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Increasing Frequency of Plastic Particles Ingested by Seabirds in the Subarctic North Pacific

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We examined gut contents of 1799 seabirds comprising 24 species collected in 1988–1990 to assess the types and quantities of plastic particles ingested by seabirds in the subarctic waters of Alaska. Of the 15 species found to ingest plastic, most were surface-feeders (shearwaters, petrels, gulls) or plankton-feeding divers (auklets, puffins). Of 4417 plastic particles examined, 76% were industrial pellets and 21% were fragments of 'user' plastic. Ingestion rates varied geographically, but no trends were evident and rates of plastic ingestion varied far more among species within areas than within species among areas. Comparison with similar data from 1968 seabirds comprising 37 species collected in 1969–1977 revealed that plastic ingestion by seabirds has increased significantly during the 10–15-year interval between studies. This was demonstrated by: (i) an increase in the total number of species ingesting plastic; (ii) an increase in the frequency of occurrence of plastic particles within species that ingested plastic; and, (iii) an increase in the mean number of plastic particles ingested by individuals of those species.

Consumption of plastic by numerous species of seabirds has been documented during the last few decades in most oceans of the world (Baltz & Morejohn, 1976; Day, 1980; Furness, 1985; Day *et al.*, 1985; van Franeker, 1985; Azzarello & Van Vleet, 1987; Fry *et al.*, 1987; Ryan, 1987a, 1988; Moser & Lee, 1992). The frequency of plastic particle ingestion varies among species and is most prevalent in surface-feeders such as shearwaters, petrels, prions and phalaropes (Day, 1980; Ryan, 1987a), as well as some planktivorous diving species (such as auklets). Plastics may be consumed because particles resemble prey items (Day *et al.*, 1985, 1990), or through the food chain by consuming prey with plastics in their gut (Kartar *et al.*, 1976). In turn, adult seabirds may pass plastics on to chicks by regurgitation (Fry *et al.*, 1987).

Available evidence suggests that plastics are damaging to seabirds when they are consumed in sufficient quantity to obstruct the passage of food or cause stomach ulcers (Fry *et al.*, 1987; Ryan, 1987b). Other effects may include bioaccumulation of PCBs (Aldershoff, 1982), diminished feeding stimulus, lowered steroid hormone levels and delayed reproduction (Azzarello & Van Vleet, 1987), but evidence of direct effects on body condition are equivocal (Day, 1980; Ryan, 1987b; Moser & Lee, 1992).

Two basic classes of plastic are commonly found in seabirds (Day *et al.*, 1985; Ryan, 1987a). Plastic 'pellets' (also known as resins or cylinders) are the raw material of the plastic industry. These enter the marine ecosystem from manufacturing plant outfalls and during transportation at sea. Plastic 'fragments' or 'user' plastics are small, weathered pieces of larger manufactured items that are discarded at sea (such as fishing floats, buckets, bottles, etcetera). Plastic pollution has risen dramatically with an increase in plastic resin production. Plastic production in the United States increased from 2.9 million t in 1960 to 47.9 million t in 1985 (Society of the Plastics Industry, 1986). This has been paralleled by a significant increase in plastic particle concentrations in sea-surface waters of the North Pacific from the 1970s to the late 1980s (Day & Shaw, 1987; Day *et al.*, 1990).

In this paper we will demonstrate that the frequency and number of plastic particles in seabirds from the subarctic North Pacific have also increased during this time period. Day (1980) analysed 1968 stomach samples from 37 species of seabirds collected during 1969–1977 (mostly 1975–1977) throughout a wide geographic area of subarctic, coastal Alaska. Most specimens were collected at major seabird colonies in the Aleutian Islands (such as Buldir Island), and in the northern Gulf of Alaska (for example Shumagin, Semidi, Kodiak Islands). One of us (J. Piatt) had been collecting seabirds in these same areas for diet studies in 1988–1989. We made a concerted effort in 1990 to collect more of several key species (petrels, auklets, puffins) studied by Day (1980) in order to assess whether plastic loads in seabirds had increased during the intervening decade since Day's analysis. Here we present our findings on the types and quantities of plastics found in 24 species of seabirds, and compare our results with Day (1980).

