INGESTION OF PLASTIC PARTICLES BY SOOTY AND SHORT-TAILED SHEARWATERS IN THE NORTH PACIFIC

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ABSTRACT

Differences in rates of ingestion and types of plastic particles ingested by 218 sooty shearwaters, *Puffinus griseus*, and 324 short-tailed shearwaters, *P. tenuirostris*, obtained between 1970 and 1987 were examined. Of these seabirds, 193 sooty shearwaters (88.5%) and 265 short-tailed shearwaters (81.8%) were found to have ingested plastic particles. Significant differences in ingestion rates by year and area of collection were observed for short-tailed shearwaters. However, only one case of significant difference was observed for sooty shearwaters in the northern North Pacific.

After analyzing plastic particles ingested by these two species of seabirds on the basis of shape and color, plastic molding materials ingested by short-tailed shearwaters were found to account for 67.2% of all particles. On the other hand, sooty shearwaters mainly ingested particles of plastic products, with plastic molding materials accounting for only 38.4%. These differences were believed to reflect the differences in food habits of the two species.

INTRODUCTION

The behavior of actively ingesting objects with no nutritional value, called Pica Phenomenon, is commonly observed among birds, including seabirds (Day 1980). Since the second half of the 1960's, plastic production has increased sharply, and plastic has become a major pollutant of the marine environment. However, the impact of plastic ingestion by seabirds has not been made sufficiently clear.

This study analyzes characteristics of plastic particle ingestion by sooty, *Puffinus griseus*, and short-tailed shearwaters, *P. tenuirostris*, based on records of the number, shape, and color of plastic particles found in gastric contents of the two species of shearwaters prevalent in the subarctic North Pacific Ocean at the same time in summer.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

MATERIALS AND METHODS

All of the shearwaters from whose stomachs plastic particles were extracted were individuals killed incidentally in the course of driftnet fishing. Dates and sites of collection and the number of specimens are shown in Figures 1 and 2 and Tables 1 and 2.

A total of 218 sooty shearwaters were examined. They were obtained at 62 driftnet fishing sites between April and October for 7 years during the period between 1975 and 1987 (Fig. 1, Table 1). A total of 324 short-tailed shearwaters were collected at 62 driftnet fishing sites between April and August for 8 years between 1975 and 1987.

Geographically, collection sites of sooty shearwaters were distributed in the North Pacific in an area bounded by lat. 31°-51°N and long. 143°E-143°W (Fig. 1). Those of short-tailed shearwaters were limited to the northwestern part of the Pacific, two sites in Bristol Bay in the Bering Sea, and all of the Aleutian Basin except for five sites around Cape Navarin (Fig. 2).

Shape and color of plastic particles taken from the stomachs of the two species of shearwaters were examined on an individual basis. Colors were classified into 11 types: white, yellow, brown, yellow-brown, blue, green, red, dark blue, dark green, dark red, and black/gray. Shapes and forms were classified into 13 types: cylinder, pill, dome, sphere, box, asymmetrical molding materials, string, cone, fragments of asymmetrical plastic products, vinyl, rubber, unidentifiable particles, and other. Of these, vinyl and rubber, whose shapes and forms are difficult of determine, are dealt with as independent categories because of their high ingestion rates by seabirds. On the basis of these data, frequencies of appearance of plastics were compared and examined by year, month, latitude, and longitude. The cases in which the number of bird individuals were 10 or fewer per item were excluded from statistical testing.

Classification and recognition of plastic particles in this study followed the method of Day (1980).

RESULTS

Interspecies Differences in Plastic Ingestion Rates

Tables 1 and 2 show the location and number of sooty and short-tailed shearwaters with and without plastic particles. The numbers of individuals ingesting plastic particles were 193 (88.5%) for sooty shearwaters (Table 1) and 265 (81.8%) for short-tailed shearwaters (Table 2). The difference in plastic particles ingestion rates between the two species was $\chi^2 = 4.023$ (df = 1, $0.025 < P < 0.05$), indicating slight interspecies differences, although they were not so obvious.

