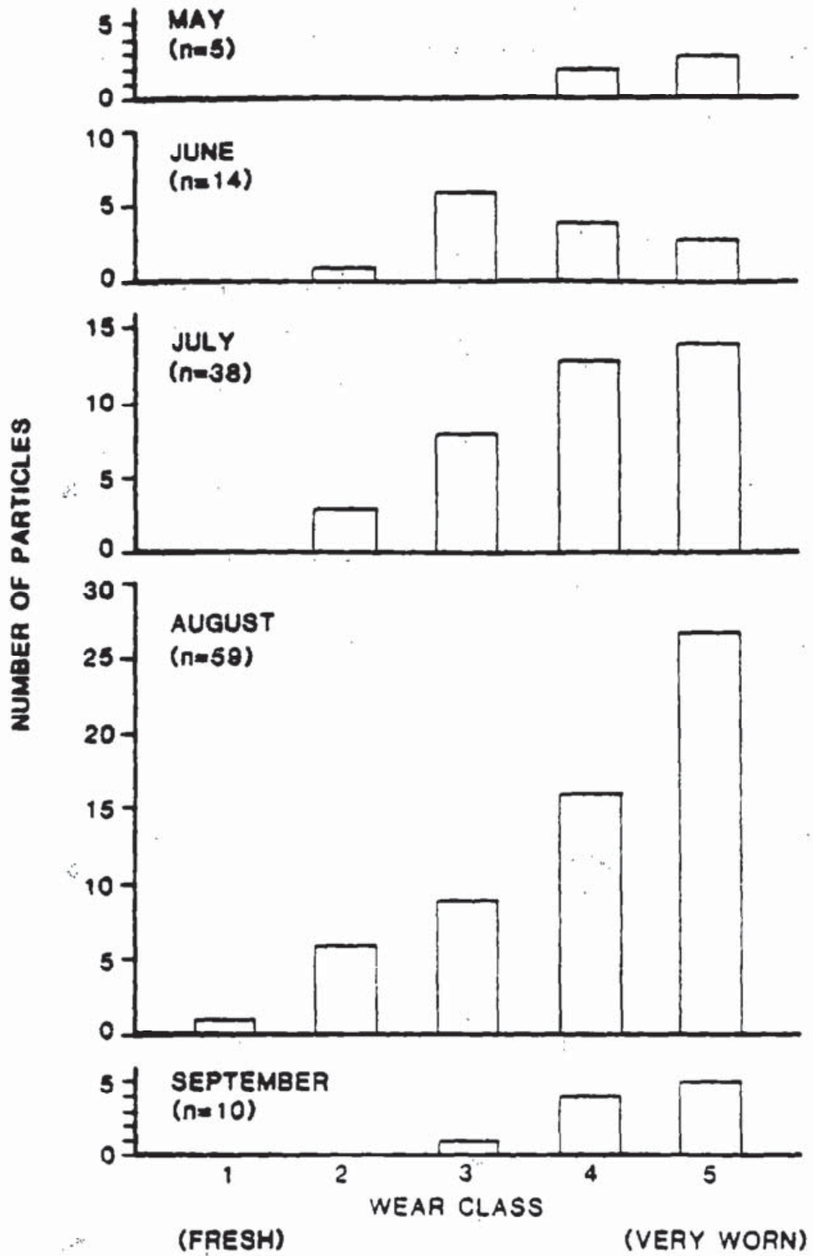

Figure 4.--Frequency distributions of the wear class of individual plastic particles found in short-tailed shearwaters collected in Alaska during the summer of 1977 (from Day 1980). All birds were collected near Kodiak Island, as in Figure 3. Wear on each piece was determined by classifying the degree of angularity of the piece's edge and by examining the general surface of each piece. The degree of wear was quantified by a five-point visual index (fresh, relatively fresh, relatively worn, worn, and very worn), as described in Day (1980).

particles per bird decreases). This condition exists until May. In late spring and early summer, the birds again begin eating plastic, causing a sharp rise in the mean number of particles per bird and a sharp decrease in the mean wear class of the plastic, as seen in the June birds. In contrast to the June data, midsummer (July and August) means show relatively little change, indicating that consumption of new particles is roughly balanced by loss of particles through wear. The ingestion of plastic decreases near the end of the summer, and smaller particles continue to be lost through wear; the mean number of particles per bird decreases, and the mean wear class approaches 5 (very worn> again. Wear then continues into the winter months, completing the cycle. Although migratory seabird species from higher latitudes appear to ingest plastic only during some months, it is believed that nonmigratory tropical species are able **to** ingest plastic all year (S. I. Fefer pers. commun.).