Study Area and Methods

Sample collection

Stomach samples of 1799 seabirds comprising 24 species were collected during the months of May–August in 1988–1990 (Table 1, note common and scientific names for all species). Samples were collected at seven sites in Alaska ranging over a distance of about 2800 km: at Agattu and Buldir Islands in the western Aleutian Islands, at Aiktak Island in the eastern Aleutian Islands, south of the Alaska Peninsula at the Shumagin and Semidi Islands, in Kachemak Bay (lower Cook Inlet), and in Prince William Sound (Fig. 1, and Appendix).

Seabirds were collected (J. Piatt) for on-going studies of feeding ecology. To ensure that samples were large enough for statistical comparisons of key plastic study species, collections were more extensive for Parakeet Auklets, Tufted Puffins, Horned Puffins, and Black-legged Kittiwakes. These species were chosen for intensive study of plastic ingestion because of their large populations, widespread distribution, ease of collection, and because they had been the focus of an earlier study of plastic ingestion by Day (1980). Stomachs were dissected and contents were preserved in the field. Stomachs were later examined in the laboratory for diet composition, and all plastic particles were extracted for analysis.

All of the specimens collected (Table 1) were also used for studies of feeding ecology and morphological variation of seabirds in Alaska (Piatt, in prep.). Tissues were also preserved for genetic and stable isotope analyses. Skeletons, specimens, and tissue samples are archived at the Alaska Fish and Wildlife Research Center (Anchorage) and at the American Museum of Natural History (New York).

Plastic analysis

For each stomach, plastic particles were counted, weighed and classified according to their colour, size, shape and type following Day (1980). Colour classes were reduced in number from Day's study to reduce subjectivity in colour identification. The Munsell Notation of colour analysis (Smithe, 1975) provides quantification of three visual aspects: hue, value and chroma. Value represents darkness of a colour on a scale of 0 (black) to 10 (white). This measure (with an accuracy of ± 0.5) was used to assign particle colours as dark (≤ 5.0) or light (≥ 5.5). Thus, particles were classified as light or dark, irrespective of their shade of colour (chroma). Light brown or tan particles were most common and classified separately. Mixed-colour plastic was classified light or dark depending on the dominant colour.

Size classes determined from a particle's largest dimension were used to categorize size. Fifteen size categories were recorded, using 0.5 mm intervals from 0.0 to 14.5 mm, and one category for all particles larger than 15.0 mm. Particles were classified as per Day (1980) for shape, with an extra classification to describe

TABLE 1

Comparison of the frequency of plastic particle ingestion by seabirds in Alaska between the years 1969–1977 (from Day, 1980) and 1988–1990 (this study).

