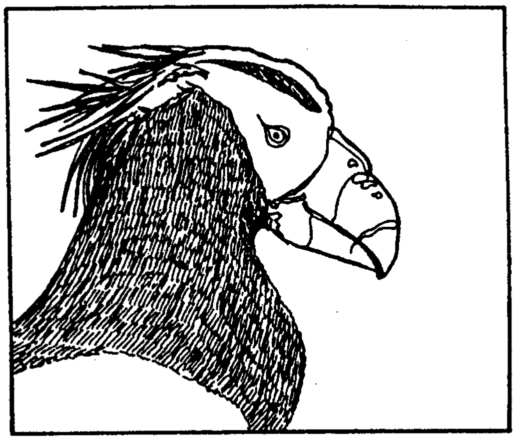
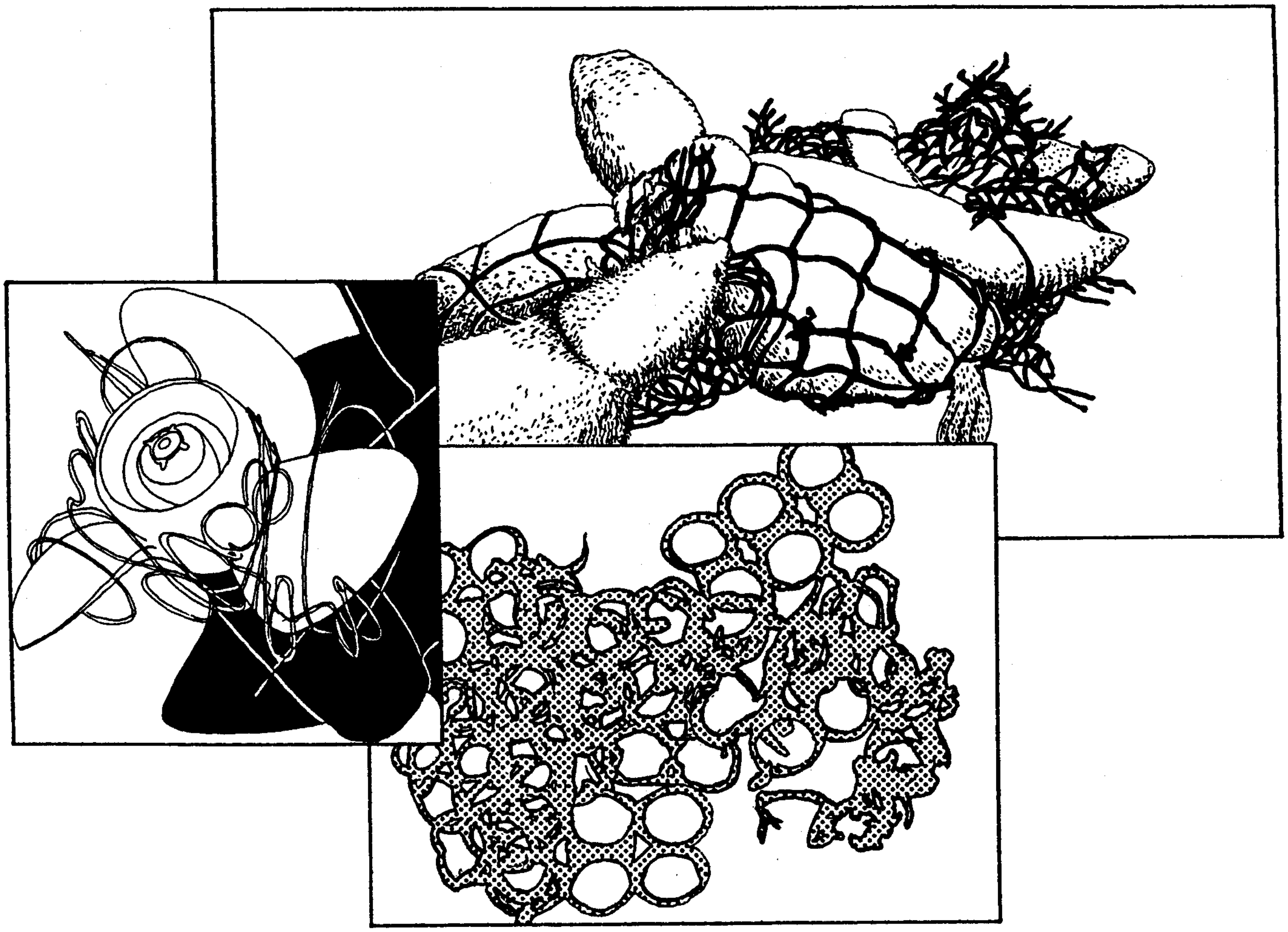
SESSION III



INGESTION BY MARINE LIFE



THE EFFECTS OF INGESTED PLASTIC AND OTHER MARINE DEBRIS ON SEABIRDS

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ABSTRACT

Seabirds ingest plastic particles and other marine debris more frequently than do any other taxon. Despite considerable speculation as to the adverse effects ingested debris has on seabirds, there have been few experiments designed to test these hypotheses. Initial attempts to demonstrate adverse effects were based on correlations between plastic load and bird condition. However, unless the influence of season and breeding status are removed, negative correlations cannot be used to infer an adverse effect from ingesting plastic. Few statistically significant negative correlations have been found among adequately controlled samples, suggesting that the effects of ingestion are either relatively minor or that they frequently are masked by other variables. To avoid ambiguous results, carefully designed experiments are required to assess the severity of the specific adverse effects that have been hypothesized to result from debris ingestion.

Ingested debris may have three specific effects on seabirds: physical damage and blocking of the digestive tract, impairment of foraging efficiency, and the release of toxic chemicals. The severity of these effects depends upon the types of debris ingested and their retention time within seabirds.

At present, severe physical damage and obstruction of the digestive tract is infrequent in seabirds, and probably affects only a small proportion of populations. Virgin (raw) plastic particles were not found to affect the assimilation efficiency of the white-chinned petrel, *Procellaria aequinoctialis*, but seabird feeding may be affected by large plastic loads that reduce the food storage volume of the stomach, causing reduced meal size and, consequently, the ability to accumulate energy reserves. Experiments on free-ranging seabirds are required to confirm this, potentially the most serious consequence of plastic ingestion by seabirds. An estimate of the critical load size is required to determine the proportion of populations likely to be affected by reduced food intake.

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Little is known about the transfer of toxic compounds from ingested plastic to seabirds, but a significant positive correlation between polychlorinated biphenyls and plastic loads in the great shearwater, *Puffinus gravis*, independent of other organochlorines, suggests that the pathway exists. This warrants confirming experimentally, and the toxicity of various additives such as plasticizers and colorants needs to be determined. Other types of debris such as tar balls and paint also are sources of toxic chemicals to seabirds; the incidence of their ingestion needs to be investigated.

Not all birds are equally vulnerable to the effects of ingested debris. Species that seldom regurgitate indigestible stomach contents, and thus accumulate large debris loads, are most prone to adverse effects. Immature petrels apparently are particularly vulnerable because they cannot unload their accumulated debris by feeding chicks.

INTRODUCTION

On a global scale, seabirds ingest plastic particles and other marine debris more frequently than do any other taxon. At least 82 seabird species out of 140 examined have been found to contain ingested plastic and other debris, and the incidence of ingestion exceeds 80% of individuals in several species (e.g., Day et al. 1985; Fry et al. 1987; Ryan 1987b; Sileo, Sievert, Samuel, and Fefer 1990). Most work to date on plastic and other debris ingestion by seabirds has focused on recording the incidence of ingestion in various taxa (e.g., Day et al. 1985; Furness 1985a, 1985b; van Franeker 1985; Ryan 1987b; van Franeker and Bell 1988; Sileo, Sievert, Samuel and Fefer 1990). This has proved valuable in several ways; in addition to providing baseline data on the temporal and spatial increase in debris at sea (e.g., Rothstein 1973; Baltz and Morejohn 1976; Harper and Fowler 1987), it has helped raise public awareness of the marine debris problem, and has provided an insight into the dynamics of ingested plastic in seabird populations (e.g., Day et al. 1985; Ryan 1988b). However, despite being the most important question arising from plastic ingestion, there have been few studies on the severity of adverse effects resulting from plastic ingestion by seabirds (Day et al. 1985; Azzarello and van Vleet 1987; Ryan 1987a). This paper reviews what is known of the impacts of ingested plastic and other debris in seabirds, and identifies key areas for future research.

GENERAL INDICATORS OF ADVERSE EFFECTS

Most attempts to demonstrate adverse effects resulting from plastic and other debris ingestion by seabirds have been based on correlations between debris load and indicators of bird condition (Day et al. 1985; Ryan 1987a). Weak negative correlations between plastic loads and either body mass or the mass of fat deposits have been detected (Day 1980; Conners and Smith 1982; Furness 1985a, 1985b; Ryan 1987a), but in most cases the lack of adequately controlled sampling (for factors such as age, reproductive status, and time of year) seriously hampers the interpretation of results (Ryan 1987a). The poor relationship between indicators of bird condition and plastic load suggest that the effects of ingestion are either relatively minor or that they frequently are masked by other variables.

The main drawback to using correlations to demonstrate adverse effects from plastic ingestion is the inability to separate cause from effect. Ingested plastic may cause poor bird condition, or a bird in poor condition may be more prone to ingest plastic (Conners and Smith 1982), assuming at least some plastic is ingested as a result of "misdirected foraging" (i.e., plastic eaten directly, not incidentally with prey; Ryan 1987b). Similarly, stranded birds may have higher-than-average plastic loads because the ingested plastic has affected the birds' ability to survive adverse weather conditions, or because starving birds are less discriminating and eat more plastic immediately prior to stranding (Bourne and Imber 1982; Ryan 1987b). Day (1980) recorded larger plastic loads in nonbreeding than in the breeding parakeet auklet, *Cyclorrhynchus psittacula*, but this could also be due to age-related foraging differences (Day et al. 1985). The only way to avoid these ambiguous results is to perform experiments designed to test the specific adverse effects postulated to result from debris ingestion.

SPECIFIC EFFECTS OF PLASTIC AND OTHER DEBRIS INGESTION

The specific effects of ingested debris on seabirds can be divided into three categories; physical damage and blocking of the digestive tract, impairment of foraging efficiency, and the release of toxic chemicals (Day et al. 1985; Ryan 1987a). The severity of these different categories of effects varies according to the types of debris ingested and their retention time within seabirds.

Physical Damage and Obstruction of the Digestive Tract

Physical damage and blocking of the digestive tract is the most obvious effect of ingested debris on seabirds, resulting in starvation in extreme cases of gastrointestinal obstruction (e.g., Parslow and Jefferies 1972; Dickerman and Goelet 1987; Fry et al. 1987). However, obstruction of the digestive tract currently is infrequent in seabirds, and probably affects only a small proportion of populations (Ryan and Jackson 1987). Gastrointestinal obstruction by plastic has been suggested to be an important cause of chick mortality among albatross chicks in the North Pacific (Pettit et al. 1981; Fry et al. 1987), but this is not supported by recent observations (Sileo, Sievert, and Samuel 1990) which found only occasional instances of obstruction.

Threads and fibers may result in obstruction more frequently than other debris types because they form dense, intertwined balls in seabird gizzards, blocking the entrance to the intestine (Parslow and Jefferies 1972; Day et al. 1985). However, intestinal obstruction was not found in any of the more than 200 white-chinned petrels, *Procellaria aequinoctialis*, sampled off southern Africa, despite fibers comprising almost half the mass of ingested plastics (Ryan 1987b; Ryan and Jackson 1987).

To test whether ingested debris interferes with digestion, the assimilation efficiency (digestive efficiency) of white-chinned petrels fed large loads (1.4 g, more than twice the maximum load recorded for the species; Ryan 1987b) of virgin polyethylene pellets was compared with that of control birds (Ryan and Jackson 1987). No significant difference was detected, suggesting that at least virgin pellets have little effect on seabird digestive efficiency. However, similar experiments with other types of plastics are warranted.

Cuts and ulcerations of the stomach lining caused by ingesting sharp objects are more frequent than is intestinal obstruction (e.g., Day et al. 1985; Zonfrillo 1985; Fry et al. 1987; Ryan and Jackson 1987). These lesions are seldom likely to be lethal, because seabirds tolerate similar injuries from sharp prey items (Baltz and Morejohn 1976; Bourne and Imber 1982; Fry and Lowenstein 1982). However, lesions may have sublethal effects, reducing disease resistance and thus influencing survival (Fry et al. 1987).

Impaired Foraging Efficiency

Debris accumulated in the stomachs of seabirds has been postulated to impair foraging efficiency as a result of mechanical distension of the stomach. This has two effects: it induces a false feeling of satiation and reduces the food-storage volume of the stomach (Day et al. 1985; Ryan 1988a). Both these mechanisms would tend to reduce foraging efficiency and consequently the ability to accumulate energy reserves essential for reproduction, molting and the survival of adverse weather conditions (Ryan 1988a). However, there have been no direct tests of this effect of ingested debris on seabirds.

Ryan (1988a) showed that chickens fed 10 virgin plastic pellets ate smaller meals and grew more slowly than did control birds, although production (growth per unit food eaten) was not affected by plastic loads (which is to be expected if plastic pellets have little or no influence on digestive efficiency, see above). This provides empirical evidence that plastic loads comparable to those found in similarly-sized seabirds affect foraging efficiency in birds. However, experiments on free-ranging seabirds are required to assess the severity of this problem. One possible test would be to monitor the breeding success of birds whose chicks are fed additional plastic loads.

Given the very large frequency of occurrence of ingested plastic and other debris in some seabird populations, it is essential to estimate the critical load size (relative to bird size) beyond which stomach distension caused by accumulated debris has a deleterious effect. A few small particles are unlikely to have an adverse effect, because many seabirds store quantities of squid beaks and naturally occurring indigestible debris such as pumice in their ventriculi (e.g., Furness 1985a; Ryan 1988b). Fortunately, the distributions of total plastic loads in individual birds are strongly skewed, with most birds having very small plastic loads (Fig. 1), and this probably results in a fairly small proportion of seabird populations being adversely affected by stomach distension caused by ingested debris. Even the species with the greatest occurrence of ingested plastic off southern Africa, the blue petrel, *Halobaena caerulea* (92% of birds containing plastic; Ryan 1987b), has 85% of birds containing plastic loads <25% of the maximum load recorded (Fig. 1).

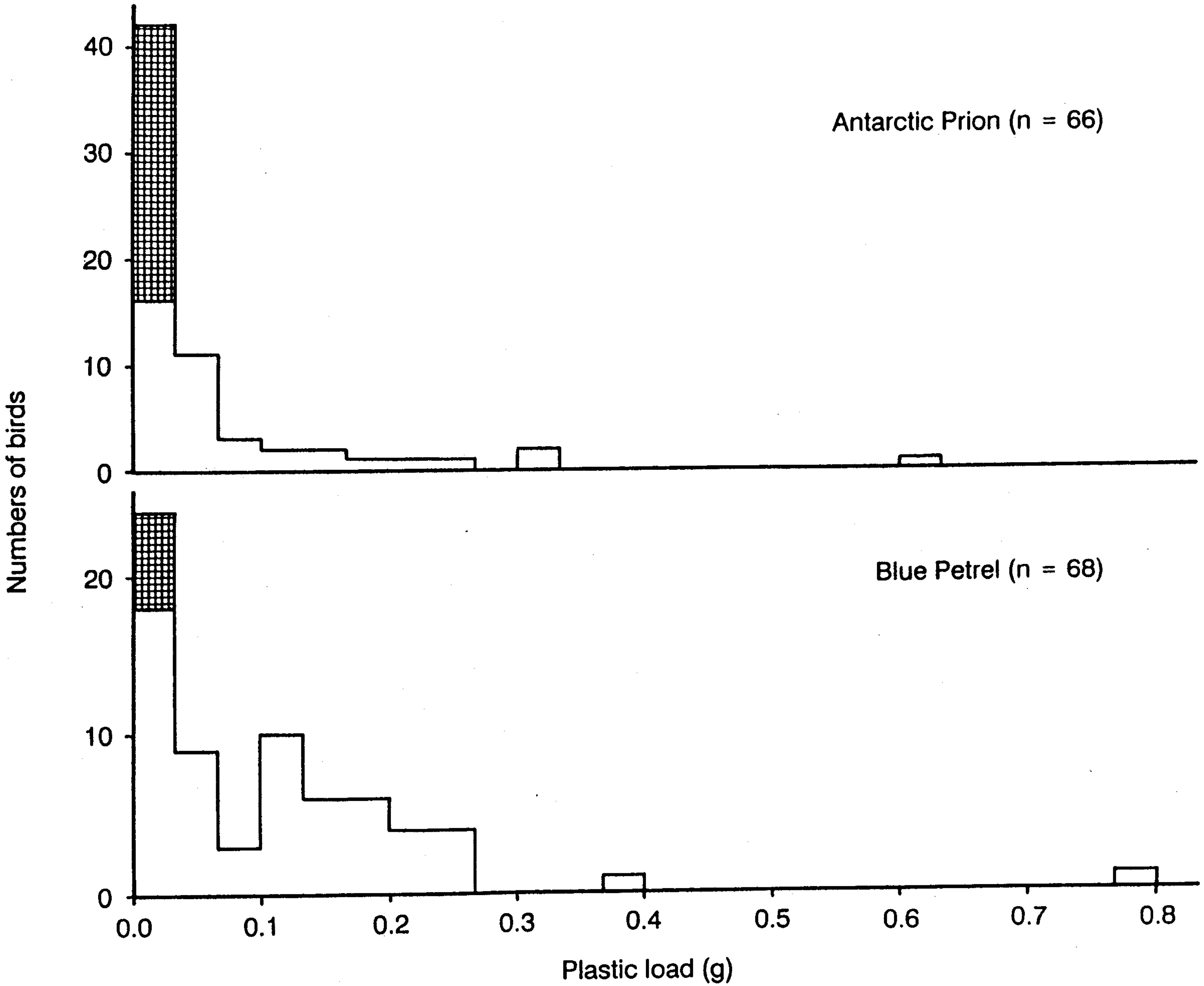

Figure 1.--The total plastic loads (by mass) of individual Antarctic prions, *Pachyptila desolata*, and blue petrels, *Halobaena caerulea*. See Ryan (1987b) for sampling procedures. Hatching depicts birds containing no plastic particles. Note the highly skewed distributions, with relatively few birds having large plastic loads.