‘Since the particles do not pass into the intestine, the mean residence time of plastic in the birds’ stomachs may he estimated. Although Day (1980) estimated residence times **of** 2-3 months for ‘soft’ polyethylene and l0-15 months for “hard” polyethylene, the data showing rapid loss rates in short-tailed shearwaters and tufted puffins presented here and data for phalaropes from Connors and Smith (1982) suggest that the mean residence time of individual particles is shorter and is on the order of 6 months. Obviously, there could be great variation in these rates, depending on the number, size, and type of particles and other hard objects (e.g., pumice) in a particular bird’s stomach.

The available data permit examination of the impact of the birds’ ingestion of the at-sea density of plastic. At the peak of summer ingestion, short-tailed shearwaters average about 7.4 particles per bird (Fig. 3). With an estimated population of 18 x 10^6 birds (I. J. Skira pers. commun.), this yields an estimated “standing stock” of 133 x 10^6 particles in the stomachs of this species. The average residence time of the particles is estimated to be 6 months. Therefore, the average removal of plastic by this species is approximately 0.7 x 10^6 particles per day in the middle of the summer. The peak of plastic ingestion by the short-tailed shearwater was in June, with a mean increase of 2.1 particles per bird; thus, a peak of 1.3 x 10^6 particles per day were removed from the ocean during June by this species.

Shaw (1977) estimated that plastic density in Alaska waters is about: one piece per 9,000 m^2 of ocean surface (= 111.1 pieces per km^2); using a rough estimate of 3.0 x 10^6 km^2 of ocean surface in the waters around Alaska, we estimate that there are approximately 333 x 10^6 pieces of ingestible plastic in the waters around Alaska. The rate of “recruitment” into this “plastic population” is probably low, since estimates of water circulation times in the subarctic North Pacific range between 2 and 5 years (T. Royer, Institute of Marine Science, University of Alaska, Fairbanks, Alaska pers. commun.). When one considers that the short-tailed shearwater alone removes about 80 x 10^6 particles from the waters around Alaska during June and August (primarily in shelf and shelf-break waters), and that other species are ingesting plastic at the same time, it appears that birds are decreasing the-at-sea density of plastic in Alaska waters. Although our estimates of rates of ingestion may be high and Shaw's estimates of plastic density may be low, it is apparent that the birds are decreasing the density of plastic enough to cause the Synchronous late-summer decline in ingestion seen in all species (Fig. 3).

Effects of Plastic Ingestion on the Physical Condition and Reproduction of Marine Birds

Perhaps the most important question to be asked about plastic ingestion is whether or not the presence of plastic in the gut has a detrimental effect on the physical condition or reproductive performance of the birds. These effects could take several forms, including direct ones such as starvation, intestinal blockage, ulceration, and internal injury, or indirect ones, such as decreased physical “quality” or reproductive performance.

Starvation could be caused by the physical presence of plastic in the stomach. In birds, hunger and satiety are regulated by receptors in the. -hypothalamus, where various stimuli reaching the central nervous system influence food intake (Sturkie 1965). Appetite (hunger) can be stimulated by the contraction of an empty stomach, cold temperatures, or the sight of food, and can be inhibited (satiety) by dehydration, distension of the stomach or intestines, warm temperatures, or exercise (Sturkie 1965). A large amount of plastic in the stomach of a bird could decrease feeding activity by maintaining stomach distension and preventing stomach contraction, thus signaling “satiety” to the hypothalamus. Although plastic has been associated with starvation in some birds (Bond 1971; Bourne and Imber 1982), Bourne and Imber correctly pointed out that one must be careful with this interpretation, for it is often difficult to determine if the plastic ingested caused the starvation or if the plastic was ingested because the bird was starving.

Intestinal blockage--preventing the passage of food into the intestine--can only occur if a bird eats a large volume of plastic or a particularly bulky piece of plastic. Intestinal blockage by elastic thread cuttings (Pal-slow and Jeffries 1972) and by nylon threads (Bourne 1976), -which tend to roll into a ball in the stomach (Parslow and Jeffries 1972; R. H. Day pers. observ.), has also been documented. Intestinal blockage by large, bulky items has been documented in Laysan albatross chicks (Kenyon and Kridler 1969; Pettit et a1. 1981; S. I. Fefer pers. commun.).