Common name	Scientific name	1969–1977 No.	1969–1977 Freq. (%)	1988–1990 No.	1988–1990 Freq. (%)	Change (%)
Northern Fulmar	*Fulmarus glacialis*	38	57.9	19	84.2	+26.3
Sooty Shearwater	*Puffinus griseus*	76	43.4	–	–	–
Short-tailed Shearwater	*Puffinus tenuirostris*	200	83.5	5	80.0	−3.5
Fork-tailed Storm-petrel	*Oceanodroma furcata*	8	100.0	21	85.7	−14.3
Leach's Storm-petrel	*Oceanodroma leucorhoa*	4	25.0	64	48.4	+23.4
Pelagic Cormorant	*Phalacrocorax pelagicus*	3	0.0	10	20.0	+20.0
Red-faced Cormorant	*Phalacrocorax urile*	2	0.0	16	0.0	0.0
Northern Phalarope	*Phalaropus lobatus*	3	66.7	–	–	–
Mew Gull	*Larus canus*	10	0.0	4	25.0	+25.0
Glaucous Gull	*Larus hyperboreus*	33	3.0	–	–	–
Glaucous-winged Gull	*Larus glaucescens*	63	0.0	21	0.0	0.0
Black-legged Kittiwake	*Rissa tridactyla*	188	4.8	256	7.8	+3.0
Red-legged Kittiwake	*Rissa brevirostris*	46	13.0	15	26.7	+13.7
Common Guillemot	*Uria aalge*	191	0.0	134	0.8	+0.8
Thick-billed Guillemot	*Uria lomvia*	138	1.4	92	0.0	−1.4
Cassin's Auklet	*Ptychoramphus aleuticus*	10	40.0	35	11.4	−28.6
Parakeet Auklet	*Aethia psittacula*	116	75.0	208	93.8	+18.8
Crested Auklet	*Aethia cristatella*	85	0.0	40	2.5	+2.5
Least Auklet	*Aethia pusilla*	89	1.1	13	0.0	−1.1
Whiskered Auklet	*Aethia pygmaea*	5	0.0	22	0.0	0.0
Ancient Murrelet	*Synthliboramphus antiquus*	16	0.0	68	0.0	0.0
Marbled Murrelet	*Brachyramphus marmoratus*	61	0.0	96	0.0	0.0
Kittlitz's Murrelet	*Brachyramphus brevirostris*	5	0.0	17	0.0	0.0
Pigeon Guillemot	*Cepphus columba*	18	0.0	43	2.63	+2.6
Rhinocerous Auklet	*Cerorhinca monocerata*	20	0.0	1	0.0	0.0
Horned Puffin	*Fratercula corniculata*	148	36.5	120	36.7	+0.2
Tufted Puffin	*Fratercula cirrhata*	348	14.7	489	24.5	+9.8

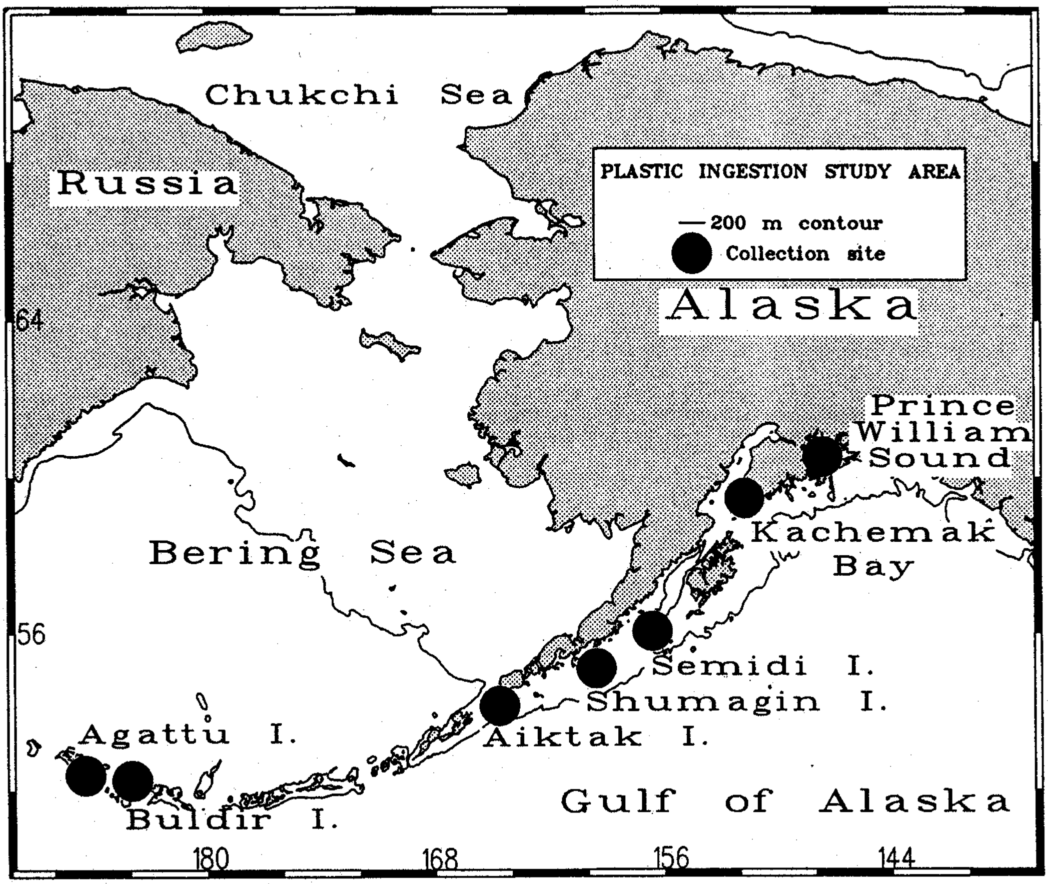

Fig. 1 Study area and sites for collection of seabirds, 1988–1990.