Ingested Debris as a Source of Toxic Chemicals

It has been suggested that plastics and other debris ingested by seabirds are a source of toxic chemicals (e.g., Pettit et al. 1981; Bourne and Imber 1982; Day et al. 1985; van Franeker 1985). Plastics contain a variety of toxic additives including colorants, plasticizers, and heat and ultraviolet stabilizers (Gregory 1978; van Franeker 1985; Wirka 1988), and at sea the surface of plastic particles adsorb certain organochlorine compounds, notably polychlorinated biphenyls (PCB's) (Carpenter et al. 1972). The only direct evidence to indicate that seabirds receive toxic chemicals from ingested plastic is the positive correlation found between plastic and PCB loads in female great shearwaters, *Puffinus gravis*, immediately after egg-laying, independent of other organochlorine loads (Ryan et al. 1988). More circumstantial evidence is that both interspecific and intraspecific (geographical) variations in PCB concentrations in eggs of Hawaiian seabirds (Ohlendorf and Harrison 1986) correlate with the prevalence of ingested plastic (Sileo, Sievert, Samuel, and Fefer 1990), although this pattern may result from foraging differences (Ryan et al. 1988). The uptake of toxic compounds from ingested plastics needs to be confirmed by examining seabird tissues for traces of plastic-specific additives (Ryan 1988b). Although the toxicity of plastic additives to seabirds (both singly and synergistically) needs to be determined, it is likely that plastics contribute only a small proportion of the total toxic chemical load borne by seabirds (Bourne 1976; Ohlendorf et al. 1978; Fry et al. 1987; Ryan 1988b).

Other types of debris ingested by seabirds are potentially more serious sources of toxic chemicals. Although not ingested at sea, Laysan albatross, *Diomedea immutabilis*, chicks are killed by lead and perhaps mercury poisoning from ingestion of paint peeling off buildings on Midway (Fry et al. 1987; Sileo, Sievert, and Samuel 1990). This presumably is a localized problem, and can be readily alleviated. However, paint flakes have also been found in the stomach of a pintado petrel, *Daption capense*, collected at sea off southern Africa (Ryan 1990). Birds that frequently scavenge from vessels are likely to ingest some paint, particularly when ship scraping and repainting occurs at sea. Seabirds also ingest tar balls (Brown et al. 1981; van Franeker 1985; Ryan 1986), and petroleum products are known to have adverse toxicological effects on seabirds (e.g., Fry et al. 1986; Koth and Vauk-Hentzelt 1988). More information is required on the incidence of paint and tar ball ingestion by seabirds before an estimate of impacts on seabird populations can be made. Particular attention should be paid to the lifespan of paint and tar balls after ingestion; if they are rapidly broken down in seabirds' stomachs, the incidence of ingestion may be greater than these scattered records indicate.

VULNERABILITY TO THE EFFECTS OF INGESTED DEBRIS

The vulnerability of a given species or age-class of seabirds to the effects of debris ingestion is determined by the type of debris ingested: the sizes and shapes of pieces of debris presumably are important in determining the degree of physical damage to the digestive tract, and different compounds vary as regards toxicity. However, probably the major factor affecting vulnerability is the dynamics of debris ingestion and loss. The magnitude of debris loads in birds are a function of the balance between the rate of ingestion and the rate of loss of ingested debris.

Virtually all debris ingested by seabirds floats in seawater, and is eaten when mistaken for food items, or in association with prey (Day et al. 1985; Ryan 1987b; but see Fry et al. 1987). Inter- and intraspecific comparisons of plastic loads illustrate that the rate of ingestion is related to foraging technique (greatest incidence in surface feeders), foraging niche width (greatest in generalists), and the local density of debris at sea (Ryan 1987b). The rate of loss is related to the maximum size of particles passed through the digestive tract, the rate of erosion within the stomach, and the frequency of regurgitation of indigestible objects. Of these factors, the frequency of regurgitation appears to be the primary determinant of whether or not seabirds accumulate plastic particles and other debris in their stomachs (Ryan 1987b, 1988b).

There are three patterns of regurgitation among seabirds (Fig. 2). Some birds, including giant-petrels, cormorants, skuas, gulls, terns, and albatrosses, frequently regurgitate indigestible stomach contents, preventing any accumulation of ingested plastic or other debris (Ryan 1988b). These birds are unlikely to suffer many serious effects from the ingestion of persistent debris. The main problems are likely to be ulcerations and lesions caused by sharp objects (e.g., glass in gulls feeding at refuse dumps) or the release of toxic chemicals (either those rapidly absorbed from the surface of particles, or those associated with debris that is not easily regurgitated, such as tar balls that adhere to the stomach lining).

Other seabird taxa apparently seldom regurgitate indigestible stomach contents (Furness 1985a, 1985b; Ryan 1987b), and it is these accumulators of ingested debris that are likely to show adverse effects resulting from debris causing stomach distension and from obstruction of the digestive tract. For the majority of procellariiform seabirds (petrels, shearwaters, storm-petrels and diving-petrels), the main avenue for removing ingested debris occurs during the chick-feeding period, when plastic particles accumulated throughout the nonbreeding season are fed to the single chick along with the chick's meals that are stored in the parents' stomachs (Fry et al. 1987; Ryan 1988b). This pattern of annual regurgitation results in an annual cycle in the amount of plastic and other debris in breeding adult petrels (Ryan 1988b, fig. 2). Other taxa that seldom regurgitate indigestible stomach contents, such as auks and phalaropes, but do not feed their chicks food stored in the stomach (e.g., Bedard 1969), apparently lack this avenue for plastic loss. These taxa accumulate ingested plastic and other debris (Conners and Smith 1982; Day et al. 1985; Ryan 1988b), but the dynamics of debris loads are poorly understood, and particle loss may depend almost entirely on erosion and subsequent excretion.

Not all seabirds that accumulate ingested plastic and other debris in their stomachs are equally vulnerable to the effects of ingested debris. A consequence of the intergeneration transfer of ingested debris is that chicks fledge with a debris load approximately equal to 2 years' accumulation by adult birds. This initial loading is exacerbated subsequently by the greater ingestion rate of young, naive birds (Day et al. 1985; Ryan 1988b) and the lack of an effective loss mechanism during the protracted immature period (up to 10 years; Croxall 1984). This suggests that immature petrels have the largest debris loads stored in their stomachs, and are most likely to show adverse effects from debris ingestion.

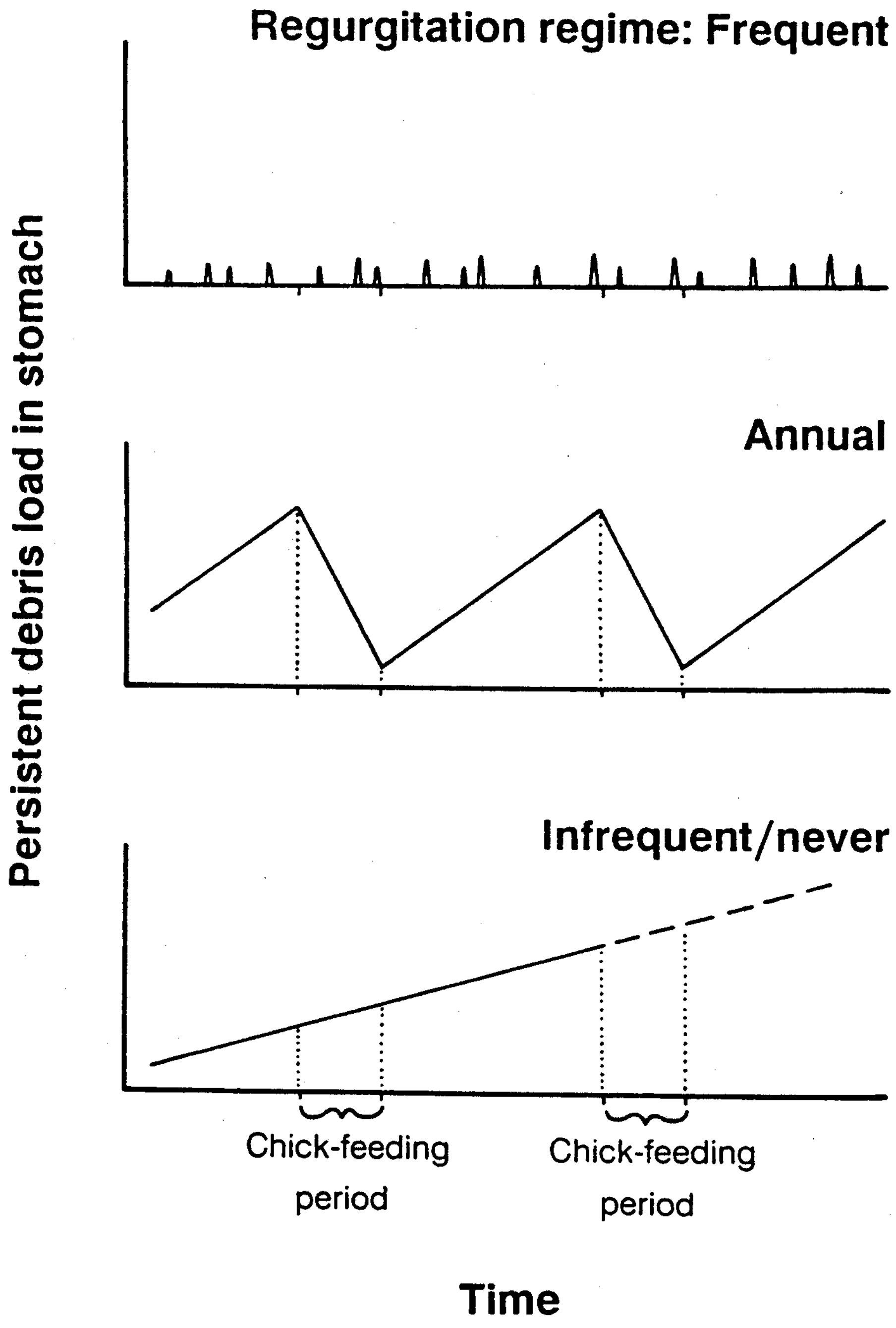

Figure 2.--Diagrammatic representation of the effect of different regurgitation frequencies on the pattern of persistent debris accumulation in seabird stomachs.

FUTURE RESEARCH DIRECTIONS

The preceding review has indicated several areas where both the effects and the dynamics of debris ingestion are poorly understood. The following points summarize key problems that warrant special attention.

1. Verification that stomach distension resulting from accumulated debris causes reduced meal size and thus reduces the foraging efficiency of seabirds.
2. Assuming that 1) holds, an estimate is needed of the critical load size beyond which stomach distension has serious effects.
3. Examination of seabird tissues for plastic-specific additives is required to test whether toxic compounds are assimilated from ingested plastic particles.
4. Assuming that 3) holds, tests of the toxicity of plastics additives to seabirds (both singly and synergistically) are needed.
5. Experimental assessment of the lifespans of different types of debris in seabird stomachs is essential to interpret correctly the dynamics of ingestion.
6. Continued monitoring of debris loads in seabirds is warranted to detect major changes in ingestion patterns or effects, such as an increase in the incidence of obstruction of the digestive tract.

Ingestion by seabirds is a function of the density of debris at sea, and it is only by reducing this density that the incidence of ingestion can be reduced. However, a thorough understanding of both the dynamics and effects of plastic ingestion may enable implementation of measures specifically targeted to lessen the effects on seabird populations.

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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.

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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.

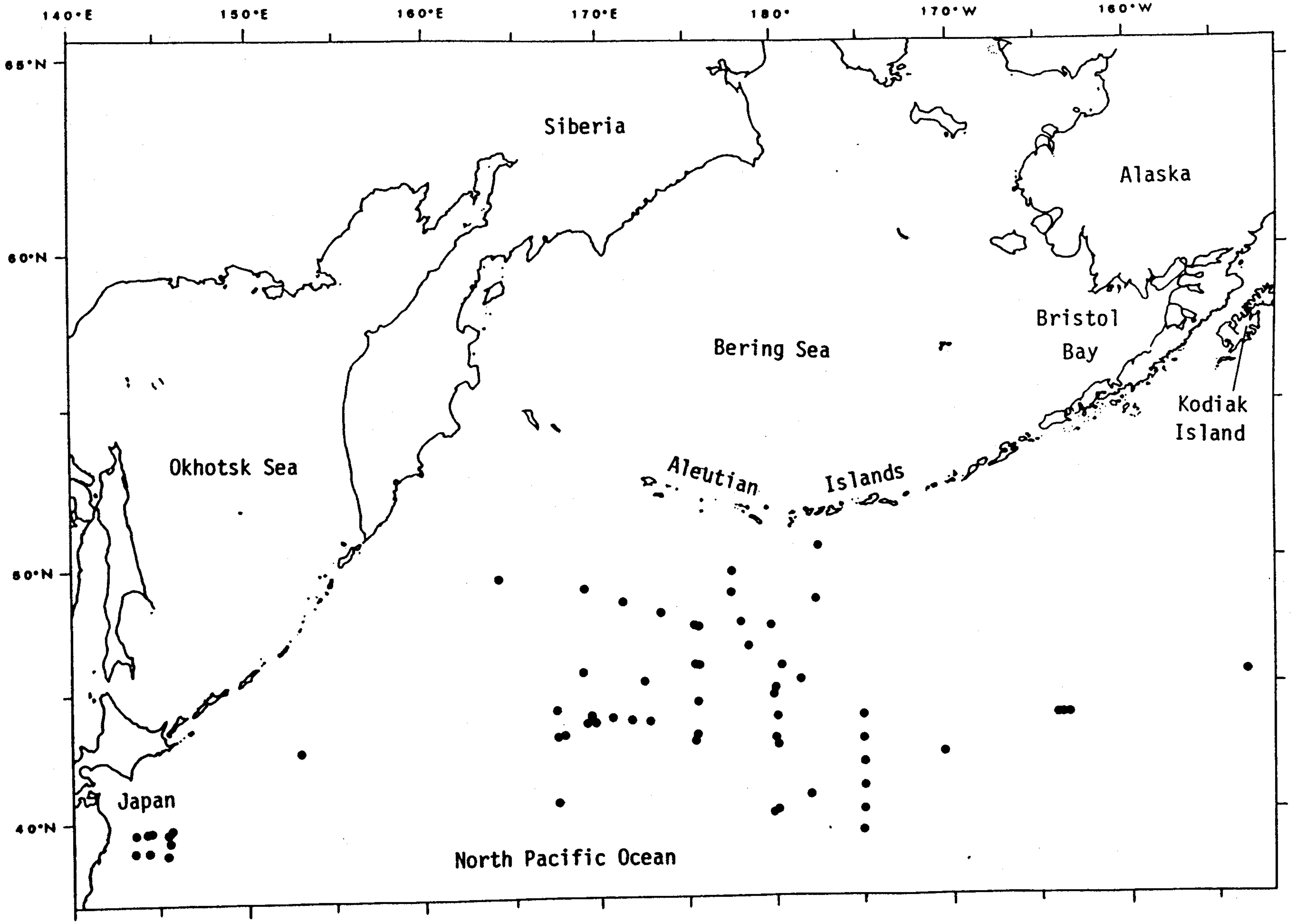

Figure 1.--Stations where sooty shearwaters were sampled.