Ulceration and internal injury could be caused by the presence of jagged edges on plastic fragments or by a long period of contact between the plastic and the mucosa of the stomach wall. Van Franeker and Camphuijsen (1984) found a nail embedded in a thick layer of fatlike material in the distal part of the gut of a northern fulmar. Local ulcerations of stomach mucosa as a result of plastic ingestion have been recorded in northern fulmars (Bourne 1976) and in Layaan albatross chicks (Pettit et al. 1981; S. I. Fefer pers. commun.).

Indirect effects of plastic ingestion may take the form of decreased physical “quality” of the bird or decreased reproductive performance. To test for the effects of plastic ingestion on the physical quality of the birds, Day (1980) calculated linear regressions for the number, weight, and volume of plastic particles versus the body weight and body fat class of short-tailed shearwaters and parakeet auklets from Alaska. In all cases, weak (r^2 < 0.17) negative slopes were found for the lines, and the lines were not significantly different from zero, (P. > 0.05), indicating a slightly negative and weak relationship between increasing amounts of plastic and weights of the birds. No relationship was found when the above variables were plotted against body fat class. Thus, plastic ingestion had limited effects on the physical quality of these birds, at least in terms of body weight and body fat condition. A negative relationship between the amount of plastic and body fat condition has been found in red phalaropes in California, however (Conners and Smith 1982).

The ingestion of plastic may have detrimentally affected the reproduction of parakeet auklets in Alaska in 1976 (Day 1980). Nonbreeding adults average twice as many particles (X = 34.3 + 23.9 particles per bird; n = 12) as did breeding adults (x = 17.4 + 16.3 particles per bird; n = 25); these differences were significant (T = 216.5; P < 0.01; Mann-Whitney one-tailed test; Conover 1971). The nonbreeder category included failed breeders and birds that had bred in previous years. Some of the parakeet auklets had up to 81 pieces of plastic in the stomach, which appeared to distend the stomach fully. In several cases, many of the particles had become embedded in “socket" that had formed in the mucosa of the stomach; under these conditions, the presence of plastic appears to have been detrimental to the function of the stomach. Day (1980) suggested that the decrease in reproductive performance also could have been related to decreased feeding during the prebreeding season.

Another interpretation of this observation is possible. Since, as we have shown, there is age-related variation in the amount of plastic ingested by subadult versus adult parakeet anklets (Table 8), there is a’ possibility that there is also age-related variation in plastic ingestion within the “adult” category. If this is true, young adults would ingest more plastic than would older adults. Young adult seabirds tend, in general, to increase in reproductive success with increasing age and experience, and many fail at reproduction in their first or second years of breeding (Richdale 1957; Asbirk 1979; Thomas 1983). As a result, the observed poor reproductive success of parakeet auklets containing large amounts of plastic may have actually been the result of normally poor reproductive success of first or second time breeders.

A decrease in reproductive performance could also result from hydrocarbon pollutants associated with plastic. Hydrocarbons such as DDE; and polychlorinated biphenyls (PCB’s) are suspected of lowering the levels of one or more -steroid hormones, resulting in delayed ovulation (Peaka11 1970); any delay in normal reproductive cycles in arctic seabirds may-contribute to reproductive failures. Although no data are available for raw polyethylene pellets, polystyrene spherules have been found to have PCB’s concentrated from seawater onto their surfaces (Carpenter et al. 1972). An increase in the number of particles ingested would thus bring more hydrocarbons into the birds’ bodies, preventing successful reproduction.

An explanation alternative to our interpretation can be proposed from the above data. Birds in poor condition may eat more plastic than do healthy birds because they are in poor condition; since these birds are already in poor condition, they probably will not reproduce anyway, yielding the same results. This possibility notwithstanding, the likelihood of decreased reproductive performance as a result of plastic ingestion warrants further investigation.

DISCUSSION AND CONCLUSIONS

Sources of Plastic

Two major types of plastic are ingested by marine birds: plastic fragmentsand raw plastic pellets. Other types of plastic such as polystyrene spherules, foamed polystyrene (i.e., Styrofoam), toys, and other objects, are eaten by seabirds only rarely (Day 1980). Only Lasean albatrosses eat much of these latter types of plastic (S. I. Fefer pers. commun .).