whether a particle was tubular, flat or three-dimensional. Shape categories included 'round', 'oval', 'cylinder', 'string', 'asymmetrical', and seven other descriptive categories. Particles are defined as pellets, plastic objects, fragments or unrecognizable objects.

Results

Frequency of occurrence

Of the 24 species of seabirds collected in 1988–1990, 15 species were found to contain plastic particles (Table 1). Most plastic particles were found in the ventriculus (gizzard), and few were found in the proventriculus (stomach). Species with high frequencies of occurrence of plastics included all the procellarids (fulmar, shearwaters, and storm-petrels), kittiwakes, Parakeet Auklets, and puffins.

Of the 24 species of seabirds that were collected in both 1969–1977 and 1988–1990, there was an increase in the number of species from 12 to 15, respectively, that contained plastic particles (Table 1). For the 17 species found to contain plastic in either study period, plastic ingestion increased in 12 species, and decreased to zero frequency in two species. Overall, there was a significant ($\chi^2=1100$, 16 df, $p<0.001$) increase in the frequency of plastic ingestion from 1969–1977 to 1988–1990. For those species that consumed plastic and for which we have adequate ($n>15$) stomach samples in both study periods (Fig. 2), the frequency of plastic ingestion increased over time by 0.2–26.3% (Horned Puffin and Northern Fulmar, respectively).

Species for which no plastic particles were found in any year of study included Red-faced Cormorant, Glaucous-winged Gull, Whiskered Auklet, Ancient Murrelet, Marbled Murrelet, Kittlitz's Murrelet, and Rhinocerous Auklet. Only three of 545 Common and Thick-billed Guillemots that were examined over all years contained plastic. Similarly low frequencies of occurrence were observed in Glaucous Gulls and Least Auklets.

Number of particles

The number of plastic particles ingested by seabirds in 1988–1990 varied widely among species and areas (see also below). The largest number of particles were found in Parakeet Auklets, which contained up to 86 particles per individual and averaged 17.1 particles per bird (Fig. 3). This rate of ingestion was much higher than among the other three key study species, which averaged 0.3–1.2 particles per bird (Fig. 3). Maximum numbers of particles per stomach varied widely among species (Tufted Puffin 51, Horned Puffin 14, Black-legged Kittiwake 15, Leach's Storm-petrel 13, Fork-tailed Storm-petrel 12, Northern Fulmar 26).

The average number of particles per bird increased significantly (Mann–Whitney $U=0.87$, $p<0.05$) between collections of key study species in 1969–1977

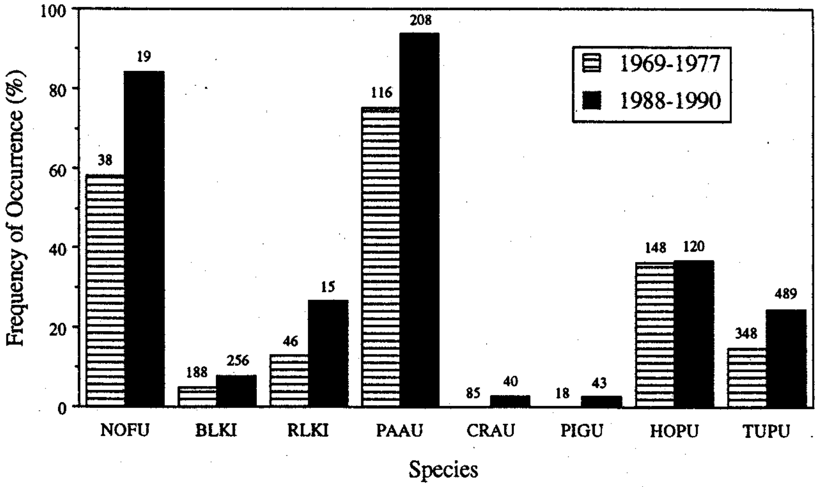

Fig. 2 Frequency of occurrence of plastic particles in stomachs of seabirds collected in 1969–1977 (Day, 1980) and 1988–1990 (this study). Note figure shows only those species for which $n \geq 15$ in both studies (see also Table 1).