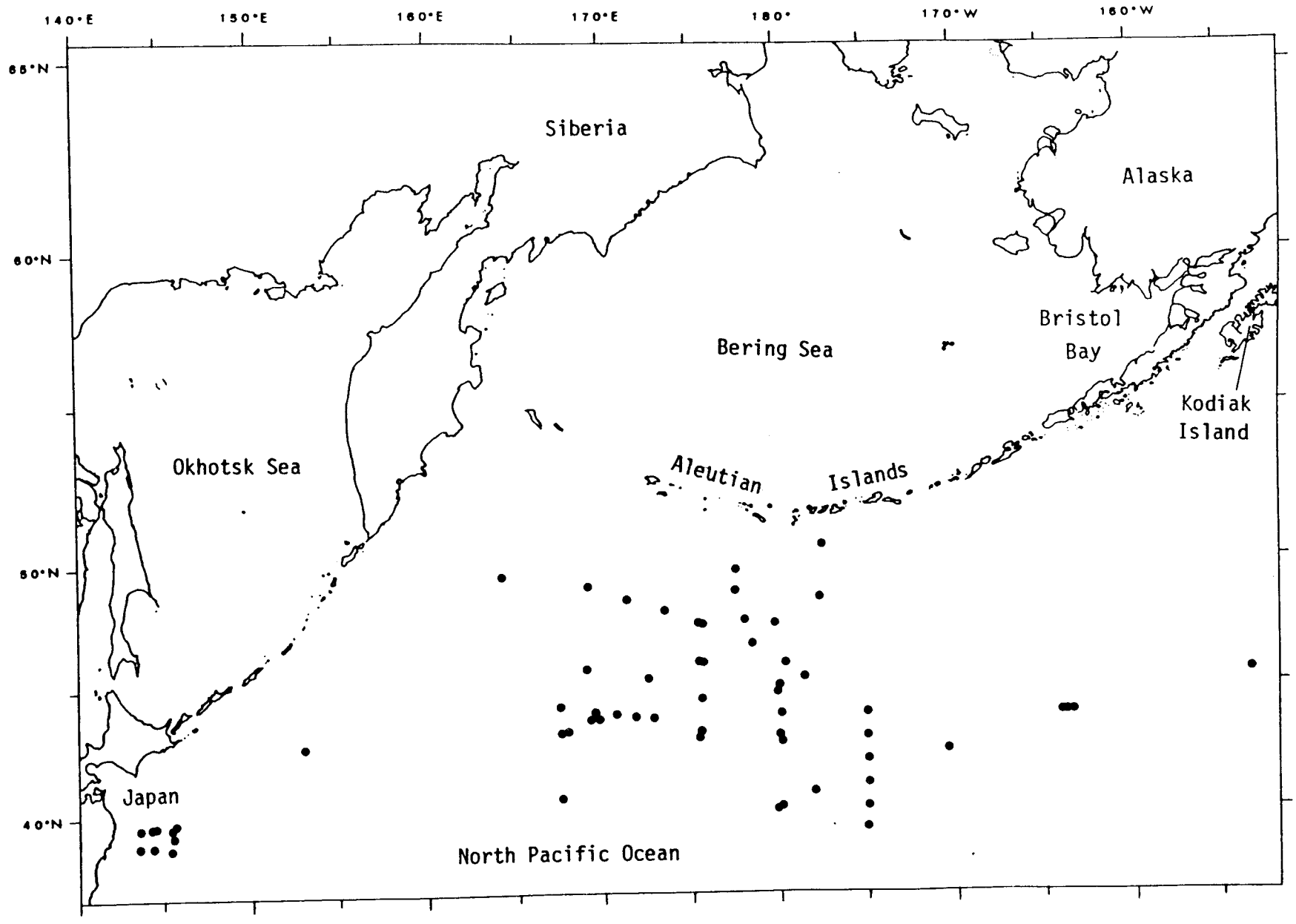

Figure 1.--Stations where sooty shearwaters were sampled.