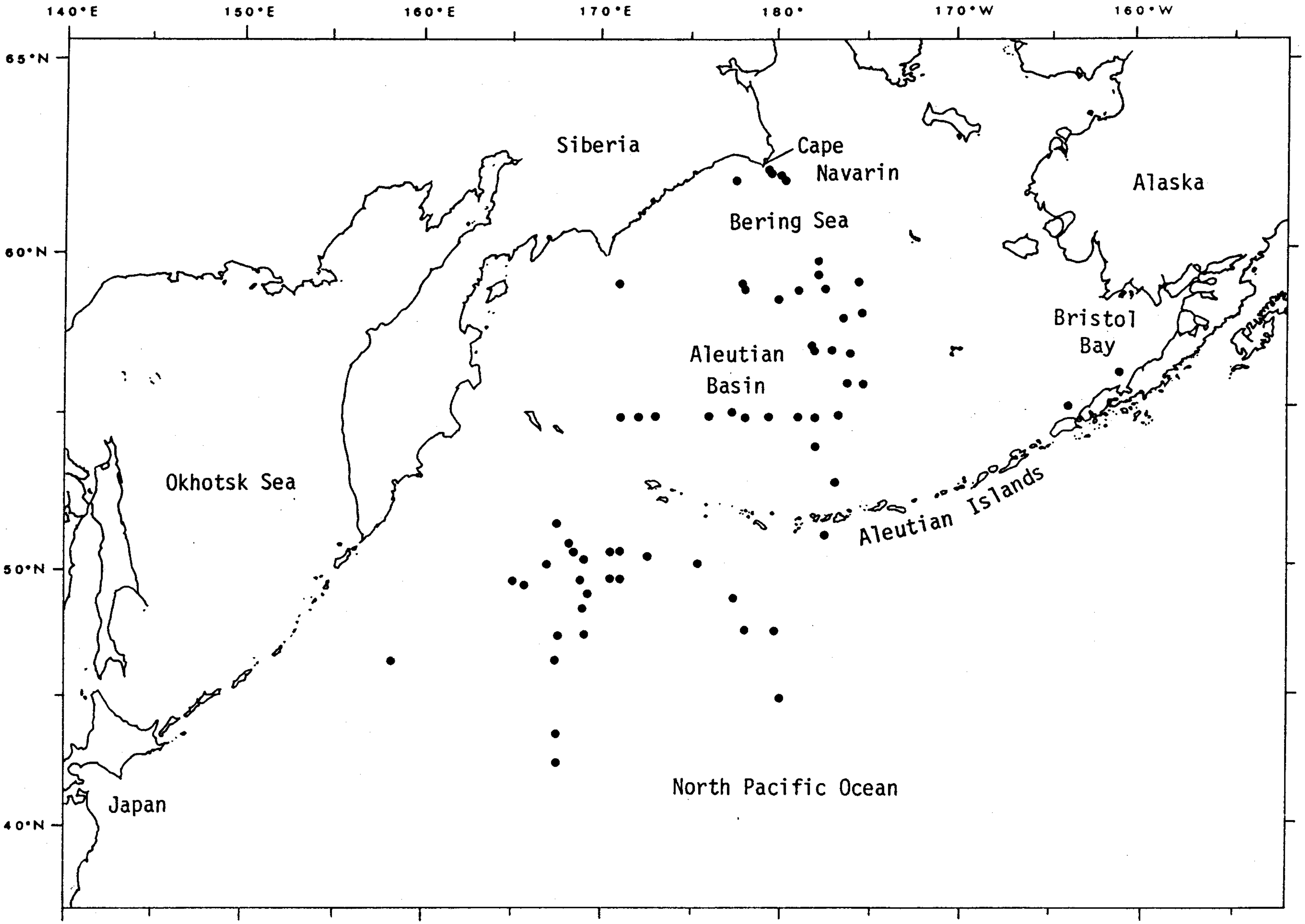

Figure 2.--Stations where short-tailed shearwaters were sampled.

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.

	With plastic		Without plastic		
Month	No.	Frequency (%)	No.	Frequency (%)	Total number
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.

	With plastic		Without plastic		
Month	No.	Frequency (%)	No.	Frequency (%)	Total number
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.

	With plastic		Without plastic		
Latitudinal range	No.	Frequency (%)	No.	Frequency (%)	Total number
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		Without plastic		Total number
	No.	Frequency (%)	No.	Frequency (%)	
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												
	White	Yellow	Brown	Yellow brown	Blue	Green	Red	Dark blue	Dark green	Dark red	Black/ gray	Total	Percent
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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THE INCIDENCE OF PLASTIC IN THE DIETS OF PELAGIC SEABIRDS IN THE EASTERN EQUATORIAL PACIFIC REGION

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ABSTRACT

Between 1984 and 1988, 921 seabirds of 39 species were collected during cruises in the eastern equatorial Pacific. Cruises were centered in the areas of the South Equatorial Current, Equatorial Countercurrent, and the northern Peru Current. The majority of species, mostly gadfly petrels and storm-petrels, had not previously been checked for plastic ingestion. Ingestion was a function of feeding behavior, area of the ocean frequented, and the amount of time passed since birds frequented polluted areas. Species that resided year-round in the equatorial region had eaten little plastic, but those species or populations that had recently come from the area of the southern Peru Current (off Chile), the North Pacific (off Japan or California), or the Tasman Sea/northern New Zealand area, had high plastic loads in their digestive tracts. Results suggest that the residency time of plastic in the digestive tract of petrels is less than 1 year.

INTRODUCTION

On the basis of research and literature reviews by Day (1980; Day et al. 1985), who worked mostly in the northern Pacific, and by Ryan (1987a, 1987b, 1988a, 1988b; Ryan and Jackson 1987) in the southern Atlantic, we now recognize that the ingestion of plastic is a pervasive phenomenon in seabirds. At present, 69 seabird species are known to ingest plastic while feeding at sea, and the incidence of ingestion has risen steadily since the

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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.

1960's. The species most likely to eat plastic are members of the order Procellariiformes. The factors that make these species so susceptible are 1) their feeding behavior (many feed at the surface, are omnivorous, and scavenge frequently); 2) their morphology (petrels have muscular gizzards in which indigestible items become trapped, whereas most other seabirds do not); and 3) their inability (albatrosses are an exception) to eject indigestible matter through the formation of pellets. It is believed that seabirds eat the plastic, usually in the form of industrial pellets and fragments of larger items, either because they mistake it for food or because edible organisms are attached to the plastic.

Geographic variation in the incidence of plastic indicates that seabirds feeding near to industrialized areas are the most likely to eat it. The plastic remains in digestive tracts until it degrades from abrasion and digestive processes or until adult birds feed it to their chicks. Day et al. (1985) estimated that the degradation process for an individual plastic pellet requires on the order of 6 months, but Ryan and Jackson (1987) proposed a time scale of 1 to 2 years. Ryan (1988b) further proposed that it is through feeding plastic to chicks that adults rid themselves of most of the plastic that has accumulated in their gut.

As yet, little work has been done on the incidence of ingestion in seabirds that forage far at sea, i.e., away from pollution sources. (See Ainley et al. 1990, who looked at plastic in the diets of Antarctic seabirds.) In this paper we present information on the incidence of plastic in the diets of seabirds that frequent Pacific equatorial waters. The sampling efforts closest spatially to ours were those by Harrison et al. (1983) and Sileo et al. (1990), who noted plastic in the diets of several species breeding in the Northwestern Hawaiian Islands, in the North Pacific a few thousand kilometers away from our study area. A number of species pass through our study area from various directions, and the incidence of plastic in them offers some clues as to where they are encountering it, and, on the basis of the time passed since visiting polluted areas, whether or not the degradation process and that of off-loading through chick feeding are important processes by which birds relieve themselves of plastic. In addition, several of the species we sampled had not been inspected before for evidence of plastic ingestion.

METHODS

In conjunction with the Equatorial Pacific Ocean Climate Study (EPOCS) of the National Oceanic and Atmospheric Administration (NOAA), we have been characterizing the community structure of open-ocean seabirds using the eastern equatorial Pacific as our study area. Included in our studies are the analyses of prey items. On six cruises (boreal autumn 1984, spring 1986, spring and autumn 1987, and spring and autumn 1988) we collected 921 seabirds of 39 species using a shotgun (Table 1). During each collection, we attempted to obtain up to five individuals of each species present. We noted which individuals had ingested plastic and, except for autumn 1984, counted the number of plastic pieces. Based on necropsy, we determined whether individuals were adults or subadults. The study area is between lat. 15°N and 15°S and long. 170° and 85°W (Fig. 1). Collections were made

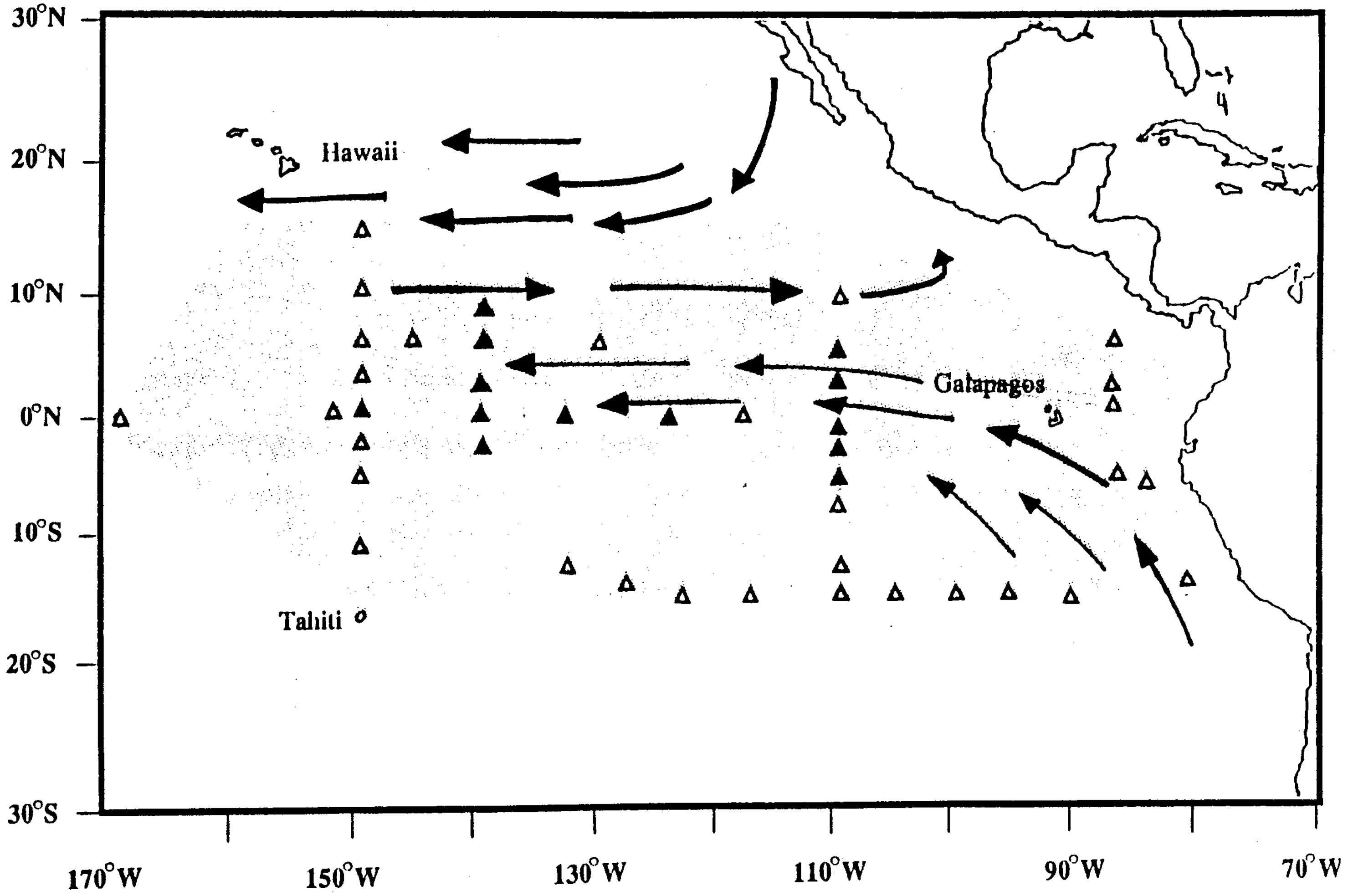

Figure 1.--The study area in the eastern equatorial Pacific (shading), and sites where seabirds were collected (open symbols, on one cruise only; closed symbols, on four or more cruises); arrows indicate ocean currents.

Table 1.--The incidence of plastic in the diets of Pacific equatorial seabirds, and a comparison to other studies.

	Cruise[a]						Total[a]		Other studies	
Species[b]	A84[c]	S86	S87	A87	S88	A88	No.	%	%	Source[d]
				Petrels						
Bulweria bulwerii			0 (7)		0 (10)	0 (2)	19	0	0	3
*Daption capense**			88 (8)				8	88	14-57	1,5
*Pachyptilla belcheri**			83 (6)				6	83	0-57	5
*Procellaria aequinoctialis**			67 (3)				3	67	0-57	1,5
Pterodroma alba			0 (2)			0 (9)	11	0		
Pterodroma arminjoniana			0 (8)			0 (3)	11	0		
*Pterodroma cookii defilippiana**		0 (3)	67 (6)				9	44	10	4
*Pterodroma e. externa**	0 (3)	0 (5)	0 (27)	0 (21)	0 (13)	0 (35)	104	1		
Pterodroma e. cervicalis		100 (1)	0 (2)		0 (7)		10	10		
Pterodroma inexpectata						0 (1)	1	0	0	1
Pterodroma leucoptera	0 (6)	75 (4)	20 (15)	7 (28)	26 (19)	5 (20)	92	15		
*Pterodroma l. longirostris**		100 (1)	50 (6)	33 (6)	50 (10)	100 (2)	25	52		
Pterodroma l. pycrofti					50 (2)		2	50		
Pterodroma neglecta				0 (2)	0 (5)	0 (1)	8	0		
Pterodroma nigripennis		0 (1)	0 (4)	0 (3)	0 (14)	7 (15)	37	3		
Pterodroma rostrata	0 (2)		0 (21)	0 (13)	7 (15)	0 (16)	67	2		
Pterodroma ultima			0 (1)			0 (4)	5	0		
Puffinus bulleri					100 (1)		1	100		
Puffinus griseus			50 (2)		0 (6)	100 (17)	25	72	10-67	2,5
Puffinus nativitatus			50 (2)			0 (1)	3	33	0	3
Puffinus pacificus			0 (15)		0 (7)	8 (13)	35	3	0	2
Puffinus tenuirostris						100 (1)	1	100	47-100	2

Table 1.--Continued.

Species[b]	Cruise[a]						Total[a]		Other studies	
	A84[c]	S86	S87	A87	S88	A88	No.	%	%	Source[d]
Storm-Petrels										
Fregetta grallaria		0 (2)	0 (3)		0 (1)	0 (2)	8	0		
Nesofregetta fuliginosa	0 (2)	0 (1)	0 (1)	0 (3)	0 (1)		8	0		
Oceanites gracilis			0 (2)				2	0		
*Oceanites oceanicus**			0 (8)				8	0	19-75	1,5
Oceanodroma castro			0 (2)		0 (3)	0 (2)	7	0		
*Oceanodroma hornbyi**		0 (1)					1	0		
Oceanodroma leucorhoa	6 (18)	0 (1)	9 (22)	13 (45)	0 (16)	16 (49)	151	11	25	2
*Oceanodroma markhami**		0 (3)	0 (7)		50 (2)		12	8		
Oceanodroma melania			0 (2)				2	0		
Oceanodroma tethys	7 (29)	0 (12)	0 (32)	0 (45)	0 (29)	0 (29)	176	1		
Pelagodroma marina		0 (1)	88 (8)		50 (4)		13	69	50-88	4,5
Other										
Fregata minor			0 (3)				3	0		
Gygis alba			0 (2)				2	0	0	3
Phaethon lepturus			0 (1)				1	0		
Phaethon rubricauda			0 (2)				2	0	0	3
Stercorarius parasiticus					50 (2)		2	0	0-50	2,5
Sterna fuscata			0 (19)	0 (2)	0 (5)	0 (9)	35	0	0	3
Sterna lunata			0 (4)		0 (1)		5	0	0	3

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[a] In each column is given the number of seabirds with plastic followed by the total number inspected.

[b] Species marked by an asterisk (*) were collected at the outer edge of the Peru Current, or breed in that area; see text.

[c] The cruises are designated as A (autumn) or S (spring) by year (e.g., A84 = autumn 1984).

[d] Source: 1, Ainley et al. 1990; 2, Day et al. 1985; 3, Harrison et al. 1983; 4, Imber *in* Day et al. 1985; 5, Ryan 1987b.

while the ship tended permanently moored oceanographic buoys, and thus were mostly from the same sites on each cruise. During spring 1987, however, the ship worked in the outer reaches of the Peru Current off Peru, and birds were collected there as well.

In our analyses, we statistically compared proportions using t-tests following angular transformations (Sokal and Rohlf 1969). Regressions were by Spearman rank correlation (r_s).