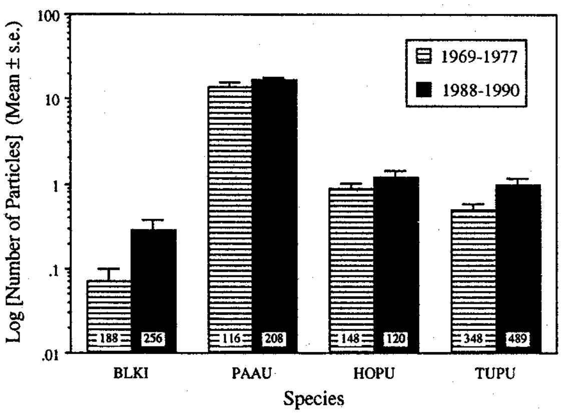

Fig. 3 Mean number of plastic particles in stomachs of four key study species in 1969–1977 (Day, 1980) and 1988–1990 (this study). Species: BLKI, Black-legged Kittiwake; PAAU, Parakeet Auklet; HOPU, Horned Puffin; TUPU, Tufted Puffin.

and 1988–1990 (Fig. 3). The observed increase was greatest in Black-legged Kittiwake (four-fold) and Tufted Puffin (two-fold), and least in Parakeet Auklet and Horned Puffin (1.3-fold each); although the latter species had historically high plastic loads and large increases may not have been physically possible. Similarly, the weight of plastic ingested by the four key study species increased significantly (Mann–Whitney $U=1.43$, $p<0.05$) between 1969–1977 and 1988–1990.

Characteristics of plastic particles

Of the 4417 plastic particles examined from 15 species (Table 1), the majority were of two main types: pellets (76.4%) and user plastics (21.5%)—which included plastic container fragments and monofilament line. The remainder (2.1%) of items were unrecognizable plastic pieces. Seven seabird species (Fig. 4) accounted for 98.9% of all particles recovered, and the composition of particle types differed greatly among species ($\chi^2=1642$, 6 df, $p<0.0001$). Pellets were ingested most by diving species like Tufted Puffins and Parakeet Auklets, whereas user plastics were more common in surface-feeding species like storm-petrels and kittiwakes (Fig. 4). Leach's Storm-petrels ingested monofilament line as well as smaller user fragments. Horned Puffins and Northern Fulmars ingested slightly more user plastics than pellets.

Most of the plastic particles ingested by birds were light brown in colour, or were a light shade of colour (Table 2). The proportion of light and dark colours that were ingested varied among species ($\chi^2=521$, 6 df, $p<0.0001$). Diving species (puffins, auklets) ingested a considerable fraction (>20%) of dark particles. Except for the Fork-tailed Storm-petrel (29%), surface-feeding species ingested few (2–6%) dark particles.

The size of plastic particles ingested by seabirds ranged from 0.5 to 28 mm (largest dimension). Black-legged Kittiwakes and Mew Gulls ingested the largest particles (maximum size: 28×11×1 mm), largely because they ingest more user plastic. The mean size index for kittiwakes was 5.87 compared with 4.08 in Parakeet Auklets, 5.03 in Horned Puffins and 4.10 in Tufted Puffins. Birds that ingested primarily pellets had a mean particle size index of 4.0 (3.5–4.5 mm).

Geographic variation

The best data for examining regional variation in plastic consumption are from Tufted Puffins (Fig. 5). The highest frequencies of plastic consumption were observed at Agattu (32.2%) and Buldir (29.0%) islands in the western Aleutians. There was no significant difference between these islands in the frequency of occurrence or mean number of particles ingested (Wilcoxon two-sample test, $Z=0.22$, $p>0.05$). Plastic particles occurred at more than twice the frequency in Tufted Puffins collected in the western Aleutians than at Aiktak Island (14.4%) in the eastern Aleutians (Fig. 5).