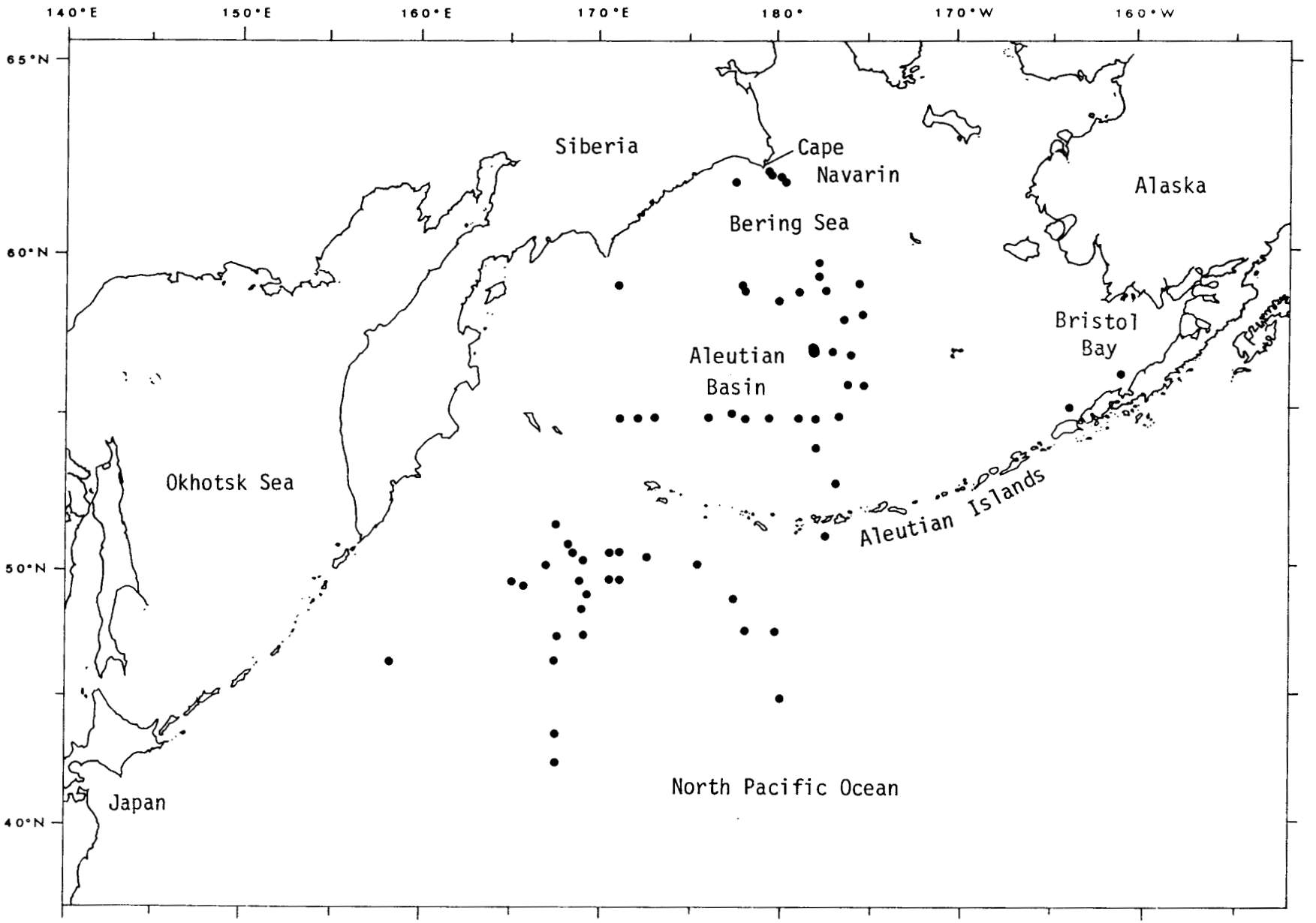

Figure 2.--Stations where short-tailed shearwaters were sampled

Table 1.--Frequency of occurrence of plastics in sooty shearwaters.

Date	Location		With plastic		Without plastic		Total number
	Latitude	Longitude	No.	Frequency (%)	No.	Frequency (%)	
19 Apr. 1975	40°35'N	167°31'E	1	100	0	0	1
13 June 1977	47°38'N	178°01'E	1	50.0	1	50.0	2
14 June 1977	47°37'N	179°44'E	0	0	2	100	2
14 July 1978	44°28'N	167°25'E	8	100	0	0	8
17 July 1978	45°30'N	172°25'E	3	75.0	1	25.0	4
26 July 1978	48°47'N	177°28'E	2	66.7	1	33.3	3
28 July 1978	44°58'N	179°58'E	1	100	0	0	1
2 Aug. 1978	48°31'N	177°34'W	3	75.0	1	25.0	4
2 Aug. 1978	46°00'N	175°33'E	1	100	0	0	1
3 Aug. 1978	47°30'N	175°30'E	2	100	0	0	2
5 Aug. 1978	50°25'N	177°32'W	1	100	0	0	1
8 Aug. 1978	49°29'N	164°12'E	1	100	0	0	1
14 June 1979	45°00'N	180°00'	1	100	0	0	1
19 June 1979	40°06'N	179°59'W	5	100	0	0	5
22 June 1979	39°00'N	175°00'W	1	100	0	0	1
23 June 1979	40°00'N	175°00'W	1	100	0	0	1
24 June 1979	41°00'N	174°59'W	9	100	0	0	9
25 June 1979	42°00'N	175°00'W	6	100	0	0	6
26 June 1979	43°00'N	175°00'W	7	100	0	0	7
27 June 1979	43°59'N	174°59'W	4	100	0	0	4
26 July 1979	49°33'N	177°32'E	0	0	1	100	1
29 July 1979	43°15'N	175°24'E	5	100	0	0	5
30 July 1979	44°32'N	175°29'E	14	77.8	4	22.2	18
31 July 1979	43°58'N	179°58'W	4	100	0	0	4
31 July 1979	46°00'N	175°30'E	3	75.0	1	25.0	4
1 Aug. 1979	43°01'N	180°00'	1	100	0	0	1
1 Aug. 1979	47°30'N	175°29'E	2	100	0	0	2
2 Aug. 1979	48°00'N	173°28'E	9	81.8	2	18.2	11
3 Aug. 1979	48°29'N	171°19'E	2	66.7	1	33.3	3
4 Aug. 1979	48°59'N	169°09'E	4	100	0	0	4
7 Aug. 1979	42°48'N	153°02'E	4	100	0	0	4
5 Sept. 1979	43°54'N	172°40'E	1	100	0	0	1
11 Sept. 1979	46°46'N	178°19'E	1	100	0	0	1
16 Sept. 1979	45°35'N	178°24'W	1	100	0	0	1
2 Oct. 1979	40°40'N	178°03'W	1	100	0	0	1
3 Oct. 1979	40°40'N	178°03'W	6	100	0	0	6
9 Oct. 1979	43°56'N	171°41'E	1	100	0	0	1
10 Oct. 1979	44°02'N	170°37'E	10	90.9	1	9.1	11
11 Oct. 1979	43°53'N	169°22'E	0	0	1	100	1
12 Oct. 1979	44°01'N	169°19'E	1	100	0	0	1
13 Oct. 1979	45°56'N	168°58'E	2	100	0	0	2
14 Oct. 1979	43°51'N	169°38'E	1	100	0	0	1
15 Oct. 1979	43°27'N	167°53'E	5	100	0	0	5
16 Oct. 1979	43°22'N	167°35'E	2	100	0	0	2

Table 1.--Continued.