The primary sources of plastic fragments appear to be at-sea solid-waste disposal and (particularly) by discarding plastic objects from fishing boats and marine shipping (Scott 1972, 1975; Cundell 1973; Venrick et al. 1973; Colton 1974; Shaw 1977; Feder et al. 1978; Merrell 1980; Morris 1980a). In the early 1970's, for example, approximately 4.5 x 10^4 metric tons of plastics were discarded at sea each year (National Academy of Sciences 1975 cited in Merrell 1980); Guillet (1974) contends that plastic packaging litter is presently increasing at an exponential rate. Some of the nearshore plastic evidently comes from nearby population centers (e.g., Cundell 1973), although currents and winds play a major role in distributing most of this debris far from its origin (e.g., Venrick et al. 1973; Scott 1975; Merrell 1980). This larger debris is subsequently. broken into smaller fragments, which are then ingested by seabirds. The areas of origin of this widely dispersed plastic are often difficult to “determine. Studies in the Pacific Ocean, however, have shown that 108 of 109 identifiable plastic items eaten by Laysan albatrosses from the “Hawaiian Islands originated in Japan (Pettit et al. 1981) and that most of ‘the litter found on beaches in the Aleutian Islands originated from Japanese and American fishing boats (Merrell 1980). At the latter site, countries represented by identifiable plastic litter were Japan, the United States, the U.S.S.R., Republic of Korea, Canada, Bulgaria, Rumania, and the Netherlands, in order of decreasing frequency. Work in Scotland has shown that most of the plastic debris there also comes primarily from shipping (Scott 1975).

Raw polyethylene pellets are the raw form of polyethylene as it is synthesized from petrochemicals; these pellets are then shipped around the world to manufacturing sites, where they are melted down and fabricated into bags, squeeze bottles, toys, and many other everyday items. Because these pellets are shipped worldwide, the origins of pellets found at sea are difficult to determine. Although the country of origin of these pellets cannot be determined, there are many ways in which they enter the sea. Many pellets probably enter the sea in effluents from plastic-synthesis plants, as has been reported for polystyrene in the North Atlantic (Kartar et al. 1973, 1976; Hays and Cormons 1974; Morris and Hamilton 1974). In Goa, India, plastic factories simply dump their waste plastic into the nearby river, which then carries it to the sea (Nigam 1982). Pellets are also used as- packing around larger objects in ships' holds and sometimes are moved in bulk, as is grain; errors in loading and unloading ships at ports allow escapement into the sea. Pellets are sometimes used on the decks of Ships to reduce -friction for moving large objects, then are washed from the decks and into the sea (Anonymous 1981). After entering the sea, pellets are dispersed through the world's oceans by currents and winds.

There are several mitigating actions that could reduce entry of plastics into the oceans. Filtering effluents from synthesizing-manufacturing plants is relatively easy and will save the companies money. Reducing effluent loss of polystyrene spherules from manufacturing sites in the United Kingdom caused a rapid reduction in ingestion of those spherules by organisms in nearby waters within 3 years (Kartar et al. 1976). Improving loading and unloading procedures at docks would also decrease entry into the oceans. Reductions in the at-sea discarding of plastic litter could be effected by making litter control a requirement for fishing permits (as suggested by Merrell 1980) or by making shipboard incinerators a requirement for licensing a ship.

Another mitigating action is to alter the degradation rates of the plastics themselves. Guillet (1974) and Gregory (1978, 1983) have shown that weathering of polyethylene and Styrofoam occurs naturally and eventually leads to disintegration and dispersal as "dust." Gregory (1983) stated that it would require 3-50 years for complete disintegration to occur on the beach, and apparently much longer at sea. One way to accelerate degradation is to make the plastics highly degradable under normal conditions. The plastics industry has encountered many practical problems in trying to produce degradable plastics, however' (Taylor 1979; contra Guillet 1974), leaving regulation of loss into the sea as a more feasible and realistic method of reducing the abundance of plastic in the oceans.,