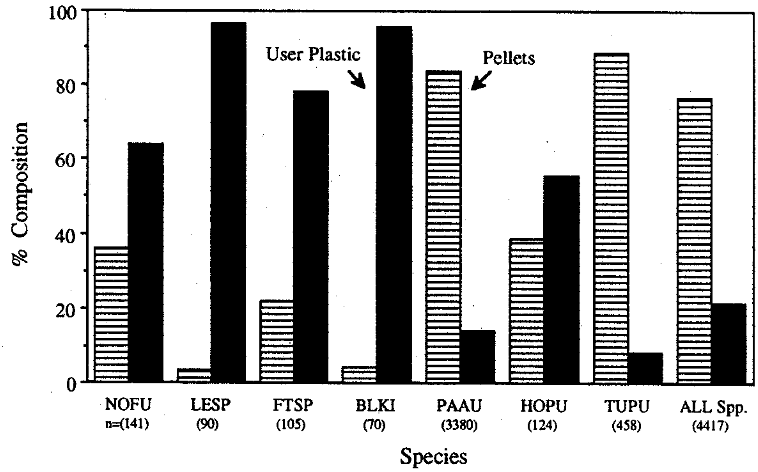

Fig. 4 Types of plastic particles ingested by seabirds in subarctic Alaska, 1988–1990.

TABLE 2

Colour composition of plastic particles removed from seabirds collected in Alaska in 1988–1990.

		Light colour (%)			Dark colour (%)	
Species	*N*	Brown	Shades	Mixture	Shades	Mixture
Northern Fulmar	141	59.6	37.6	0.0	2.8	0.0
Leach's Storm-petrel	90	48.9	47.8	1.1	2.2	0.0
Fork-tailed Storm-petrel	105	38.1	33.3	0.0	28.6	0.0
Black-legged Kittiwake	70	24.3	70.0	0.0	5.7	0.0
Parakeet Auklet	3380	65.6	12.8	0.3	21.2	0.2
Horned Puffin	124	29.0	50.0	0.0	21.0	0.0
Tufted Puffin	458	66.2	10.5	0.4	22.9	0.0
All species	4417	62.4	16.8	0.3	20.4	0.1

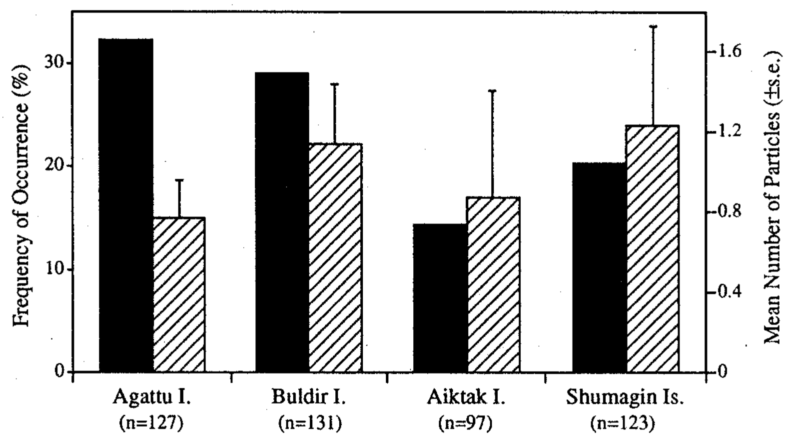

Fig. 5 Geographic variation in the frequency of occurrence and mean number of plastic particles ingested by Tufted Puffins in subarctic Alaska, 1988–1990.

The frequency of plastic particles in Tufted Puffins from the Shumagin Islands (20.3%) was intermediate between levels observed in the eastern and western Aleutians. The mean number of plastic particles in Tufted Puffins varied inconsistently, and the only significant differences were observed between Buldir (1.14 particles per bird) and Aiktak (0.87 particles per bird) islands (Wilcoxon two-sample test, $Z=-2.58$, $p<0.01$), and between Aiktak and Agattu (0.77 particles per bird) islands (Wilcoxon two-sample test, $Z=-2.93, p<0.01$).