Date	Location		With plastic		Without plastic		Total number
	Latitude	Longitude	No.	Frequency (%)	No.	Frequency (%)	
13 June 1980	40°02'N	179°58'E	2	66.7	1	33.3	3
16 June 1980	42°58'N	179°59'W	0	0	1	100	1
20 June 1980	46°04'N	179°34'W	1	50.0	1	50.0	2
29 July 1980	43°00'N	175°28'E	4	100	0	0	4
21 Apr. 1986	38°35'N	145°30'E	3	100	0	0	3
27 Apr. 1986	39°30'N	144°30'E	1	50.0	1	50.0	2
29 Apr. 1986	39°37'N	145°38'E	10	90.9	1	9.1	11
30 Apr. 1986	38°32'N	144°23'E	1	100	0	0	1
1 May 1986	38°31'N	143°32'E	1	100	0	0	1
2 May 1986	39°00'N	145°30'E	1	50.0	1	50.0	2
18 July 1986	45°00'N	150°02'W	1	100	0	0	1
5 May 1987	39°30'N	143°29'E	1	100	0	0	1
6 May 1987	39°30'N	144°30'E	2	100	0	0	2
7 May 1987	39°29'N	145°30'E	0	0	1	100	1
18 Aug. 1987	42°28'N	170°33'W	7	100	0	0	7
21 Aug. 1987	43°59'N	163°33'W	6	100	0	0	6
23 Aug. 1987	43°59'N	163°57'W	4	80.0	1	20.0	5
24 Aug. 1987	43°58'N	163°40'W	1	100	0	0	1
3 Sept. 1987	45°40'N	153°24'W	9	100	0	0	9
Total			193	88.5	25	11.5	218

Yearly Differences in Plastic Ingestion Rates

Plastic ingestion rates by year and by species are shown in Tables 3 and 4. Based on comparisons of data for the period (excluding 1975, 1977, and 1980), the plastic ingestion rate of sooty shearwaters was $\chi^2 = 1.034$ (df = 3, $0.5 < P < 0.75$), indicating no significant differences (Table 3). On the other hand, the ingestion rate for short-tailed shearwaters for the entire period excluding 1973 was $\chi^2 = 74.757$ (df = 6, $P < 0.005$), showing significant differences (Table 4). The plastic particle ingestion rate of short-tailed shearwaters for 1970-73 was conspicuously lower than rates for other years, although the number of specimens was small for all the year. Comparing 1970-72 with 1975-79, an extremely significant difference of $\chi^2 = 67.822$ (df = 1, $P < 0.005$) was observed. It was suggested that the increase in plastic particle ingestion by short-tailed shearwaters reflected the increased production of synthetic resins.

Monthly Differences in Plastic Ingestion Rates

Plastic ingestion rates of two species of shearwaters by month were shown in Tables 5 and 6. No significant difference was found in plastic

Table 2.--Frequency of occurrence of plastics in short-tailed shearwaters.

Date	Location		With plastic		Without plastic		Total number
	Latitude	Longitude	No.	Frequency (%)	No.	Frequency (%)	
5 July 1970	55°21'N	164°00'W	13	46.4	15	53.6	28
18 July 1972	56°23'N	161°03'W	27	52.9	24	47.1	51
29 Apr. 1973	49°30'N	170°30'E	2	50.0	2	50.0	4
30 Apr. 1973	50°30'N	170°30'E	2	100	0	0	2
21 Apr. 1975	42°30'N	167°30'E	1	100	0	0	1
22 Apr. 1975	43°33'N	167°30'E	4	100	0	0	4
26 Apr. 1975	46°30'N	167°30'E	2	50.0	2	50.0	4
28 Apr. 1975	47°30'N	167°30'E	1	50.0	1	50.0	2
4 May 1975	51°30'N	167°30'E	1	100	0	0	1
9 May 1975	50°30'N	171°00'E	1	100	0	0	1
11 May 1975	49°30'N	171°00'E	2	66.7	1	33.3	3
16 May 1975	47°30'N	169°01'E	4	100	0	0	4
17 May 1975	48°30'N	169°00'E	3	100	0	0	3
27 May 1975	50°25'N	172°30'E	2	100	0	0	2
10 June 1976	55°00'N	171°00'E	11	100	0	0	11
11 June 1976	55°00'N	172°00'E	12	100	0	0	12
13 June 1976	55°00'N	173°00'E	12	92.3	1	7.7	13
15 June 1976	55°00'N	176°00'E	2	100	0	0	2
16 June 1976	55°10'N	177°17'E	2	66.7	1	33.3	3
17 June 1976	55°00'N	178°00'E	1	100	0	0	1
18 June 1976	55°03'N	179°20'E	1	100	0	0	1
19 June 1976	55°00'N	179°00'W	2	100	0	0	2
20 June 1976	55°00'N	178°00'W	1	100	0	0	1
21 June 1976	55°03'N	176°50'W	1	100	0	0	1
24 June 1976	56°55'N	176°00'W	1	100	0	0	1
26 June 1976	57°00'N	177°00'W	5	100	0	0	5
27 June 1976	57°00'N	178°00'W	2	100	0	0	2
29 June 1976	58°56'N	178°08'E	2	100	0	0	2
30 June 1976	59°00'N	178°00'E	1	100	0	0	1
6 July 1976	59°00'N	171°00'E	2	100	0	0	2
9 July 1976	61°44'N	177°40'E	4	100	0	0	4
11 July 1976	61°54'N	179°59'W	2	100	0	0	2
12 July 1976	61°48'N	179°39'W	1	50.0	1	50.0	2
13 July 1976	62°02'N	179°40'E	2	66.7	1	33.3	3
17 July 1976	62°05'N	179°36'E	2	100	0	0	2
2 June 1977	49°30'N	165°01'E	1	100	0	0	1
3 June 1977	49°22'N	165°43'E	4	100	0	0	4
4 June 1977	50°03'N	166°59'E	4	100	0	0	4
5 June 1977	49°26'N	168°48'E	5	100	0	0	5
7 June 1977	50°16'N	169°00'E	4	100	0	0	4
8 June 1977	50°35'N	168°31'E	3	100	0	0	3
9 June 1977	50°54'N	168°10'E	2	100	0	0	2
11 June 1977	50°08'N	175°21'E	16	94.1	1	5.9	17
13 June 1977	47°38'N	178°01'E	2	100	0	0	2