RESULTS

We looked for plastic in the stomachs of 39 species, 21 of which had not been previously inspected for this. Highest rates of plastic ingestion were evident in species that frequented the periphery of the study area or moved through it. Most obvious were the nine species that came from the edge of the Peru Current (Table 1). Plastic was found in all but one of these, and in seven the incidence equaled or exceeded 45% of the birds inspected. Incidence was very low in the Juan Fernandez petrel, *Pterodroma e. externa*, which nests on islands off Chile, but in the cape petrel, *Daption capense*, and the narrow-billed prion, *Pachyptila belcheri*, both of which only winter in the Peru Current, incidence exceeded 80%.

Various patterns of ingestion were apparent in several longer distance migrants that either pass through or spend the nonbreeding portion of their annual cycle in the study area. Incidence of plastic was very high in the sooty shearwater, *Puffinus griseus*, a species that migrates across the study area between its breeding islands in the southwestern Pacific (New Zealand) and its wintering grounds in the North Pacific. Incidence was 0% in shearwaters collected on their northward postbreeding journey during spring (n = 6) but was 95% among those individuals flying south in the autumn (n = 19). In the Leach's storm-petrel, *Oceanodroma leucorhoa*, which breeds on islands ringing the eastern and central North Pacific but which otherwise resides in the study area, frequency of plastic relative to its annual cycle was the opposite of the shearwater. Plastic occurred in 11% overall. During autumn, just after the breeding season, 13.4% contained plastic (n = 112) compared to 5.1% during spring (n = 39; t = 3.261, P = 002), after breeders had departed. The same relative seasonal pattern was also evident in the white-winged petrel, *Pterodroma leucoptera*, which breeds in the Tasman Sea but otherwise resides in the study area. Plastic occurred in 15% of these birds overall, with a seasonal breakdown of 5.6% (n = 54) during autumn, just before the nesting period, and 28.9% (n = 38) during spring, just after the nesting period (t = 3.104, P = 0.003). Finally, in the Stejneger's petrel, *Pt. l. longirostris*, which breeds off Chile and then migrates to North Pacific waters off Japan, plastic occurred in the same proportion of birds regardless of season (spring, coming from the nesting grounds off Chile: 52.9%, n = 17; autumn, coming from waters off Japan: 50.0%; n = 8).

Among species that reside in equatorial waters year-round, the incidence of plastic ingestion was very low, and in most it was nil. An instructive comparison is that between the migratory Leach's storm-petrel and the year-round resident wedge-rumped storm-petrel, *O. tethys*, two species that are closely associated in the study area (unpubl. data). In Leach's, ingestion was 11%, but in wedge-rumped storm-petrel, it was only 1% ($t = 4.289$, $P < 0.001$).

Ingestion frequencies for each species were tracked by the number of plastic particles per bird. Individuals of species in which ingestion frequency was high also had large numbers of pieces in their gizzards and vice versa ($r_s = 0.7385$, df = 14, $P < 0.001$; for species where $n > 4$ individuals; Table 2). On the basis of that relationship, we might project for species in which samples were small, that if the one or two individuals inspected had eaten a large number of pieces, a larger sample should show a high proportion of individuals with plastic. For example, we inspected only one short-tailed shearwater, *Pu. tenuirostris*, but it contained 14 pieces of plastic. This species is known to eat large amounts of plastic (Day et al. 1985). The pattern should hold for the Buller's shearwater, *Pu. bulleri*, for which there are no other published data on plastic ingestion (the one individual in our sample contained seven pieces). One exception would be Juan Fernandez petrel, in which only 1 individual of 104 inspected contained plastic: 4 pieces, a relatively large number of pieces in our data set.

We compared the frequency of plastic as a function of age (subadult versus adult) in species where $n > 10$ birds. Compared to adults, a larger proportion of subadults should have ingested plastic (Day et al. 1985; Ryan 1987b). We found, though, that the proportion of breeding adults, nonbreeding adults, subadults, and unknowns that had ingested plastic (5.9, 35.6, 56.4, and 2.0%, respectively) did not differ from the proportion of these age classes in the total samples (7.9, 37.4, 51.8, and 3%, respectively; $\chi^2 = 8.78$, df = 3, $P > 0.05$). Plastic was not more prevalent in subadults.

DISCUSSION

We found little evidence that terns, tropicbirds, or frigatebirds ate plastic, as also noted by Harrison et al. (1983), Day et al. (1985), and Sileo et al. (1990). These species eat active prey, and even if they did ingest plastic, they lack a gizzard where, in Procellariiformes, plastic accumulates.

Among the petrels we sampled, ingestion was mainly a function of feeding behavior, what parts of the Pacific Ocean they frequented, and the amount of time passed since leaving polluted areas. Petrels such as Juan Fernandez petrel or wedge-tailed shearwater, *Pu. pacificus*, which chase airborne flyingfish and squid or prey being driven to the surface by predatory fish (i.e., very active prey), exhibited low rates of plastic ingestion. The majority of other petrel species are less specialized feeders, and they eat prey both live and dead. Some species, such as white-faced storm-petrel, *Pelagodroma marina*, and prions, genus *Pachyptila*, almost always contain very high loads of plastic (Day et al. 1985; Ryan 1987b). It is probable that their prey search-images (including particle size) and their propensity to associate with convergences account for their high susceptibility to plastic as food. On the other hand, some species

Table 2.--The average number of pieces of plastic, and standard error, in the gizzards of seabirds collected in the study area.

Species	Average number of pieces	SE	Number of birds
Daption capense	8.4	2.3	7
Pachyptila belcheri	8.2	3.4	5
Procellaria aequinoctialis	3.5	1.5	2
Pterodroma cooki defillipiana	9.8	4.8	4
Pterodroma e. externa	4		1
Pterodroma e. cervicallis	1		1
Pterodroma leucoptera	2.1	0.8	14
Pterodroma l. longirostris	3.1	0.6	14
Pterodroma l. pycrofti	2		1
Pterodroma nigripennis	1		1
Pterodroma rostrata	1		1
Puffinus bulleri	7		1
Puffinus nativitatus	1		1
Puffinus griseus	10.5	2.7	18
Puffinus tenuirostris	14		1
Puffinus pacificus	1		1
Oceanodroma leucorhoa	3.3	0.4	16
Oceanodroma markhami	2		1
Pelagodroma marina	12.2	3.5	9

that are obligate scavengers, such as Tahiti petrel, *Pt. rostrata*, do not eat much plastic (unpubl. data). They, too, might have a particular search-image.

Temporal and geographic aspects of plastic ingestion were also evident, and these patterns bear on the question of how long plastic is retained in seabird guts. Ryan (1988b) proposed that most of the observed seasonal change in plastic loads is a function of the transfer of plastic from breeding adults to chicks rather than degradation within the digestive tracts of adults. If this is correct, we should have found highest incidence in subadults (who have never bred and thus have never had an opportunity to disgorge plastic), lowest incidence in postbreeding adults, and intermediate values in nonbreeding adults. Our data do not indicate such a pattern. First, in species for which samples were sufficiently large to make comparisons, we found no indication that subadults had more or less plastic than adults. Second, the seasonal patterns we observed suggest that degradation is an important process, and that the time scale is on the order of 6 months or slightly longer. Ryan and Jackson (1987) assumed that degradation rate is constant throughout the time that plastic resides in a seabird digestive tract, and they based their extrapolation on plastic fed to birds and then inspected after retention for only 12 days.

However, plastic subjected constantly to digestive acids and abrasion could degrade at a faster rate as time passes, especially if its surface-to-volume ratio increases. Van Franeker and Bell (1988) found that the mass of plastic particles in cape petrels collected in the Antarctic (where there is no plastic to replenish ingested loads) decreased by 50% over a 3-month period. This rate supports a shorter degradation period than that proposed by Ryan and Jackson (1987; see Day et al. 1985).

We interpret our seasonal and geographic data as follows. Those birds that reside year-round in the region of the South Equatorial Current and the Equatorial Countercurrent (Wyrtki 1967), i.e., our study area, exhibited only incidental ingestion of plastic. We observed little floating debris during our censuses, probably because there are few, if any, large industrial source areas in the central Pacific for plastic and there are no large human population centers except for Oahu. Among petrel species of the Northwestern Hawaiian Islands, which lie in the North Equatorial Current, Harrison et al. (1983) also found only low levels of plastic ingestion. We did not collect any samples in the Panamanian Bight, where we observed much floating plastic and other flotsam on our bird censuses.

Compared to year-round equatorial residents, results were much different for petrels that were either passing through the study area or that came a long way from polluted areas to spend their nonbreeding period there. Those species that had just come from areas where industrial plastic pellets are common, for example, off Japan and California (Day et al. 1985; Pruter 1987), had ingested significant amounts of pellets. Several of these species, including adults and subadults, had higher plastic loads after frequenting polluted waters (where adults bred). This suggests that loss of plastic while in plastic-free waters (because erosion outpaces ingestion) is important. Since the migrations are annual, degradation over a 6- to 12-month period would best fit the patterns. As examples, species or populations that had come from the eastern and central North Pacific had high plastic loads (i.e., Buller's, short-tailed, and sooty shearwater and Leach's storm-petrel). The first three were in the prebreeding portion of the annual cycle, and the last was postbreeding. This inconsistency is contrary to the off-loading through chick-feeding hypothesis. When specimens of these speciews have been inspected in California waters they contain much plastic (Balz and Morejohn 1976). The fact that sooty shearwaters migrating north from New Zealand or Leach's storm-petrel not newly arrived from the north have low plastic loads confirms that it is in the eastern North Pacific that these species are ingesting plastic. Sooty shearwaters, probably of the South American breeding population, also frequent the Peru Current, but we did not collect any. A portion of the New Zealand population of this species migrates to polluted waters off Japan, but the eastern Pacific position of our study area and the flight directions observed indicate that the birds we sampled were moving between New Zealand and the eastern North Pacific.

The incidence of plastic ingestion was also high in species collected at the periphery of the Peru Current or that came to the study area from waters off Chile (i.e., cape petrels, prions, white-chinned petrel, *Procellaria aequinoctialis*, Cook's petrel, *Pt. cooki defilippiana*, and Stejneger's petrel). Cape and white-chinned petrels collected south of South America have much lower plastic loads than those inspected in this study (Ainley et al. 1990). This supports the suggestion that the specimens inspected in this study encountered the plastic in the Peru Current. Stejneger's petrel moves through the study area between Chilean waters and waters off Japan, and thus its plastic could have come from either area. Unlike the other migrants discussed above, these petrels had similar plastic loads regardless of whether they were moving south or north. This supports the suggestion that they were ingesting plastic off Chile and off Japan. Bourne and Clark (1984) noted specific areas of nearshore Chile where significant amounts of plastic had accumulated, but little information is available on a larger geographic scale. One species they observed in association with scum and flotsam lines was *Pa. belcheri*, which in our samples contained much plastic. Species from the northern part of the Peru Current (i.e., several species of the genus *Oceanodroma*) had low plastic loads.

Though not as high as in the birds noted above, the occurrence frequency of plastic was high in white-winged petrel, which as far as we know nests in the subtropical Tasman Sea area. The pattern of low plastic incidence before breeding and after wintering away from polluted areas, but high incidence after breeding, again is contrary to the chick off-loading hypothesis. Along the Equator, one of two individuals of Pycroft's petrel, *Pt. longirostris pycrofti*, which breeds in northern New Zealand, contained plastic, and four of six white-faced storm-petrels, that could also have come from northern New Zealand, contained much plastic. Imber (in Day et al. 1985) reported plastic in 50% of specimens of the latter species from Chatham Island (NZ); Harper and Fowler (1987) found that plastic was prevalent in prions washed ashore in northern New Zealand; van Franeker and Bell (1988) noted significant loads of plastic in Antarctic-breeding species that wintered in the Indian Ocean and Tasman Sea; and Gregory (1978) has noted significant amounts of plastic on most New Zealand beaches, north and south. Thus, it is not surprising that petrels that spend time in New Zealand waters show high plastic ingestion. It is surprising that those sooty shearwaters that were newly arrived to our study area from New Zealand had no plastic, although the large majority of sooty shearwaters nest away from and south of the main islands of New Zealand, and thus away from industrialized areas. This may account for the lower rates of plastic ingestion in these birds.

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PREVALENCE AND CHARACTERISTICS OF PLASTIC INGESTED BY HAWAIIAN SEABIRDS

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ABSTRACT

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

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INTRODUCTION

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

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

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

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

STUDY AREA AND METHODS

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

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

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

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

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

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

RESULTS

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

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

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

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

[a] Volumes were measured in 5 cc increments.

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

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

Table 2.--Continued.

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

Table 2.--Continued.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

DISCUSSION

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

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

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

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

[a] Both = Juveniles plus adults.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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THE INCIDENCE OF PLASTIC IN THE DIETS OF ANTARCTIC SEABIRDS

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ABSTRACT

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

INTRODUCTION

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

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

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

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

METHODS

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

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

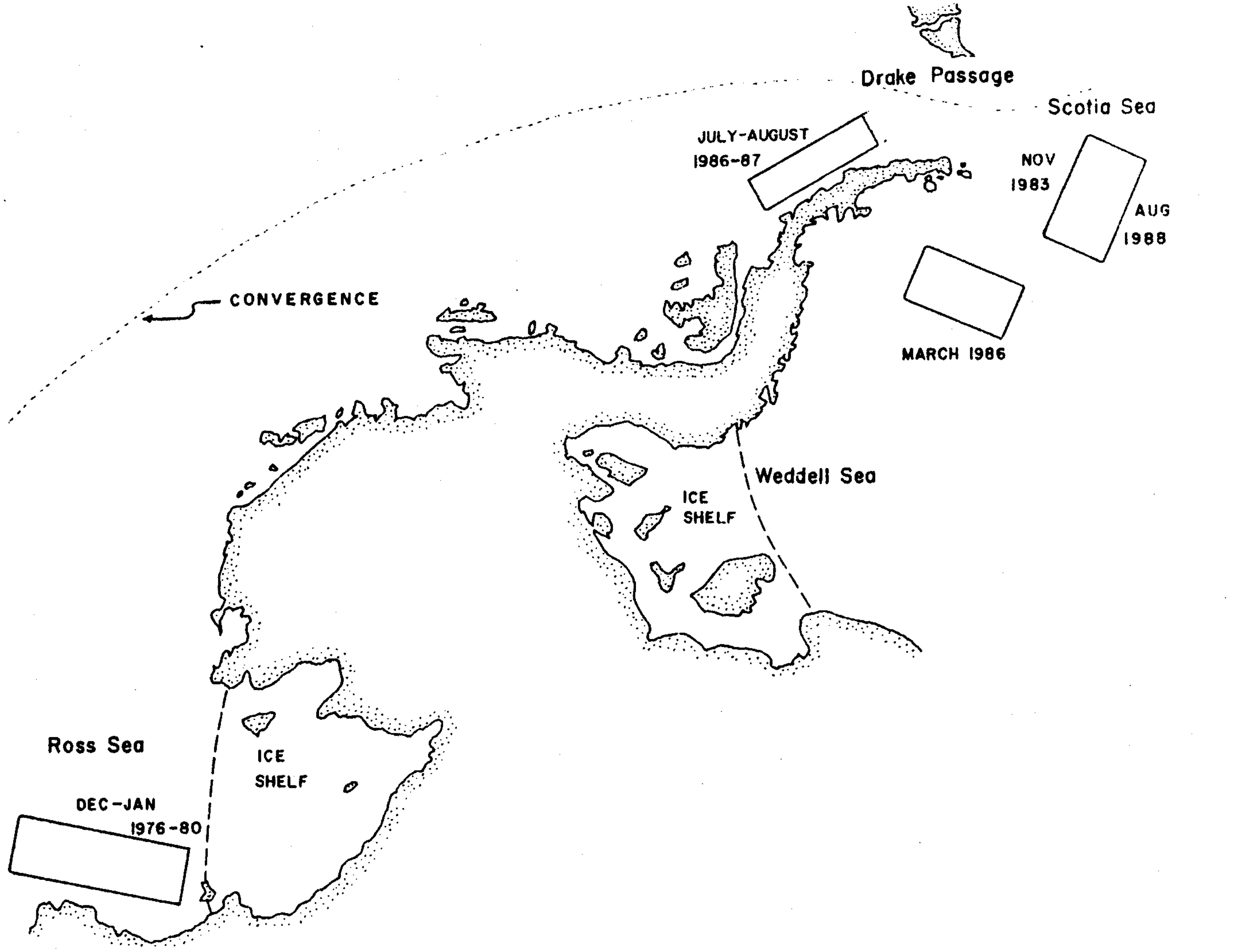

Figure 1.--The areas and time periods in which seabird stomach samples were collected.

RESULTS

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

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

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

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

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

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

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

DISCUSSION

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

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

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

[a] Percentages, with sample size in parenthesis, are given; see Table 1 for procellariiform species.

[b] Approximate northern edge of the pack ice.