Parakeet Auklets were sampled in large enough numbers for geographic comparison only at Buldir Island ($n=102$) and the Shumagin Islands ($n=99$). As with Tufted Puffins, plastic particles occurred at a higher frequency in Parakeet Auklets at Buldir (97.1%)

than at the Shumagins (89.9%), although there was no significant difference in the mean number of particles ingested at each site (15.8 and 18.0 particles per bird, respectively; Wilcoxon two-sample test, $Z=-0.20$, $p>0.05$).

In contrast to Tufted Puffins and Parakeet Auklets, plastic particles occurred more frequently in Black-legged Kittiwakes at the Shumagins (14.3%, $n=84$) than at Buldir (6.4%, $n=125$). The mean number of particles per bird was also higher (Wilcoxon rank test, $Z=2.31$, $p<0.05$) at the Shumagins (0.41) than at Buldir (0.31). Although sample sizes were small, no plastic was found in Black-legged Kittiwakes collected at Agattu Island ($n=30$) or the Semidi Islands ($n=12$).

The occurrence of plastic in Leach's Storm-petrels was similar in birds collected at Buldir Island (51.9%, $n=27$) and the Semidi Islands (48.3%, $n=29$). The same was true for Horned Puffins collected at the Shumagin Islands (41.2%, $n=85$) and the Semidi Islands (40%, $n=15$). No other species was collected in large enough numbers to make geographic comparisons (Appendix).

The frequency of particle types, irrespective of seabird species, was similar between areas. Particles recovered from birds at Buldir Island ($n=1760$) were mostly pellets (76.3%) and user fragments (22.3%). Particles ($n=2131$) recovered from a similar suite of species at the Shumagin Islands were also composed mostly of pellets (82.1%) and user fragments (14.9%).

Discussion

The purpose of this survey was to determine whether the quality and quantity of plastics ingested by seabirds in Alaska had changed during the 10–15-year period between our collections and those examined by Day (1980). With respect to types of plastic ingested, some differences were observed, although these are difficult to assess statistically because of differences between studies in the number of each species sampled in each collection locality (detailed information not provided by Day, 1980). Whereas Day found that about 93% of ingested plastics were 'light' (brown, shades, etc.) in colour, this was reduced to about 80% in this study. This difference was most pronounced among diving species (Horned and Tufted Puffins, Parakeet Auklet). However, the proportion of total particles that were pellets (76%) vs asymmetric (user) plastic fragments (24%) remained remarkably similar since Day's study (75 and 25%, respectively). Similar to Day, we found that in general, surface-feeding species took mostly 'user' plastics, whereas diving species ingested more pellets. Also like Day, we found that larger species tended to ingest larger particles, as did species that ingested more 'user' fragments—which tend to be larger than pellets.

Geographic variability in plastic pollution could account for some of the differences observed among species and years, simply because of differences in sampling of seabirds among areas. Day (1980) did not address this question. For species with adequate sample sizes, we did detect significant differences in mean plastic loads and frequency of plastic occurrence throughout an area spanning about 2000 km from the Semidi Islands to the western Aleutian islands. However, geographic differences were inconsistent within and among species, and no obvious trend emerged. Differences in rates of plastic ingestion among species were far greater than geographic differences within species.

We conclude that levels of plastic ingestion, which may reflect plastic pollution, are relatively uniform throughout this subarctic region of the North Pacific. Indeed, east–west gradients in neustonic plastic particle densities are much smaller than north–south gradients (Day *et al.*, 1990). Our study area is influenced predominantly by east–west currents of the Alaska Stream, and contains relatively uniform, moderate levels (12 800 particles km^{-2}) of neustonic plastic pollution compared with the Bering Sea (100 particles km^{-2}) to the north, or Transitional and Subtropical waters (57 900–74 700 particles km^{-2}) to the south (Day *et al.*, 1990).