Table 2.--Continued.

Date	Location		With plastic		Without plastic		Total number
	Latitude	Longitude	No.	Frequency (%)	No.	Frequency (%)	
14 June 1977	47°37'N	179°44'E	3	100	0	0	3
23 June 1977	56°04'N	176°14'W	2	100	0	0	2
25 June 1977	56°00'N	175°14'W	5	100	0	0	5
30 June 1977	57°02'N	178°02'W	1	100	0	0	1
2 July 1977	57°58'N	176°18'W	5	100	0	0	5
4 July 1977	58°10'N	175°37'W	4	100	0	0	4
5 July 1977	59°03'N	175°32'W	1	100	0	0	1
8 July 1977	58°45'N	178°54'W	1	100	0	0	1
9 July 1977	58°30'N	179°58'E	1	100	0	0	1
11 July 1977	59°13'N	177°51'W	4	80.0	1	20.0	5
12 July 1977	58°52'N	177°28'W	2	100	0	0	2
14 June 1978	52°55'N	176°59'W	14	93.3	1	6.7	15
19 June 1978	54°00'N	178°02'W	10	83.3	2	16.7	12
26 July 1978	48°47'N	177°28'E	1	50.0	1	50.0	2
28 July 1978	44°58'N	179°58'E	1	100	0	0	1
14 June 1979	51°02'N	177°31'W	33	91.7	3	8.3	36
4 Aug. 1979	46°24'N	158°18'E	1	50.0	1	50.0	2
4 Aug. 1979	48°59'N	169°19'E	1	100	0	0	1
Total			265	81.8	59	18.2	324

particle ingestion rates for either species. The rate for sooty shearwaters was $\chi^2 = 3.517$ (df = 5, $0.5 < P < 0.75$), and the rate for short-tailed shearwaters was $\chi^2 = 4.060$ (df = 3, $0.25 < P < 0.5$).

More than 85% of the sooty shearwaters were found to have ingested plastic particles in all the months between April and October except May, when there were few specimens collected (Table 5). Slightly lower values were obtained for short-tailed shearwaters in April, although no significant differences were shown in ingestion rates (Table 6). Day (1980) made clear that there are seasonal differences in plastic particle ingestion by short-tailed shearwaters observed near Kodiak Island, and showed that the birds there actively ingest in June and August. In this study, no seasonal trend in plastic particle ingestion was identified, as collection sites of short-tailed shearwaters were scattered in outer waters and collection was not made at regular monthly intervals in areas where this species stays for a long time.

Latitudinal Differences in Plastic Particle Ingestion

Tables 7 and 8 show the plastic particle ingestion rates by 5° latitudinal belts. A significant difference of $\chi^2 = 7.248$ (df = 2,

Table 3.--Frequency of occurrence of plastics in sooty shearwaters by year.

	With plastic		Without plastic		
Year	No.	Frequency (%)	No.	Frequency (%)	Total number
1975	1	100	0	0	1
1977	1	25.0	3	75.0	4
1978	22	88.0	3	12.0	25
1979	114	91.2	11	8.8	125
1980	7	70.0	3	30.0	10
1986	18	85.7	3	14.3	21
1987	30	93.8	2	6.3	32
Total	193	88.5	25	11.5	218

Table 4.--Frequency of occurrence of plastics in short-tailed shearwaters by year.