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

Our findings also indicate that the greater the distance south from the Antarctic Convergence the less likely birds are to have eaten plastic. More southerly individuals either have weaker ties to waters outside the Antarctic (where densities of plastic are greater, Morris 1980; Pruter 1987), or they have not frequented northern waters recently. If bird residency time in pollution-free waters is a factor, such a pattern might also support the idea that over time there is a gradual attrition of plastic from digestive tracts (Day et al. 1985; Ryan and Jackson 1987; Ryan 1988a; van Franeker and Bell 1988; Ainley et al. 1990). Again, however, the pattern indicates that the density of plastic is very low in Antarctic waters. In other words, once south of the Antarctic Convergence, northern seabirds lose plastic from their digestive tracts faster than they gain it.

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

Assuming that most of the plastic found in the birds inspected in this study was ingested near to or north of the Antarctic Convergence, the frequency of occurrence of plastic in seabirds provides an index of how strongly certain petrel species are tied to Antarctic seas. Considering the dearth of ecological studies in Antarctic waters during the spring and winter, such an index is useful in characterizing the avifauna. Those seabird species with low frequencies of occurrence of plastic should exhibit the weakest tendencies to exit the Antarctic during the winter. These data, therefore, suggest that Antarctic and snow petrels, and a significant proportion of Antarctic fulmars, do not leave the Antarctic during winter, as do so many other "Antarctic" seabirds. In fact, the only plastic found in snow petrels was in individuals that had moved north with the pack ice during winter, and were thus close to the Antarctic Convergence. Along these same lines of reasoning, one might expect a large amount of plastic to accumulate along the Antarctic Convergence, and the higher incidence of plastic in certain species, especially the blue and Kerguelen petrels, may indicate that these species frequent the convergence area more than most other species or that in general they frequent water mass convergences (cf. Bourne and Clark 1984). Census results support these distributional patterns (Ainley and Fraser, unpubl. data).

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PLASTIC DEBRIS INCORPORATED INTO DOUBLE-CRESTED CORMORANT NESTS IN THE GULF OF MAINE

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ABSTRACT

The incorporation of plastic debris into double-crested cormorant, *Phalacrocorax auritus*, nests is reported on three islands in the Gulf of Maine. Of the 497 nests examined during 1987 and 1988, 188 nets (37%) contained plastic debris. Sections of lobster trap line, plastic bags, and pieces of fishing net dominated this debris. The significance of this is discussed and future monitoring of plastics in seabird nests is recommended.

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INGESTION OF PLASTICS BY TELEOST FISHES

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ABSTRACT

Ingestion of plastic debris by many types of animals such as turtles and seabirds is well documented and considered to be a serious threat to their survival. Marine fishes also ingest plastic debris but the amount ingested and the effect of the ingested debris are not well documented. If large amounts of inert plastic debris were ingested, it might affect the fishes' well-being by blocking the digestive tract and reducing the feeding drive. Also, certain types of debris could cause injury to the digestive tract and, depending on its chemical composition, might even have a toxic effect.

In this paper we review the literature to determine what is known about ingestion of plastics by marine fishes and report on our studies on ingestion of plastic particles by larvae and juveniles. There is at present no comprehensive list of fishes known to have ingested plastic. However, observations made incidental to other studies indicate that many species do at least occasionally ingest plastic. Plastics have been found in larvae, juveniles, and adults of both pelagic and demersal species. Currently, there is no clear evidence that juvenile and adult fish have been affected by ingesting plastic. Studies in the field on larval fish have suggested that swallowed plastic spheres could cause intestinal blockage and that polychlorinated biphenyls associated with the surface of the spherules could have toxic effects.

Laboratory experiments to determine the effects of plastic ingestion on larval and juvenile fish have been equivocal. In some cases the fish were observed to take particles, but then reject them.

We have found in our laboratory studies on larvae that five of six species tested--Atlantic menhaden, *Brevoortia tyrannus*, pinfish, *Lagodon rhomboides*, spot, *Leiostomus xanthurus*, striped mullet, *Mugil cephalus*, and two species of flounder, *Paralichthys* spp.--will feed on polystyrene microspheres. However, only spot and mullet were found to have particles in their gut. Particles passed from the gut after a period of time and larvae subsequently fed on brine shrimp larvae.

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.

INTRODUCTION

Plastic debris is a common contaminant of marine waters and is potentially available for ingestion by marine life. Since the report of Carpenter and Smith (1972) on contamination of the Sargasso Sea surface by plastic particles, numerous surveys have reported on finding various types of plastics in waters from around the world (Carpenter et al. 1972; 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; Shaw 1977; Shaw and Mapes 1979; Shiber 1979, 1987; Morris 1980; Dahlberg and Day 1985; Day et al. 1986; Ignell and Dahlberg 1986). A more extensive discussion of the worldwide distribution of plastics in the sea is given by Pruter (1987).

Ingestion of plastic debris by many types of animals (e.g., marine turtles and birds) is, in fact, well documented and in many cases considered to be a serious hazard (Balazs 1985; Day et al. 1985; Azzarello and Van Vleet 1987; Fry et al. 1987; Gramentz 1988). For marine fishes, the ingestion of plastic debris and its subsequent effect is not well documented, but it is assumed that they, like other marine animals, will be unable to distinguish between normal prey and small pieces of plastics. Fish may swallow pieces mistaken for prey or ingest pieces incidental to normal feeding. Once ingested, this debris may block the digestive tract, lessen feeding, and cause ulceration or other physical injury to the stomach lining. It has been suggested that ingested plastics may also release toxic chemicals (Day et al. 1985). Animals weakened by the adverse effects of ingestion may then be more susceptible to disease and predators (Laist 1987).

The objectives of this paper are twofold:

1. to review what is known about the ingestion of plastics by marine fishes, and
2. to present recent field and laboratory data on plastic ingestion in larval and juvenile fishes.

REVIEW OF INGESTION

Larvae and Juveniles

The best documentation for ingestion of plastic by marine fishes is, somewhat surprisingly, for larval and juvenile stages. Carpenter et al. (1972) were the first to report larval fishes feeding on plastic. They reported that of 14 species of fishes collected by oblique plankton tows, 8 species contained plastic in their guts (Table 1). These authors found bacteria and polychlorinated biphenyls (PCB's) present on surfaces of the plastic particles. They speculate that a main effect of ingesting the particles may be intestinal blockage in some of the smaller fish.

Kartar et al. (1973), working in the Severn Estuary, United Kingdom, in 1972-73, found as many as 30 polystyrene particles in the stomachs of

Table 1.--Larval and juvenile fishes collected in the field with plastics in their gut.

Species	Mean size (mm)	Source
Clupeidae		
Brevoortia patronus, gulf menhaden	7.6	Govoni (pers. commun.)
Clupea harengus, Atlantic herring	42	Carpenter et al. 1972
Gadidae		
Ciliata mustela, five-beard rockling	--	Kartar et al. 1976
Pollachius virens, pollock	30	Carpenter et al. 1972
Atherinidae		
Menidia menidia, Atlantic silverside	16	Carpenter et al. 1972
Sciaenidae		
Micropogonias undulatus, Atlantic croaker	6.3	Govoni (pers. commun.)
Labridae		
Tautogolabrus adspersus, tautog	91	Carpenter et al. 1972
Gobiidae		
Govius minutus, sand goby	--	Kartar et al. 1976
Cottidae		
Myoxocephalus aenus, grubby	5.8	Carpenter et al. 1972
Cyclopteridae		
Liparis liparis, striped seasnail	--	Kartar et al. 1976
Pleuronectidae		
Platichthys flesus, flounder	20-50	Kartar et al. 1973
Pseudopleuronectes americanus, winter flounder	4.6	Carpenter et al. 1972

0+ and 1+ year class flounder, *Platichthys flesus* (Table 1). In more recent work in the same estuary, Kartar et al. (1976) found only a few particles in the sediment and none in four common species of fish which previously contained plastics. Flounder contained particles, but the numbers found per fish had declined between 1973 and 1975. They conclude that this type of plastic pollution has almost ceased in this particular estuary.

The gut contents of over 3,000 larval gulf menhaden, *Brevoortia patronus*, spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, from the northern Gulf of Mexico were examined at the Beaufort

Laboratory, National Marine Fisheries Service (NMFS), between 1979 and 1982. Inert material, some of which was plastic, was found in only 20 of the fish (Govoni pers. commun.). Although this research was not designed to look specifically for plastic, it is certain that particles would have been observed had they been present in the gut in amounts found by Carpenter et al. (1972) and Kartar et al. (1973).

Colton et al. (1974) examined over 500 larvae from 22 species collected in water containing high concentrations of plastic spheres and found no plastic particles in the gut contents. They followed up their field work with laboratory experiments to determine if fish held in tanks would feed on these plastic particles and, if so, to measure any resulting effects of ingestion. Five species were tested over a 2-week period (Table 2). Samples were taken at regular intervals to determine if they had fed on the plastic particles. No particles were found in the guts of juveniles or larvae. Tomcod, *Microgadus tomcod*, and striped killifish, *Fundulus majalis*, juveniles were observed to feed on the particles, but they either rejected the particle or it passed through the gut with no harmful effect. These authors concluded that at present levels of abundance, the ingestion of plastics by larvae and juveniles would be minor compared to other pollution problems.

In the laboratory, Hjelmeland et al. (1988) demonstrated that larval Atlantic herring, *Clupea harengus*, would ingest polystyrene spheres (Table 2). The spheres, which had no nutritional value and were not degradable by digestive enzymes, nevertheless induced digestive secretion. However, the response was significantly lower than that obtained when the larvae were fed living prey.

Adults

To our knowledge, there has been no study specifically directed at ingestion of plastics or the effects of ingestion of plastics on adult fish. Most available information has been collected incidental to other studies. This is in spite of the fact that ingestion of plastics is continually cited as a potential hazard to fish (Laist 1986; U.S. Congress 1986).

There are several feeding studies that report finding plastics in the guts of fish incidental to the main objective of the study. A series of papers by Manooch (1973) and various coauthors (Manooch and Hogarth 1983; Manooch and Mason 1983; Manooch et al. 1984, 1985) are a good example. These authors found plastics of various types in five species of pelagic fishes and one anadromous fish (Table 3).

It is assumed that these plastic items were eaten accidentally or that they were mistaken for natural prey. Tuna, *Thunnus* spp., and dolphin, *Coryphaena hippurus*, seem to have the most diverse collection of plastics in their guts (Fig. 1), and this is probably due to both their feeding habits and their association with drift lines where plastic and other debris are known to collect (Manooch and Mason 1983; Manooch et al. 1984). These authors suggested that gut contents of dolphins could serve as indicators of surface water quality.

Table 2.--Results of laboratory experiment using plastic microspheres.

Species	Life stage	Results
Clupeidae		
Clupea harengus, Atlantic herring	Larval	Ingested pellets.[a]
Gadidae		
Melangrammus aeglefinus, haddock	Larval	Ingestion negative no plastic in gut.[b]
Microgadus tomcod, tomcod	Juvenile	Ingested plastic but rejected or passed it.[b]
Cyprinodontidae		
Fundulus majalis, striped killifish	Juvenile	Ingested plastic but rejected or passed it.[b]
Gasterosteidae		
Gasterosteus aculeatus, threespine stickleback	Juvenile	Ingestion negative no plastic in gut.[b]
Pleuronectidae		
Pseudopleuronectes americanus, winter flounder	Larval and juvenile	Ingestion negative no plastic in gut.[b]

[a] Hjelmeland et al. 1988.
[b] Colton et al. 1974.

There is some observational evidence (Manooch pers. commun.) that plastics may remain in the guts of fish for long periods of time and be encysted in the stomach or gut lining. The long-term effect of this is not known but could hardly be beneficial to the fish.

Plastic cups were reported from the stomachs of cod, *Gadus morphua*, whiting, *Micromesistius poutassou*, and pollock, *Pollachius virens*, off the coast of the United Kingdom (Anonymous 1975). One pollock was found to contain four cups. Apparently the source of the cups was from the cross-channel ferries. The author concludes that the fish will eventually die since the cups are indigestible, but no evidence is presented for this statement.

CURRENT NATIONAL MARINE FISHERIES SERVICE RESEARCH

Previous studies have shown a high degree of patchiness in plastic distribution in the sea. This patchiness is attributable to currents, winds, and differential inputs (Shaw and Mapes 1979). In recent years scientists have focused increasingly on oceanographic fronts for numerous

Table 3.--Plastic found in adult marine fishes.

Species	Type of plastic	Source
Gadidae		
Gadus morphua, Atlantic cod	Plastic cups	Anonymous 1975.
Micromesistius poutassou, blue (pout) whiting	Plastic cups	Anonymous 1975.
Pollachius virens, pollock	Plastic cups	Anonymous 1975.
Percichthyidae		
Morone americana, white perch	Plastic pellets	Carpenter et al. 1972.
Morone saxatilis, striped bass	Plastic cigar holder	Manooch 1973.
Coryphaenidae		
Coryphaena hippurus, dolphin	Nylon rope, bottle, packaging, colored fragments	Manooch et al. 1984.
Scombridae		
Acanthocybium solanderi, wahoo	Fragment of black plastic sheeting	Manooch and Hogarth 1983.
Euthynnus alletteratus, little tunny	Packaging	Manooch et al. 1985.
Thunnus albacares, blackfin tuna	Plastic bag, colored fragments	Manooch and Mason 1983.
Thunnus atlanticus, yellowfin tuna	Colored fragments	Manooch and Mason 1983.
Triglidae		
Prionotus evolans, striped searobin	Plastic pellets	Carpenter et al. 1972.

reasons; among them are the observations that fishes (as well as sea turtles, marine mammals, and seabirds) are often aggregated about these zones along with the flotsam and other debris.

Both adult and larval fishes, including species of economic importance, have been observed in aggregations along frontal zones, but there has been little work describing the possible effects of associated debris.

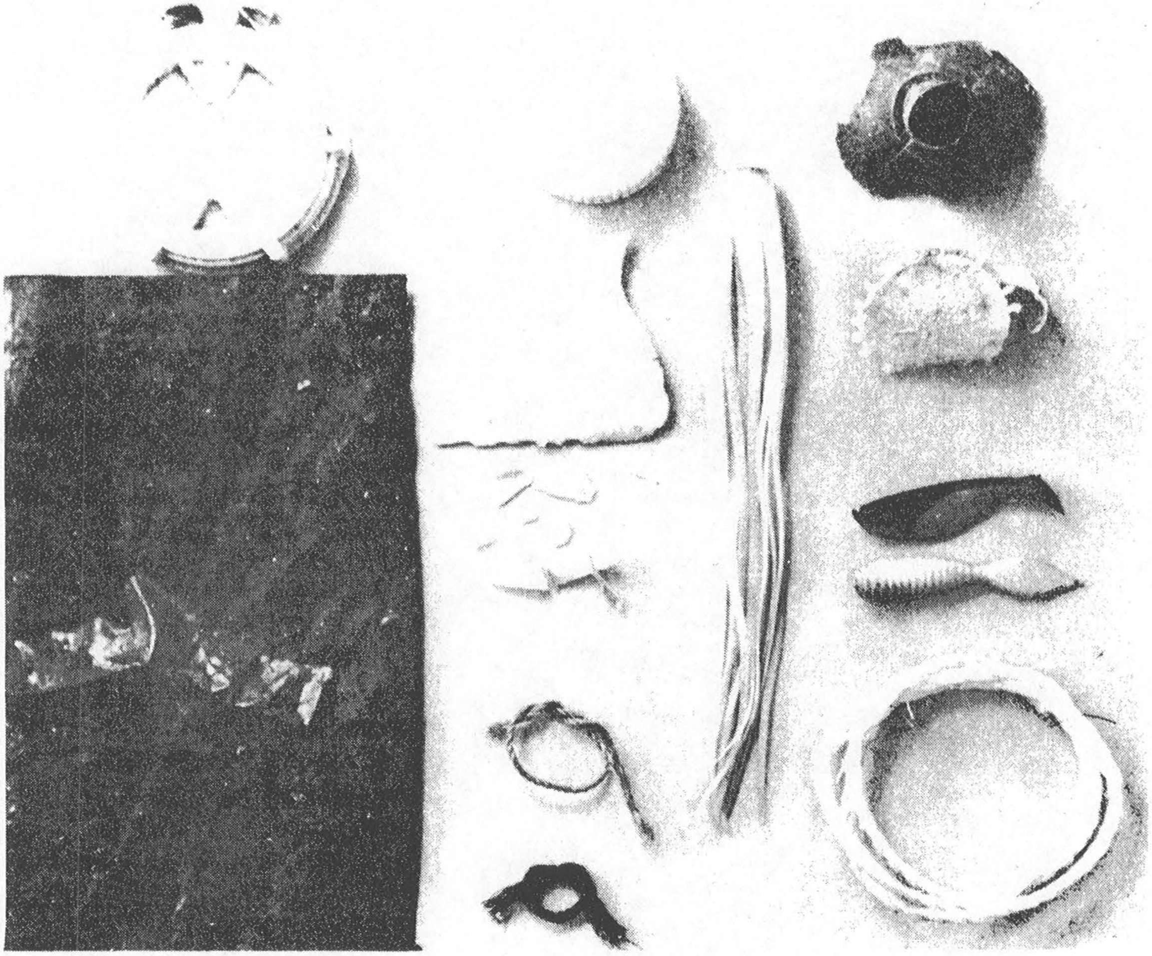

Figure 1.--Material removed from stomachs of adult dolphin and tuna by Manooch (see Table 3).