Rates of Ingestion in Marine Birds: A Look to the Future

We feel that it is appropriate to discuss the monitoring of species or groups of seabirds for rates of plastic ingestion. Those species or groups ingesting the most plastic (either with the highest frequencies of occurrence or the highest mean number of particles per bird) should be monitored closely in the future. As we have shown, procellariiform birds are the seabirds most vulnerable to plastic pollution (Tables l-3). A high percentage of the species examined contain plastic, the two highest average amounts of ingestion occurred in this group, and the earliest records of' plastic ingestion by marine birdswere from this group (Kenyon and Kridler 1969; Rothstein 1973). Procellariiform birds tend to scavenge at sea and, to ingest randomly any plastic that they encounter (Table 7; Ashmole 1971; Day 1980; Day pers. observ.) . They also tend to eat large or oddly-shaped plastic objects (see comments in Table 2) that may cause intestinal blockage or internal injury (e.g., Bourne 1976; Pettit et al. 1981). These birds also pass ingested plastic on to their chicks through regurgitation-feeding (e.g., Kenyon and Kridler 1969; Rothstein 1973), perhaps increasing prefledgling mortality. Procellariiform birds also feed at or near the sea's surface and eat a high frequency of crustaceans and cephalopods (Ashmole 1971), two prey groups that are correlated with high rates of plastic ingestion (Tables 4, 5). On the other hand, procellariiform birds are able to eliminate some plastic by egesting casts containing indigestible items, such as squid beaks.

Another species of major concern is the parakeet auklet (Table 2). This species averaged the highest number of plastic particles of 37 species of seabirds in Alaska, 13.7 particles per bird, and showed evidence of decreased reproductive performance there as a result (Day 1980). This species preys primarily on crustaceans, a prey group linked to high rates of ingestion of plastic (Table 5). Some of the stomachs examined by Day were fully distended because **so** much plastic was present. Phalaropes also should be monitored closely for ingestion, because the few data available (Table 2) indicate a capacity for high rates of plastic contamination. At present, the other species of seabirds appear to have low rates of plastic ingestion, indicating that less-intensive monitoring is needed.

Monitoring should be done at selected sites in the Northern and Southern Hemispheres and in all oceans. Birds found dead on beaches and birds collected for museums should be examined closely for frequencies of ingestion and for the amount of plastic ingested; birds found dead should also be checked for the cause of death and chlorinated hydrocarbon levels should be determined. Any sampling gaps can then be filled with selective collecting of species of interest. We **suggest** a 2- or 3-year cycle for monitoring.

Feeding Habits and Plastic Ingestion

A few species of seabirds evidently ingest at random any plastic or objects that they encounter. Before the production of plastics, most objects encountered by birds at the sea's surface were digestible (except for floating pumice) ; selection may have favored those species that ingested any such objects (Rothstein 1973). Many species, however, select for specific kinds, colors, shapes, color-shape combinations, or sizes of ‘plastic (Day 1980). Such selection suggests that these species are mistaking plastic objects (a recent addition to the surface of the ocean) for prey items. Prey items that the light-brown pellets most resemble to the authors are planktonic crustaceans and pelagic fish eggs. Other colors of pellets may resemble the eyes of fishes or squids, the bodies of larval fishes, or other, unknown food items.

It is likely that not a single factor, but a suite of (sometimes) interacting factors, affects the amount of plastic ingested by seabirds. These factors include the feeding method and prey type-of the species, the tendency for generalist or specialization in feeding habits, age of the birds, time of year, at-sea density of plastic, and geographic location of the birds.

The Problem of Effects of Plastic Ingestion

It is unfortunate that we still do not know, the true extent of the effects of plastic ingestion. We suspect that, for most species, the rates of ingestion and the amounts of plastic ingested are low enough that there is little detrimental effect on the birds involved. There are several species, mentioned earlier, that have been shown to exhibit sufficiently high rates of ingestion to warrant concern. Decreased feeding rates before breeding may result in poorer physical condition of the bird, leading to an inability to secure or maintain a breeding territory,: to lay high-quality eggs, or to successfully incubate those eggs. Data from parakeet auklets

(Day 1980) suggest that any or all of these conditions may apply to that species, and data from short-tailed shearwaters (Day 1980) and red phalaropes (Connors and Smith 1982) suggest a link between high amounts of plastic ingested and decreased physical "quality." The possibility of hydrocarbon contamination through plastic ingestion (Carpenter et al. 1972) also has serious implications. Consequently, we believe that carefully controlled experiments on the effects of plastic ingestion need to be performed to determine whether or not a serious problem really exists. These experiments could conceivably be performed in conjunction with zoos or schools Of veterinary Science.

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