	With plastic		Without plastic		
Year	No.	Frequency (%)	No.	Frequency (%)	Total number
1970	13	46.4	15	53.6	28
1972	27	52.9	24	47.1	51
1973	4	66.7	2	33.3	6
1975	21	84.0	4	16.0	25
1976	69	94.5	4	5.5	73
1977	70	97.2	2	2.8	72
1978	26	86.7	4	13.3	30
1979	35	89.7	4	10.3	39
Total	265	81.8	59	18.2	324

$0.025 < P < 0.05$) was found for sooty shearwaters as a result of comparisons of the first three belts in Table 7. Further, examination by belt presented a rate of $\chi^2 = 5.750$ (df = 1, $0.01 < P < 0.025$) between lat. 40°-45°N and 45°-50°N, indicating a difference. The plastic ingestion rate for the belt of lat. 40°-45°N was higher at 93.1%, while that for lat. 45°-50°N was slightly lower at 80.3%.

Table 5.--Frequency of occurrence of plastics in sooty shearwaters by month.

Month	With plastic		Without plastic		Total number
	No.	Frequency (%)	No.	Frequency (%)	
April	16	88.9	2	11.1	18
May	5	71.4	2	28.6	7
June	38	86.4	6	13.6	44
July	45	84.9	8	15.1	53
August	48	90.6	5	9.4	53
September	12	100	0	0	12
October	29	93.5	2	6.5	31
Total	193	88.5	25	11.5	218

Table 6.--Frequency of occurrence of plastics in short-tailed shearwaters by year.

Month	With plastic		Without plastic		Total number
	No.	Frequency (%)	No.	Frequency (%)	
April	12	70.6	5	29.4	17
May	13	92.9	1	7.1	14
June	205	81.0	48	19.0	253
July	33	89.2	4	10.8	37
August	2	66.7	1	33.3	3
Total	265	81.8	59	18.2	324

Table 7.--Frequency of occurrence of plastics in sooty shearwaters by 5° latitudinal belts.

Latitudinal range	With plastic		Without plastic		Total number
	No.	Frequency (%)	No.	Frequency (%)	
35°-40°N	21	84.0	4	16.0	25
40°-45°N	122	93.1	9	6.9	131
45°-50°N	49	80.3	12	19.7	61
50°-55°N	1	100	0	0	1
Total	193	88.5	25	11.5	218

Table 8.--Frequency of occurrence of plastics in short-tailed shearwaters by 5° latitudinal belts.

Latitudinal range	With plastic No.	With plastic Frequency (%)	Without plastic No.	Without plastic Frequency (%)	Total number
40°-45°N	6	100	0	0	6
45°-50°N	31	81.6	7	18.4	38
50°-55°N	93	92.1	8	7.9	101
55°-60°N	124	74.7	42	25.3	166
60°-65°N	11	84.6	2	15.4	13
Total	265	81.8	59	18.2	324

As regards short-tailed shearwaters, a significant difference of $\chi^2 = 12.645$ (df = 3, $0.005 < P < 0.01$) was found after comparing the last four belts in Table 8. Further, in the comparison of all areas, there were significant differences, with the rates standing at $\chi^2 = 0.030$ (df = 1, $0.01 < P < 0.05$) between lat. 45°-50°N and 60°-65°N and $\chi^2 = 11.347$ (df = 1, $P < 0.005$) between lat. 50°-55°N and 50°-60°N. This suggests the presence of differences in plastic ingestion rates for short-tailed shearwaters between the North Pacific and the north Bering Sea. Comparing lat. 45°-50°N and 55°-60°N, a rate of $\chi^2 = 8.954$ (df = 1, $P < 0.005$) was obtained. Thus visible differences were found in the plastic ingestion rates between north and south.

These were believed to reflect both differences in distribution, migration, and summer residence of both species of shearwaters in the subarctic North Pacific region, and differences in abundance of plastic particles by area.

Longitudinal Differences in Plastic Ingestion Rates

Tables 9 and 10 show the plastic particle ingestion rates for two species of shearwaters by 5° longitudinal strips.

With regard to sooty shearwaters, no significant difference in ingestion rates was found between strips ($\chi^2 = 13.559$, df = 7, $0.05 < P < 0.1$). On the other hand, a significant difference was observed for short-tailed shearwaters, with $\chi^2 = 69.748$ (df = 4, $P < 0.005$). This significant difference occurred because the plastic ingestion rate for 40 individuals obtained in Bristol Bay in Alaska was only 50.6%, and the collection sites for these seabirds were limited to long. 165°-160°W. It was not evident why the plastic particle ingestion rate for short-tailed shearwaters in this strip was conspicuously low. These 40 short-tailed shearwaters were full of *Thysanoessa raschii*, a species of euphausiids, suggesting that the abundance of plastic particles in the area was low and plastic particles in the stomach and gizzards had moved to the intestine.

Table 9.--Frequency of occurrence of plastics in sooty shearwaters by 5° longitudinal belts.

Longitudinal range	With plastic		Without plastic		Total number
	No.	Frequency (%)	No.	Frequency (%)	
140°-145°E	6	85.7	1	14.3	7
145°-150°E	14	82.4	3	17.6	17
150°-155°E	4	100	0	0	4
155°-160°E	--	--	--	--	--
160°-165°E	1	100	0	0	1
165°-170°E	24	96.0	1	4.0	25
170°-175°E	26	83.9	5	16.1	31
175E°-180°	40	78.4	11	21.6	51
180°-175°W	22	88.0	3	12.0	25
175°-170°W	35	100	0	0	35
170°-165°W	--	--	--	--	--
165°-160°W	11	91.7	1	8.3	12
160°-155°W	--	--	--	--	--
155°-150°W	10	100	0	0	10
Total	193	88.5	25	11.5	218

Table 10.--Frequency of occurrence of plastics in short-tailed shearwaters by 5° longitudinal belts.