The objectives of the ongoing studies are to:

- continue to characterize and quantify microdebris particles in coastal waters in and around fronts, and
- determine if larval and early juvenile fish will ingest plastic particles under laboratory conditions, and if so, to assess the effect of the particles on the fish (e.g., prevention of feeding).

Distribution and Characterization

Although plastic pellets have been reported in average densities of 1,000 to 4,000 km^2 on the surfaces of the North Atlantic, South Atlantic, and Pacific Oceans (Carpenter et al. 1972; Carpenter and Smith 1972; Colton et al. 1974; Morris and Hamilton 1974; Wong et al. 1974; Gregory

1977; Shiber 1979; Day 1980), their distribution and abundance in the Gulf of Mexico is not well documented. We examined samples from three sites in the northern Gulf of Mexico (Cape San Blas, Florida, the plume of the Mississippi River, and Galveston, Texas) collected on a cruise in 1981. At each of these sites, sample tows were made with a multiple opening and closing net and environmental sensing system (MOCNESS) (Wiebe et al. 1976) at the surface, mid-depth, and bottom of the water column. Water samples from these stations were examined for the presence of small plastic particles such as those found by Carpenter et al. (1972) and Colton et al. (1974) (Fig. 2).

Of the 51 samples examined from the December collection, 27 were from the surface and the remaining 24 were from the middle of the water column. The greatest number of particles were found in the upper 7 m of the water column in the vicinity of Southwest Pass (Tester et al. 1987) (Table 4). This may be a reflection of both the high utilization of this area by shipping and industry and the outflow of the Mississippi River.

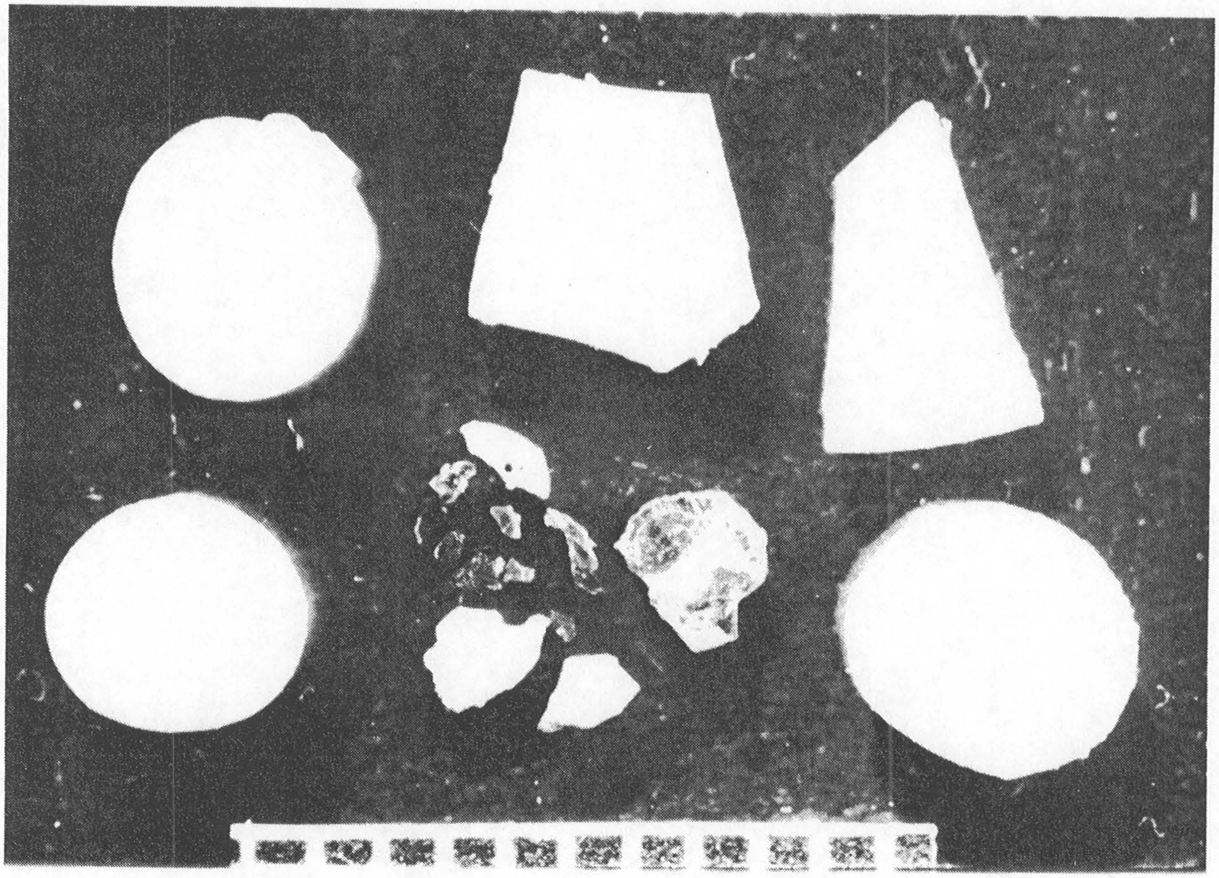

Figure 2.--Plastic material removed from samples collected at three sites in the northern Gulf of Mexico. Scale at bottom in millimeter.

Feeding Experiments

During 1988 and 1989, we conducted a series of feeding experiments (Settle et al. in prep.) to determine 1) if early life stages of marine fishes would ingest plastic particles in the laboratory, and 2) what effects ingestion might have. A similar, but inconclusive, investigation was attempted by Colton et al. (1974). We used polystyrene microspheres sorted to appropriate food particle size (100-500 μm). All plastic particles were "aged" in algae-rich seawater for at least 2 weeks. Six species of fish were used: Atlantic menhaden, *Brevoortia tyrannus*, pinfish, *Lagodon rhomboides*, spot, *Leiostomus xanthurus*, striped mullet, *Mugil cephalus*, southern flounder, *Paralichthys lethostigma*, and flounder, *Paralichthys* spp. Menhaden were laboratory spawned; all others were collected from the Newport River estuary, North Carolina. Fish were maintained in 5-L tanks and starved for 48 h prior to the introduction of plastic particles. Particle concentrations ranged from 200 to 1,000 L^{-1}.

All species except *Paralichthys* spp. were observed ingesting plastics, but rejection was also commonly observed (Table 5). Experiments lasted from 10 min to 19 h. At the end of the experimental period, fish were killed and their guts examined. Four of the six species had plastic particles in their alimentary tract. Thus, even though some plastics were rejected, some were fully ingested as well. Mullet and spot ingested the greatest quantity of particles, with some containing over 30 particles (maximum 45) (Fig. 3).

These results showed conclusively that these species would ingest aged plastic particles when deprived of food for 48 h, and in some cases retain particles in the gut for several hours.

Based on these results, a second series of experiments were conducted on mullet (21-25 mm SL) and spot (16-23 mm) to investigate if plastic ingestion would cause mortality. As in the previous work, the fish were starved for 2 days prior to the start of the experiment. The fish were initially fed plastic spheres (1,000 L^{-1}), with brine shrimp, *Artemia* spp., added after 10 min. These experiments were conducted for 10 days during which brine shrimp were added on a daily basis. Plastic spheres were left in the tank throughout the experiment.

Both spot and mullet were observed to ingest plastic particles when they were first added. They also were observed to reject some of the particles. Spot took plastic from the water column and off the bottom while mullet fed only from the water column. When brine shrimp were present, both species appeared to select them over the plastic and usually rejected plastic if ingested. There was no experimental mortality observed during the 10-day period and the fish were observed defecating. Therefore, it does not appear that the plastic blocked the gut.

At the end of the experiment the fish were sacrificed, measured, and examined for plastic in their guts. Six of twenty-four spot contained plastic. It is likely that spot ingested particles throughout the experiment, either those resuspended in the water each day or those on the

Table 4.--Small plastic particles in the Gulf of Mexico. Samples were taken from the surface to near bottom. Stations A1, B1, and D1 were only in 18.3 m (10 fathoms) of water, and A2, B2, and D1 were in 91.4 m (50 fathoms) of water. Plastics were collected only at the depths indicated.

Region	Station	Sample depth (m)	Particles per 100 m^3
Mississippi River	A1	1	26
		2	67
		5	31
		5	19
		6	5
		7	60
	A2	1	2
		2	1
Cape San Blas, Florida	B1	1	5
		3	1
		8	2
	B2	1	1
		30	1
		31	2
Galveston, Texas	D1	1	4
		5	9
	D2	1	1

bottom. Particles were well distributed throughout the alimentary tract, giving the impression that they were being effectively passed (Fig. 4). None of 20 mullet contained pellets at the end of the 10 days although they were observed to feed on them during the course of the experiment.

DISCUSSION AND CONCLUSIONS

There is now ample evidence to state that marine fish of many species will eat plastic debris. Larval and juvenile fishes have been collected in the field with plastic fragments and raw plastic pellets in their guts. Adult fishes have been found with a wide variety of material in their guts ranging from unidentified fragments to whole cups and bottles. There is almost no evidence, however, to determine the magnitude of the problem or to determine if ingestion is an important cause of mortality in fish.

Table 5.--Results of aged polystyrene microsphere feeding experiments (Settle et al. in prep). (+ indicates plastics were ingested, - indicates plastics were not ingested.)

Species	Size range (mm)	Particle size (m)	Ingestion	Percent with plastic in gut
Clupeidae				
Brevoortia tyrannus, Atlantic menhaden	9-29	100-500	+	0
Sparidae				
Lagodon rhomboides, pinfish	11-14	350-500	+	15
Sciaenidae				
Leiostomus xanthurus, spot	19-25	350-500	+	15
Mugilidae				
Mugil cephalus, striped mullet	18-25	210-350	+	75
Bothidae				
Paralichthys lethostigma, southern flounder	13-15	210-250	+	6
Paralichthys spp., flounder	10-15	350-500	-	0

It has been suggested that ingestion of plastic production pellets by larval and juvenile fishes may cause blockage of the digestive tract and prevent normal feeding. There is no experimental evidence that we know of to support this. In those laboratory experiments where larvae have fed on pellets (Colton et al. 1974; Hjelmeland et al. 1988; Settle et al. in prep.), the pellets have either been rejected or passed through the gut. In our experiments the larvae subsequently fed on brine shrimp nauplii and appeared healthy. Had the larvae been fed angular particles or particles containing toxic chemicals, the results may have been different. In the sea, dead larvae would seldom if ever be collected because of rapid decomposition.

Food habit studies confirm that large fish also eat plastic material, but the frequency and quantity of material eaten is not well documented. Ingestion of large pieces of plastic by fish may cause a health problem. Many predatory fish have large mouths and can swallow large pieces of plastic. They cannot digest the plastic, however, and it may prove to be too large to pass from the stomach into the gut and out the anus. If the fish cannot regurgitate the piece, it may block the intestine or cause ulceration.

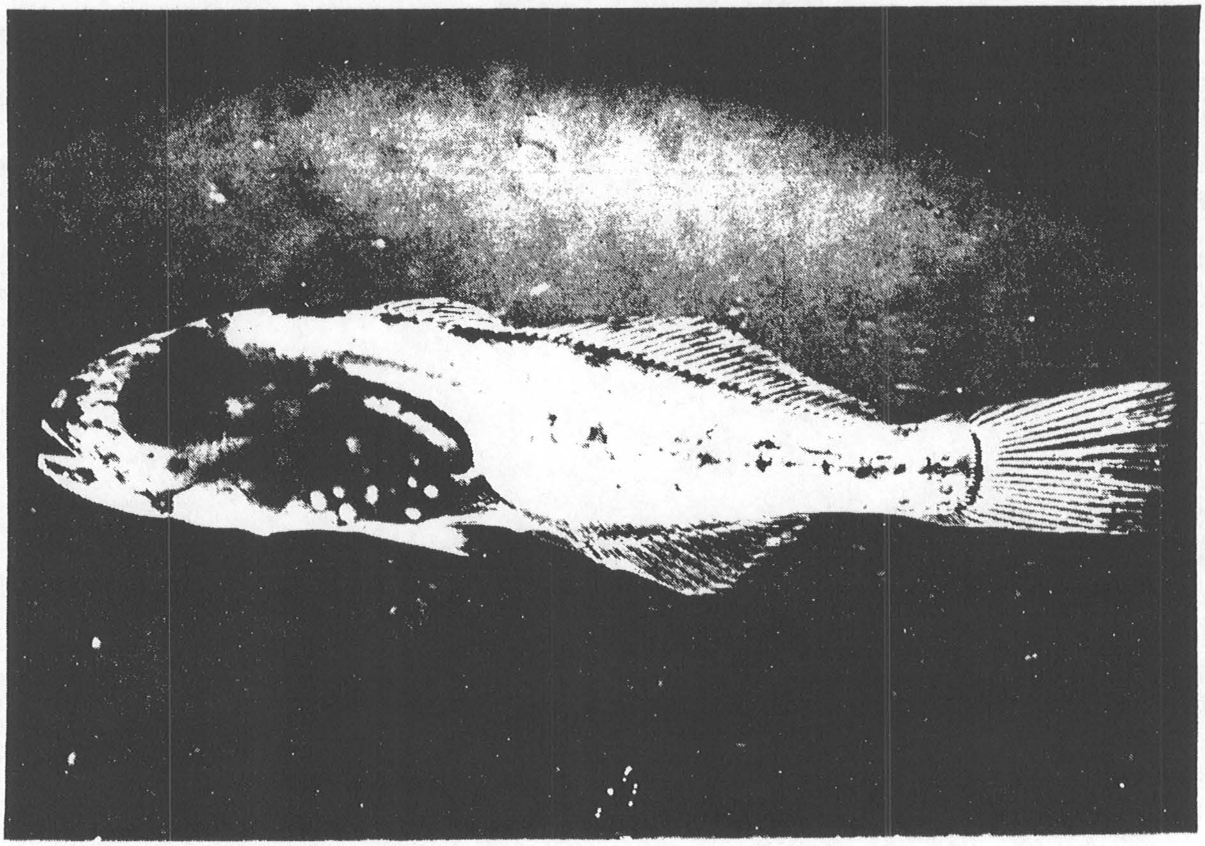

Figure 3.--Spot, *Leiostomus xanthurus* (17 mm standard length), with ingested polystyrene microspheres (350-500 μm) in the gut.

We conclude that the overall ingestion of inert plastic by larval and juvenile fish is probably not a significant mortality factor at this time in the ocean environment. Monitoring of larval fishes from different areas to determine if the frequency of occurrence of plastic in the guts is changing should be continued and incorporated into ongoing ichthyoplankton studies.

We also recommend that studies be conducted to determine if larger predatory fishes can swallow and subsequently pass large, irregular pieces of plastic. Additional mortality caused by plastic ingestion might be detrimental to populations of certain species of sport fish already under intense fishing pressure.