If we assume that differences in sampling intensity among species and geographic areas between Day's (1980) and our study introduce little bias to our analyses, then it appears that plastic ingestion by seabirds has increased significantly during the 10–15 year interval between studies. This was demonstrated by: (i) an increase in the total number of species ingesting plastic; (ii) for those species found to ingest plastic in both studies, an increase in the frequency of occurrence of plastic particles within species; and (iii) an increase in the mean number of plastic particles for individuals of those species.

This increase in plastic particle ingestion parallels an observed increase in plastic pollution in the North Pacific during the same time period. In subarctic waters and the Gulf of Alaska, levels of small plastic particle pollution rose from 0 to 132 particles km^{-2} in 1974–1976, to 3370 particles km^{-2} in 1985 (Day & Shaw, 1987), to 12 800 particles km^{-2} in 1985–1988 (Day *et al.*, 1990). Similar increases were observed in the Bering Sea (68, 80, and 600 particles km^{-2}, respectively) and in subtropical waters (100, 1210, and 726 g km^{-2}, respectively).

Strikingly similar temporal observations of plastic pollution and ingestion of plastics by seabirds in the North Atlantic have recently been reported by Moser & Lee (1992). They analysed the stomach contents of 1033 seabirds collected off the coast of North Carolina from 1975–1989. Twenty-one of 38 seabird species contained plastic particles. Procellariiform birds contained the most plastic, and the frequency of occurrence of plastic increased in seven of eight procellarid species during the study period. This increase was attributed to increasing levels of plastic particle pollution in the North Pacific (Moser & Lee, 1992).

In conclusion, our study corroborates Day's (1980) finding of widespread ingestion of plastic particles by seabirds in the subarctic North Pacific. The types and quality of ingested plastics have changed little over a 10–15-year period, but there has been an increase in the frequency and quantity of plastic ingestion by a variety of seabird species. This increase corresponds to increases in plastic pollution in the North Pacific, and parallels the situation with seabirds and plastic pollution in the North Atlantic. Data from this study will be archived with the US Fish and Wildlife Service (Anchorage, Alaska) in anticipation that surveys of plastic ingestion by seabirds will be conducted again in the future; thus allowing for quantitative comparison of species and localities used in this study.

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APPENDIX

Numbers of seabirds collected in different areas of Alaska, 1988–1990, for studies on diets (including plastic), morphology and genetics.

	Area						
Common name	AGA	BUL	AIK	SHU	SEM	KAC	PWS
Northern Fulmar	0	1	0	7	11	0	0
Short-tailed Shearwater	0	1	0	3	1	0	0
Fork-tailed Storm-petrel	0	2	18	0	1	0	0
Leach's Storm-petrel	4	27	4	0	29	0	0
Pelagic Cormorant	1	0	0	7	2	0	0
Red-faced Cormorant	10	1	0	1	4	0	0
Mew Gull	0	0	0	4	0	0	0
Glaucous-winged Gull	3	1	0	11	6	0	0
Black-legged Kittiwake	30	125	5	84	12	0	0
Red-legged Kittiwake	0	15	0	0	0	0	0
Common Guillemot	47	24	1	23	39	0	0
Thick-billed Guillemot	10	67	0	2	3	0	0
Cassin's Auklet	0	11	1	21	2	0	0
Parakeet Auklet	2	102	0	99	5	0	0
Crested Auklet	1	8	0	31	0	0	0
Least Auklet	0	13	0	0	0	0	0
Whiskered Auklet	0	22	0	0	0	0	0
Ancient Murrelet	4	14	0	45	5	0	0
Marbled Murrelet	0	0	23	31	0	15	27
Kittlitz's Murrelet	0	0	4	0	0	13	0
Pigeon Guillemot	2	0	4	25	7	0	5
Rhinocerous Auklet	0	0	0	1	0	0	0
Horned Puffin	2	8	10	85	15	0	0
Tufted Puffin	127	131	97	123	11	0	0
Totals	243	573	167	603	153	28	32

AGA, Agattu Island; BUL, Buldir Island; AIK, Aiktak Island; SHU, Shumagin Island; SEM, Semidi Island; KAC, Kachemak Bay; PWS, Prince William Sound.