Longitudinal range	With plastic		Without plastic		Total number
	No.	Frequency (%)	No.	Frequency (%)	
155°-160°E	1	50.0	1	50.0	2
165°-170°E	40	93.0	3	7.0	43
170°-175°E	46	92.0	4	8.0	50
175°E-180°	41	91.1	4	8.9	45
180°-175°W	97	92.4	8	7.6	105
175°-170°W	--	--	--	--	--
170°-165°W	--	--	--	--	--
165°-160°W	40	50.6	39	49.4	79
Total	265	81.8	59	18.2	324

Number of Shapes and Colors of Plastic Particles Ingested by Two Species of Shearwaters

Tables 11 and 12 show the number of plastic particles classified by shape and color found in the stomachs of 192 sooty shearwaters and 265 short-tailed shearwaters. For both species, 13 shapes and 11 colors were used.

Such shapes as cylinder, pill, dome, sphere, box, and asymmetrical plastic pellets were apparently molding materials for making plastic products. All the other particles were judged to be fragments of plastic products. Ingestion rates of these molding materials were 38.4% for sooty shearwaters (Table 11) and 67.2% for short-tailed shearwaters (Table 12). A significant difference was found in the interspecies comparison of ingestion rates ($\chi^2 = 298.7$, df = 1, $P < 0.005$), showing that sooty shearwaters have a strong tendency to ingest plastic particles with no preference as to shape. On the other hand, short-tailed shearwaters have a strong tendency to ingest molding material particles having consistent shapes. Molding materials were 39.4% of the total weight for sooty shearwaters, whereas for short-tailed shearwaters they were 74.6%. It is interesting to note that a highly significant difference of $\chi^2 = 624.830$ (df = 12, $P < 0.005$) was found after comparing the rates of total number of particles by shape for the two species. However, in terms of order of ingestion by shape, $r_s = 0.9272$ ($n = 13$, $P < 0.01$), indicating similarity between the two species.

As for the color of plastic particles ingested by the two species of seabirds, a highly significant difference ($\chi^2 = 515.588$, df = 10, $P < 0.005$) was found when comparing the numbers of particles by color, but the order of ingestion was similar for the two species ($r_s = 0.8727$, $n = 11$, $P < 0.01$).

The average number and weight of plastic particles ingested per individual were 8.45 particles weighing 134 mg for sooty shearwaters and 8.79 particles weighing 140 mg for short-tailed shearwaters.

DISCUSSION

Day (1980) examined plastics ingested by seabirds in Alaska and discussed the occurrence and characteristics of plastic pollution in them. Much remains unknown about the impact of plastic particle ingestion on seabirds, but Carpenter et al. (1972) found that polychlorinated biphenyls (PCB's) are concentrated on the surface of spherical polystyrene molding materials. Further, as regards great shearwater, *P. gravis*, Ryan et al. (1988) found that a high-level positive interrelation of $r_s = 0.700$ existed between the amount of ingested plastic particles and PCB in adult birds. Day (1980) suggested that hydrocarbon pollutants arising from plastic particle ingestion are not only affecting breeding capability but also causing abnormal behavior.

For short-tailed shearwaters, a species subject to global-scale migration, it is believed that the variation in amounts of body fat in

Table 11.--Number of shapes and colors of plastic ingested by sooty shearwaters.

Shape	Color											Total	Percent
	White	Yellow	Brown	Yellow brown	Blue	Green	Red	Dark blue	Dark green	Dark red	Black/ gray		
Cylinder	41	6	0	70	0	2	1	0	1	0	117	238	14.6
Pill	14	6	29	26	0	0	0	0	1	1	28	105	6.4
Dome	2	0	2	4	0	0	0	0	0	0	1	9	0.6
Sphere	0	0	64	2	0	0	1	0	0	0	8	75	4.6
Box	1	0	2	6	0	0	0	0	0	0	3	12	0.7
Asymmetrical molding material	53	10	21	40	4	40	1	1	3	0	14	187	11.5
String	52	0	5	0	2	4	0	0	1	0	50	114	7.0
Cone	1	0	0	0	0	0	0	0	0	0	1	2	0.1
Asymmetrical plastic products	168	27	28	67	12	42	8	1	6	1	41	401	24.6
Vinyl	90	0	16	0	9	3	0	0	0	0	180	298	18.3
Rubber	0	0	1	0	0	0	0	0	0	0	3	4	0.3
Unidentifiable particles	27	3	3	17	2	10	0	1	2	1	21	87	5.3
Other	17	7	12	36	0	15	1	2	1	0	8	99	6.1
Total	466	59	183	268	29	116	12	5	15	3	475	1,631	
Percent	28.6	3.6	11.2	16.4	1.8	7.1	0.7	0.3	0.9	0.2	29.1		

Table 12.--Number of shapes and colors of plastic ingested by short-tailed shearwaters.