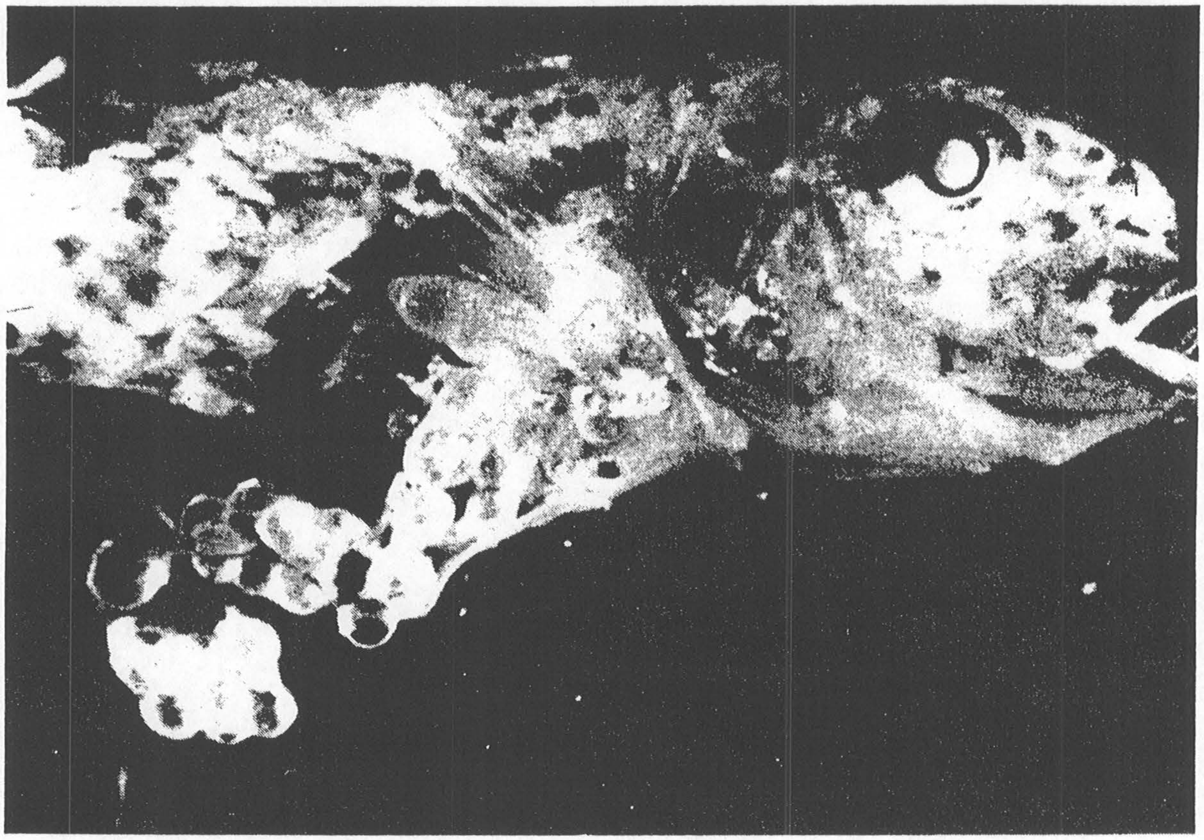

Figure 4.--Spot, *Leiostomus xanthurus* (17 mm standard length), partially dissected to show polystyrene microspheres (350-500 μm) distributed throughout the alimentary tract.

ACKNOWLEDGMENTS

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SYNTHETIC MATERIALS FOUND IN THE STOMACHS OF LONGNOSE LANCETFISH COLLECTED FROM SURUGA BAY, CENTRAL JAPAN

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ABSTRACT

Stomach contents of a total of 372 longnose lancetfish, *Alepisaurus ferox* Lowe, 296 stranded on the beach of Miho Key in Suruga Bay between 1964 and 1983 and 76 fished by gillnets in waters near the key between 1969 and 1975, were examined. In addition to food organisms, many synthetic items such as pieces of polyethylene and vinyl were found in the stomachs. This paper examines the presence of these synthetic materials in the stomachs of longnose lancetfish. Major results of this study were as follows:

- Synthetic materials found in the stomachs were mostly soft polyethylene and vinyl pieces of various sizes and colors. Intact plastic soft drink bottles were also found.

- The feeding ratio of synthetic materials in the stomach of lancetfish was 62.2% for stranded specimens and 63.2% for gillnet specimens.

- Average number of pieces of synthetic materials in the stomach was 3.1 for stranded specimens and 2.2 for gillnet specimens.

- The feeding ratio and number of synthetic pieces in the stomachs of longnose lancetfish have increased sharply during the past several years, suggesting that there have been increases in the amounts of synthetic materials in Suruga Bay and neighboring waters. There are concerns that the neglected synthetic materials may impact large marine organisms adversely.

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INTRODUCTION

Longnose lancetfish, *Alepisaurus ferox* Lowe (Alepisauridae), is widely distributed in the Pacific, Atlantic, and Indian Oceans. It has a large mouth, large eyes, and very sharp bladelike teeth. Its body tissue is soft and watery. It is well known as voracious fish (Fig. 1).

In Suruga Bay and Sagami Bay, located at the center of Honshu in Japan, longnose lancetfish are often stranded alive on the shore by waves. Strandings are especially frequent between December and May on the shores of Kambara, Numazu, Miho, and Ohsesaki, which are located at the inmost part of Suruga Bay (Kubota and Uyeno 1970).

Since 1964, the author has been collecting lancetfish caught with gillnets and boat seines and those stranded on the shore of Miho Key to study their morphology and food habits (Fig. 2; Kubota and Uyeno 1970, 1978; Kubota 1971, 1973, 1977; Kubota and Mori 1975; Okutani and Kubota 1976).

The stomachs of the fish examined contained many pieces of synthetic materials such as polyethylene and vinyl in addition to ordinary food items (e.g., fishes, cephalopods, shrimps, salps, *Pyrosoma*).

It was pointed out that synthetic materials found in the stomachs of lancetfish are from pollution of the ocean and that they served as an index for effects on large nekton such as fish (Kubota 1977). No previous study has examined the effects of synthetic materials on marine nekton.

The objectives of this study were to determine the amounts of synthetic material ingested by longnose lancetfish and to determine how it had changed with the time.

MATERIALS AND METHODS

In this study, 372 fish were examined. Of these, 296 were found stranded on the shore of Miho Key and the remaining 76 were caught in gillnets in the area near Miho Key between December and May. The lengths of the fish range from 50 to 125 cm. Immediately after collection, measurements of meristic characters were made in the laboratory. Food items found in stomachs were removed for identification. The amount and size of nonfood items were also recorded. Nonfood items included leaves, pieces of wood, straw, fragments of orange, fragments of vegetable, rubber, vinyl pieces, polyethylene pieces, and intact plastic soft drink bottles.

RESULTS

Synthetic materials eaten by lancetfish were mostly soft polyethylene and vinyl pieces. Both size and color of these items varied (Fig. 3). Besides these materials, intact plastic soft drink bottles (38 mm in diameter and 74 mm in height) were found in the stomachs of 11 lancetfish stranded on the shore between 1971 and 1973. Of these, four lancetfish had two bottles each in their stomachs in addition to food items.

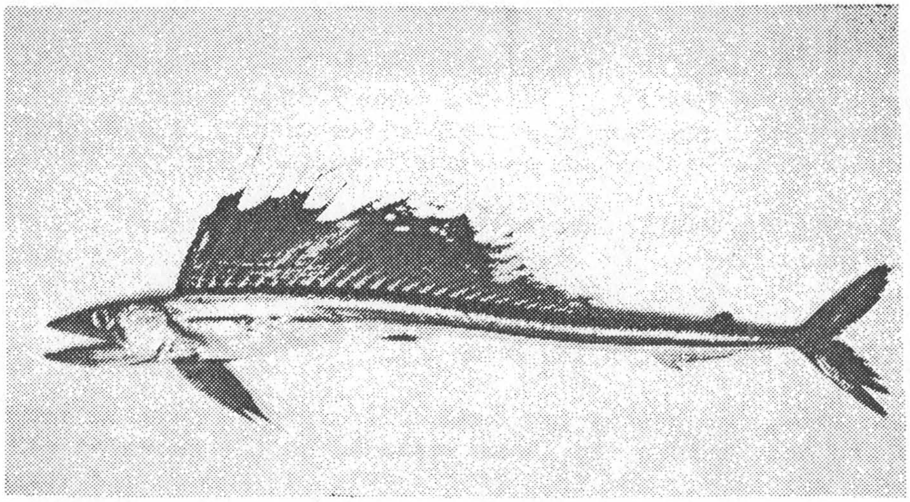

Figure 1.--A longnose lancetfish collected from Suruga Bay. Date collected: 27 April 1967, body length: 887 mm. Scale in figure indicates 300 mm.

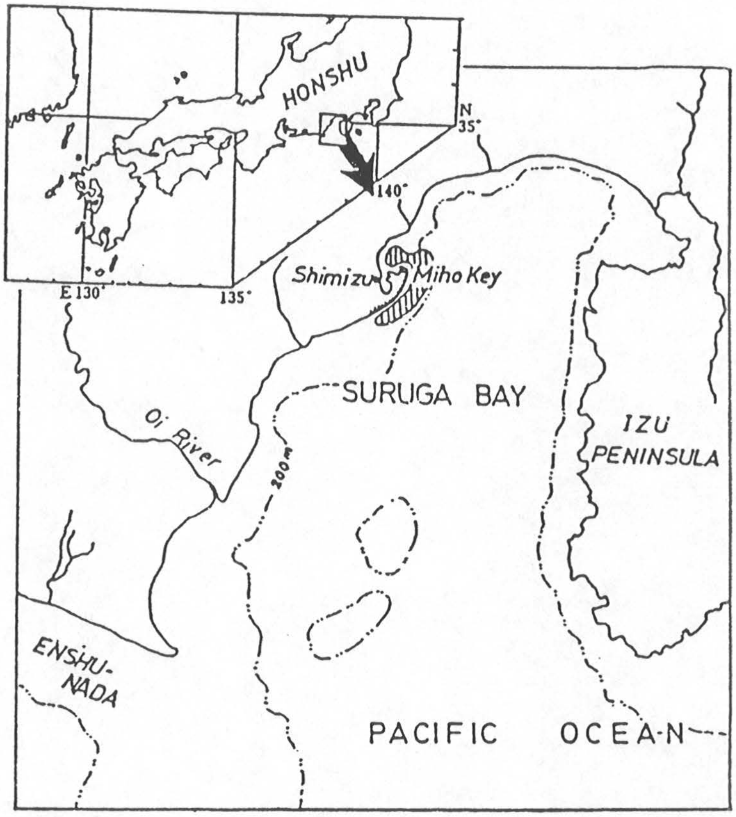

Figure 2.--Suruga Bay, central Japan. The shaded portion of Miho Key is the beach where longnose lancetfish have been stranded and the shaded area off Miho Key indicates a gillnet fishing ground.

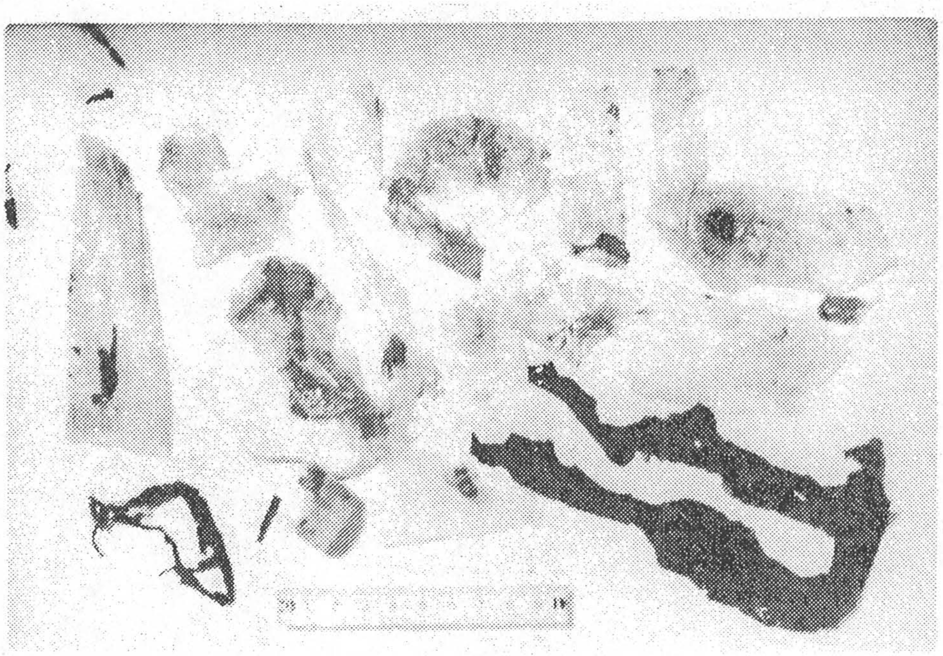

Figure 3.--Synthetic materials from stomachs of longnose lancetfish stranded on the beach of Miho Key. Date collected: May 1971. Scale in figure indicates 100 mm.

The feeding ratio of synthetic materials to food was examined for each year. The feeding ratio for 184 of the 296 specimens that were stranded on the shore was 62.2%, whereas the feeding ratio for 48 specimens among 76 caught with gillnets was 63.2%. The average amount of synthetic material per specimen for each year was also studied. The average amount of synthetic materials per specimen was 3.1 pieces for specimens stranded on the shore and 2.2 pieces for those caught in gillnets.

The results from stranded specimens cover a long time period. Therefore, the study period was divided into two parts, 1964-75 and 1978-83. The feeding ratio of synthetic materials in stomachs of lancetfish was 58.0% in the period 1964-75, and it increased to 72.0% in 1978-83. The average amount of synthetic material per specimen increased from 2.2 pieces in 1964-75 to 4.5 pieces (more than double) in 1978-83 (Tables 1 and 2).

For the samples that had synthetic materials in their stomachs, the frequency of the amount of synthetic materials was studied to see how many pieces were eaten per specimen.

Of those fish on the shore, 112 specimens did not have synthetic materials in their stomachs at all. Thirty-six samples had one piece. Of 184 fish, 135 (73.4%) ate 1 to 6 pieces of synthetic material. One lancetfish ate 17 pieces.

Table 1.--Number of synthetic pieces found in the stomachs of longnose lancetfish stranded on the beach of Miho Key.

Year	Number of lancetfish	Number of lancetfish with pieces of synthetic materials	Total number of pieces of synthetic materials	Average number of pieces of synthetic materials
1964	2	1	5	2.5
1965	2	1	7	3.5
1966	2	1	15	7.5
1967	9	2	10	1.1
1968	19	12	33	1.7
1969	19	11	29	1.5
1970	18	9	38	2.1
1971	56	30	99	1.8
1972	21	15	70	3.3
1973	24	17	72	3.0
1974	2	1	3	1.5
1975	2	1	1	0.5
1976	--	--	--	--
1977	--	--	--	--
1978	57	39	281	4.9
1979	37	24	145	3.9
1980	16	12	76	4.8
1981	--	--	--	--
1982	--	--	--	--
1983	10	8	38	3.8
Total	296	184	922	

For the fish caught with gillnets, 28 did not have any synthetic material pieces and 12 fish ate only 1 piece. One specimen had 15 pieces in its stomach. All the others contained 10 or fewer pieces (Tables 3 and 4).

These results show that synthetic material in the stomachs of longnose lancetfish is increasing. This is from the increase in synthetic materials being discarded by people into rivers and the ocean.

DISCUSSION

The longnose lancetfish is a voracious feeder. It has nonselective food habits and will catch anything in the ocean it can swallow. In most cases, the stomach contents can be identified to the species level. The feeding habits of lancetfish are the same in other areas (Haedrich 1964; Haedrich and Nielsen 1966; Fourmanoir 1969; Rancurel 1970; Fujita and Hattori 1976). Therefore, it is possible to identify the organisms in the

Table 2.--Number of synthetic pieces found in the stomachs of longnose lancetfish caught by gillnet.

Year	Number of lancetfish	Number of lancetfish with pieces of synthetic materials	Total number of pieces of synthetic materials	Average number of pieces of synthetic materials
1969	1	1	1	1.0
1970	14	6	12	0.9
1971	33	23	74	2.2
1972	21	12	63	3.0
1973	5	4	10	2.0
1974	1	1	3	3.0
1975	1	1	5	5.0
Total	76	48	168	

Table 3.--Number and frequency of synthetic pieces found in each stomach of longnose lancetfish stranded on the beach of Miho Key.

Number of pieces of synthetic materials found in each stomach	Number of lancetfish
0	112
1	36
2	29
3	25
4	16
5	16
6	13
7	6
8	9
9	6
10	5
11	4
12	4
13	3
14	4
15	3
16	4
17	1

Table 4.--Number and frequency of synthetic pieces found in each stomach of longnose lancetfish caught by gillnet.

Number of pieces of synthetic materials found in each stomach	Number of lancetfish
0	28
1	12
2	9
3	8
4	7
5	4
6	3
7	2
8	0
9	1
10	1
15	1

habitat where lancetfish live using stomach analysis. The distribution of nonfood items such as synthetic materials can also be determined.

Results showing that polyethylene and vinyl pieces found in the stomachs of lancetfish have increased over time imply that fairly large quantities of synthetic materials are present in the waters near Miho Key. In the last few years, the author has observed water surfaces of the area from the innermost part to the central part of Suruga Bay from on board a research vessel, and has seen large floating vinyl pieces. These items were not seen at all in the sea 8 years ago. This study documents the notion that quantities of discarded synthetic materials have increased in recent years. Synthetic materials mass-produced to meet the consumer demands will continue to contaminate the seas around Japan because they are discarded from houses and factories as waste and enter the sea through rivers.

Because of their feeding habits, lancetfish can serve as a biological monitor of synthetic pollution in the ocean.

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ECOLOGICAL ASPECTS OF MARINE TURTLES IMPACTED BY OCEAN DEBRIS: A 1989 PERSPECTIVE

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ABSTRACT

Authenticated reports of debris entanglement and ingestion by marine turtles have continued to accumulate since a comprehensive, worldwide list of such events was first assembled in 1984. Although fragmentary, available evidence indicates that ingestion of man-made debris floating on the high seas has the greatest potential for adversely impacting sea turtle populations. A major problem in gathering detailed information on this phenomenon is the inability of researchers to locate and study pelagic habitats used by juvenile turtles of all species. Consequently, those cases of debris ingestion that do become known should be considered as the tip of the iceberg. Due to the insights of the late Archie Carr, pelagic habitats used as foraging sites by sea turtles are not believed to be frontal systems (convergences, rips, drift lines) where buoyant food and debris are drawn together by advection. International concern for the impact of buoyant wastes in the ocean is heightened by the fact that many sea turtle populations are endangered and have experienced serious declines from overfishing and other adverse factors.