Shape	Color											Total	Percent
	White	Yellow	Brown	Yellow brown	Blue	Green	Red	Dark blue	Dark green	Dark red	Black/ gray		
Cylinder	232	21	225	407	3	7	9	0	0	4	68	976	41.9
Pill	47	1	56	111	0	0	1	0	0	3	14	233	10.0
Dome	3	6	7	18	0	0	0	0	0	0	0	34	1.5
Sphere	4	0	2	11	0	10	0	0	0	0	2	29	1.2
Box	6	0	10	10	0	1	0	0	0	0	1	28	1.2
Asymmetrical molding material	58	13	49	92	12	26	2	0	1	0	12	265	11.4
String	20	0	3	0	6	15	0	0	0	0	4	48	2.1
Cone	1	0	1	1	0	1	0	0	0	0	0	4	0.2
Asymmetrical plastic products	97	16	18	126	10	42	49	3	8	1	10	380	16.3
Vinyl	102	0	5	0	19	5	1	0	0	0	9	141	6.1
Rubber	29	0	1	7	0	0	0	0	0	0	6	43	1.9
Unidentifiable particles	20	0	12	28	4	10	5	2	3	0	12	96	4.1
Other	19	1	4	14	2	9	2	1	0	0	1	53	2.3
Total	638	58	393	825	56	126	69	6	12	8	139	2,330	
Percent	27.4	2.5	16.9	35.4	2.4	5.4	3.0	0.3	0.5	0.3	6.0		

connection with long-distance migration between Northern and Southern Hemispheres causes changes in PCB density in internal organs and tissues (Tanaka et al. 1986). It will be necessary to examine the impact of plastic particle ingestion on seabirds throughout their entire life history.

In this study, it is suggested that differences in plastic particle ingestion by sooty and short-tailed shearwaters are related not only to food habits of the two species but also to their distribution and migration in the subarctic North Pacific region. Sooty shearwaters arrive in the area just south of the Subarctic Boundary at lat. 38°-40°N in early April. These adult birds have just completed breeding in the Southern Hemisphere. Sooty shearwaters migrate northward, keeping pace with northward migration of Pacific saury, *Cololabis saira*, and the Japanese sardine, *Sardinops melanostictus*. In June and July, subadults and hatching year birds arrive also from the Southern Hemisphere to the area just south of the Subarctic Boundary, and then migrate even farther north in the same manner as adult birds. Therefore, as Day and Shaw (1987) showed, life of the sooty shearwaters in the Northern Hemisphere starts in areas where plastic pollution is intense. Further, they range in summer from lat. 41°-42°N to the Aleutian Islands, extending to around lat. 55°N in the Okhotsk Sea. Sooty shearwaters tend to stay in this area longer than short-tailed shearwaters. Especially to be noted is that sooty shearwaters migrate only in a nomadic mode after arriving in the North Pacific Subarctic Zone, and their movement is determined by food distribution. This causes emergence of flocks composed of individuals in different stages of growth. Therefore it may be difficult to determine changes in plastic particle ingestion rates in terms of year, month, latitude, and longitude.

Short-tailed shearwater parent birds, which complete breeding in Tasmania in the Southern Hemisphere, fly toward the Northern Hemisphere in mid- and late March and arrive in the Bering Sea in late April (Shuntov 1961). These short-tailed shearwaters continue northward migration without resting around the Subarctic Boundary. After staying in the summer resident area, they migrate directly southward to the Southern Hemisphere for breeding. They therefore live in a condition immune from the plastic-polluted areas in the North Pacific. Lower plastic particle ingestion rates for 40 short-tailed shearwater individuals collected at Bristol Bay in the Bering Sea were probably due to the fact that they were breeding adult birds. Subadult and hatching year birds arrive in areas around lat. 40°N in mid-April and early June, continuing northward to around lat. 53°N in June-July. The northern limit for adult birds is north of lat. 70°N, while subadult and hatching year birds live in a nomadic mode between lat. 45°-60°N. This means that younger birds are exposed to plastic pollution for a longer period of time, with the likelihood of increased plastic particle ingestion rates over both time and space. The results of this study coincide with this finding.

This study showed that short-tailed shearwaters had a tendency to ingest more plastic molding materials, while sooty shearwaters ingested more plastic product fragments. This reflects the food habits of the two species. Short-tailed shearwaters feed mainly on small, low-class

organisms originating from the biological production process in the surface layers of the ocean, these include juvenile fish, euphausiids, copepods, larval and juvenile squid, and amphipods (Ogi et al. 1980). They are particularly fond of euphausiids, which appear in the surface not as single individuals but usually as patches or swarms. The body size of euphausiids is relatively uniform. Short-tailed shearwaters must catch them quickly and continuously. They probably actively ingest plastic molding materials because these resemble organisms forming patches or swarms.

Sooty shearwaters, on the other hand, feed on Japanese sardines (Ogi unpubl. data) and Pacific sauries (Ogi 1984) in large quantities. They are also known to consume large quantities of larval and juvenile squid and euphausiids (Brown et al. 1981), but regardless, it is obvious that the food niche of sooty shearwaters is higher than that of short-tailed shearwaters. It is assumed, therefore, that they select less specifically plastic molding materials resembling small-sized organisms.

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