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.

STUDIES ON THE INGESTION OF PLASTIC AND LATEX BY SEA TURTLES

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ABSTRACT

Small pieces of latex and plastic sheeting were offered to sea turtles on different occasions and the turtles' feeding behavior was noted, as well as the time taken for the turtles to pass ingested materials. The physiological and clinical status of turtles that had consumed plastic sheeting was also monitored. We observed that green sea and loggerhead turtles actively seek out and consume the offered material. Some color preference was shown, clear plastic having the lowest acceptance rate. The amount consumed was influenced by appetite. At the low feeding levels allowed in these experiments, we detected no effects of plastic ingestion on gut function, metabolic rate, blood chemistry, liver function, or salt balance. However, blood glucose declined for 9 days following ingestion, indicating a possible interference in energy metabolism or gut function. The sojourn of the ingested latex material in the gut ranged from a few days to 4 months. Moreover, some of the turtles passed multiple pieces all bound together, although they had ingested the individual pieces at different times. Since the gut clearance time for food is in the order of days, it appears that some of the latex pieces were being held up in the intestine. Latex pieces that had been retained for the longest time in the gut showed evidence of deterioration.

INTRODUCTION

As man's use of nonbiodegradable products increases, so does the amount of such material dumped into the ocean. Offshore garbage dumping by ships at sea was legal until recently and the ocean is considered by some (e.g., Osterburg 1986) as "nature's trash basket." However, one consequence of this practice is that contact by marine animals with nonbiodegradable refuse such as plastic bags and Styrofoam products also increases. Hopefully, the ratification of the MARPOL V agreement will help

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to alleviate the problem, but recent incidents of entanglement and ingestion in marine mammals and seabirds (Cawthorn 1985) suggest that harmful contact with refuse may occur much more frequently than previously thought.

It is becoming increasingly recognized that the ocean dumping of plastic waste presents a particularly serious hazard for sea turtles. Sea turtles consume a wide variety of debris and, in the man-made category, plastic bags and sheets appear to be the most prevalent material ingested (Balazs 1985). In some instances, the level of contamination can be very high. For example, plastic bags were found in 23% of a sample of green sea turtles in Peruvian waters (Hays de Brown and Brown 1982), and in one analysis 44% of adult nonbreeding leatherbacks were found to have plastic in their stomachs (Mrosovsky 1981). It has been suggested that one cause for ingestion is that turtles mistake the plastic for their natural jellyfish prey (Fritts 1982). More recently concern has been expressed over spent balloon material in the ocean, the result of increasing popularity of massive balloon launches.

Is the ingestion of plastic and latex by sea turtles any cause for concern? Clearly, if sufficient material is swallowed to cause a complete stoppage of the gut, death will result from starvation. However, there are only a few such documented cases (Balazs 1985; Cawthorn 1985), and most of the evidence for turtles swallowing plastic comes from butchered turtles (Balazs 1985). In domestic vertebrates, persistent partial blockage of the intestine can interfere with gut function (Fraser 1986). In the sea turtle, a coating of the gut wall by plastic could cause a reduction in absorption efficiency and also cause mechanical damage to the gut lining. Sublethal ingestion, therefore, where complete intestinal blockage does not occur, may be quite common and could adversely affect behavior, growth, reproduction, and general homeostatic physiological functioning and lead to other potentially lethal situations.

There is, unfortunately, no information on whether the ingestion of such material is accidental or deliberate, or information on the effects of sublethal ingestion of plastics by sea turtles. Given the critical position of most sea turtle populations and the huge magnitude of ocean dumping (van Dolah et al. 1980; Horsman 1982), it is clearly important to determine if the swallowing of such inert material by sea turtles is harmful and to establish the seriousness of any harm.

The purpose of this study was to document the mode of plastic and latex ingestion in sea turtles and to give a first estimate of how serious the resultant harm might be.

MATERIALS AND METHODS

This is the first study of its kind, and since there were no previous data to use as a guide, and as we did not wish to cause any lasting harm to the experimental sea turtles, we were particularly careful and cautious in designing our experimental protocol.

Animals

Green sea and loggerhead turtles were kept in tanks of approximately 3,785 L (1,000 gal) capacity. Each tank was supplied with running, filtered seawater. The turtles were fed a specially formulated feed for sea turtles (Purina sea turtle chow) each day during the experiments unless otherwise noted.

Ingestion

In the initial experiment, green and loggerhead yearlings (ca. 1 kg weight) and juvenile (10 to 18 kg) turtles were allowed to consume a small single piece of plastic sheeting (1 to 10 cm^2) and were observed for about 2 weeks during which time various behavioral (yearling and juvenile) and physiological (juvenile) measurements were taken. The animals were fed turtle chow daily during this experiment. Since a preliminary examination of the data showed no adverse effects, a second set of experiments was undertaken at an increased (but still modest) level of plastic ingestion. Seven loggerheads weighing 13 to 18 kg were used in this section (four experimental, three control) and were fed five to seven small pieces of plastic. They were also fed daily and observed for 2 weeks. In these experiments the initial measurements before feeding plastic served as individual controls. In order to understand the effects of simple food limitation per se, a third set of turtles was starved for 2 weeks and the various physiological parameters were monitored. This set also served as a control for those turtles in the previous experiments that occasionally refused food for a few days.

An additional study on latex was undertaken in order to determine whether the ingestion of balloon material was accidental or deliberate and if the latex material was altered on passage through the gut. Five turtles were isolated in separate tanks and were offered small (ca. 1 cm^2) pieces of colored latex and clear plastic sheeting under different conditions. The turtles' feeding behavior was noted, as well as the time taken for the turtles to pass ingested materials. The passed material was collected for examination.

Gut Function

Food consumption was measured as the number of pellets consumed each day. The pellets weighed on average 0.918 ± 0.085 g. Feces were collected in plastic bags attached to the turtles and stored frozen at -20°C. It was noted that defecation usually started 1 to 2 h after feeding. Samples of food and feces were dried at 67°C for 48 h and their calorific value measured using a Parr 1241 Adiabatic Calorimeter.

The ash content of food and feces was estimated by weighing samples before and after being heated in a muffle furnace at 600°C for 24 h. Ash was used as a digestibility marker (Conover 1966). Although this method has been criticized because of its unproven assumption that ash-forming materials are neither added nor absorbed as food passes through the gut (Bjorndal 1985; Newman et al. 1985), it is used fairly commonly in studies of digestibility in marine organisms, and gives values in reasonable agreement with the acid insoluble method in sea turtles (Vargo et al. 1986). It also has value as a comparative estimate.

Gut passage time was determined from the first appearance in the feces of the plastic sheets and of small plastic markers (Teflon disks, 2-3 mm diameter) that had been included in the food.

Occult blood in the feces was tested for using the benzidine reaction (Henry 1974).

Dive Time

Dive time was recorded on a stopwatch while observing the turtles' diving behavior in the tank. Surface time was not measured since the interval was, almost without exception, less than 3 sec (usually one breath).

Oxygen Consumption

A closed circuit method was used for oxygen consumption measurements. The turtle was placed in a sealed humidified air chamber connected to an Applied Electrochemistry oxygen analyzer. Chamber air was pumped through the analyzer and returned to the chamber. Carbon dioxide and water vapor were removed from the analyzer input line by chemical scrubbers (Ascarite and Dririte). The experiments were run for approximately 1 h, and the minimal chamber partial oxygen pressures (PO_2) were always >100 torr.

Blood Chemistry

Blood was taken from the dorsal cervical sinus as previously described (Bentley and Dunbar-Cooper 1980).

Blood gases (PO_2, PCO_2) and pH were determined immediately on whole blood using a Radiometer BMS Mk 2 blood-gas analyzer set to the experimental temperature (22°C). Plasma bicarbonate was calculated from the pH and PCO_2 data using the temperature- and pH-dependent CO_2 solubility and dissociation constants of Severinghaus (1965).

The blood was then centrifuged and the plasma divided into two parts. One part was deproteinized with 8% chilled perchloric acid and served for plasma lactate and urea measurements using the Sigma kit No. 826-uv for lactate and the Sigma kit No. 640 for urea. The untreated plasma was analyzed for osmotic pressure using a Wescor 6100 osmometer and saved frozen for measurement of ions and metabolites. Plasma chloride was measured by an Aminco chloride titrator and plasma cations by atomic absorption spectrophotometry (Perkin Elmer PE 403). Column chromatography was used to estimate plasma cortisol, and glutamic pyruvate transaminase levels were measured by spectrophotometry using Sigma kit No. 505. The hematocrit and the percentage volume of white blood cells were read after centrifugation.

RESULTS

Feeding and Digestion

Ingestion

During normal feeding, green sea turtles were each offered, on different occasions, five pieces of pink, blue, and yellow latex, and clear plastic (Fig. 1). Each turtle had its own preference: No. 1, blue; No. 2, pink; and No. 3, yellow; Nos. 4 and 5 refused all. Surprisingly, none of the turtles accepted the clear plastic. On offering yellow material to turtles that had been fasted for 3 days, there was a substantial increase in the amount of ingestion. Turtles No. 1, No. 2, and No. 3 consumed all of the material offered, but turtle No. 5 continued to hold itself aloof from this experiment (Fig. 2). In two additional sets of experiments on fasted turtles, turtle No. 1 ingested clear plastic but the others continued to ignore it (Fig. 3).

Gut Passage Time

The ingested material started appearing in the tank water after a few days and then declined over the next few weeks (Fig. 4). This time course corresponded with normal gut passage time as measured by the Teflon markers (11.3 days, range 10 to 13 days, n = 3). Quite unexpectedly, latex material continued to appear in the tank for up to as long as 4 months, peaking at about 8 weeks. Some of the turtles passed multiple pieces all bound together, although they had ingested the individual pieces at different times. The latex pieces that had been held for the longest time in the gut showed evidence of deterioration.

Food Consumption

In the loggerheads, daily food consumption did not vary much on an individual basis and when changes occurred they were fairly smooth (Fig. 5A). There was no noticeable pattern after feeding plastic. The average daily rate of consumption (grams of food per kilogram body weight per day) for individual loggerheads was 5.07 ± 1.97, n = 7; 5.9 ± 3.08, n = 7; 9.2 ± 1.59, n = 11; 9.3 ± 2.06, n = 8. In the green sea turtles, the average rates were similar, i.e., 6.7 ± 3.8, n = 8; 10.9 ± 1.93, n = 8; 11.82 ± 2.8, n = 9. However, in one of the green sea turtle consumption gradually diminished to zero on day 4 and then recovered (Fig. 5B). The consumption patterns for the other two turtles were similar to those observed in the loggerheads.

Energy Adsorption

The calorific value of the feces showed no consistent change with time in either the green sea turtles or the loggerheads (Fig. 6). Interestingly, the green sea turtle feces had a higher calorific content than the loggerhead (loggerhead feces 3,328 ± 145 cal/g, n = 10; green 4,126 ± 324 cal/g, n = 9). These differences were statistically significant ($P < 0.01$). It can be calculated that an amount of loggerhead food containing 1 g of ash

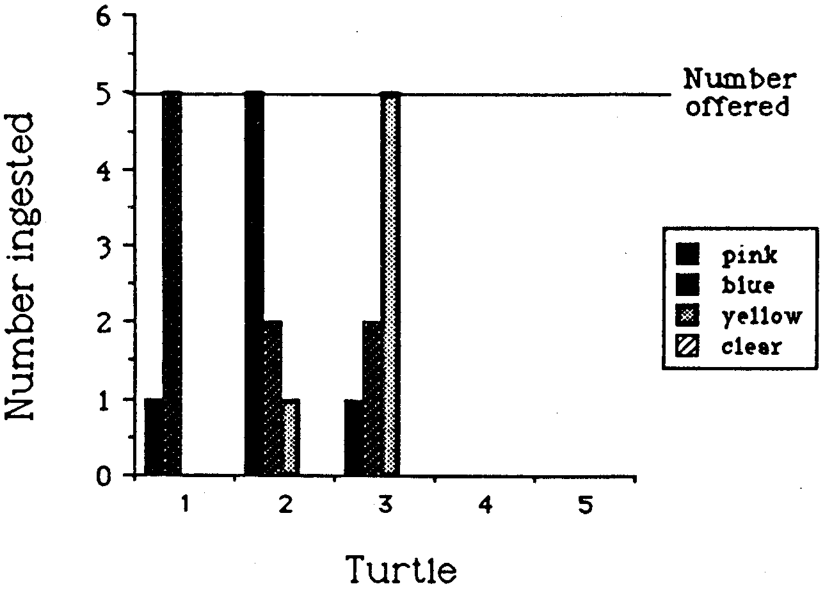

Figure 1.--Voluntary ingestion of latex pieces in green sea turtles.

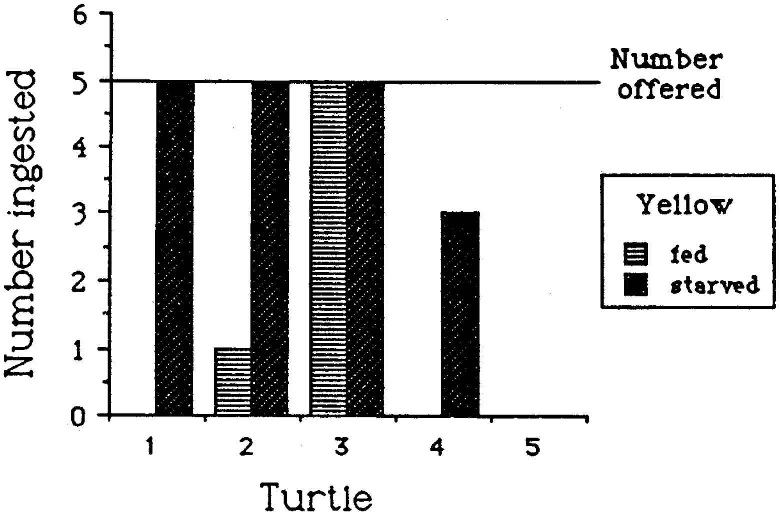

Figure 2.--Effect of 3 days fasting on latex ingestion in green sea turtles.

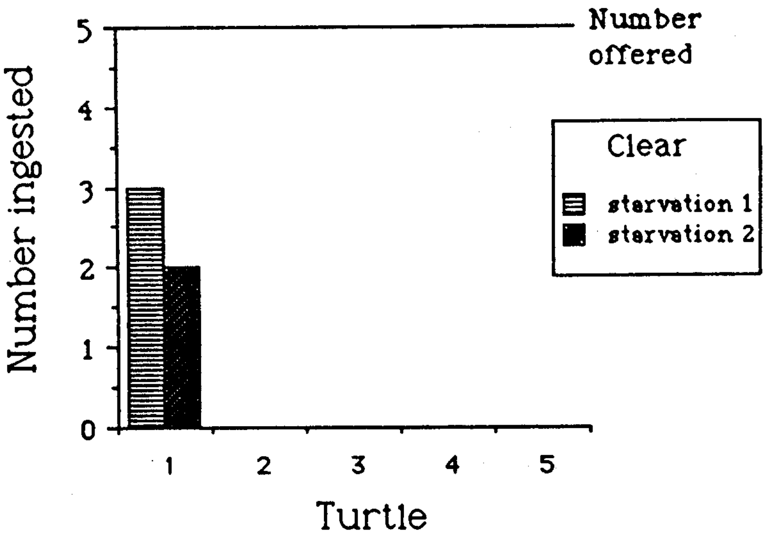

Figure 3.--Effect of 3 days fasting on the ingestion of clear plastic in green sea turtles.

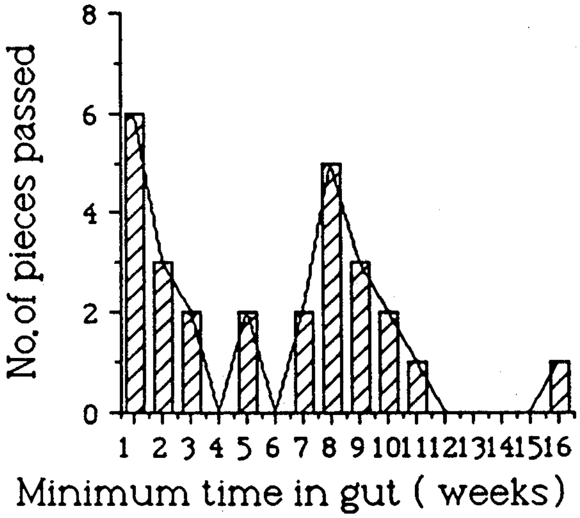

Figure 4.--Gut passage time for ingested pieces of latex in the green sea turtle.

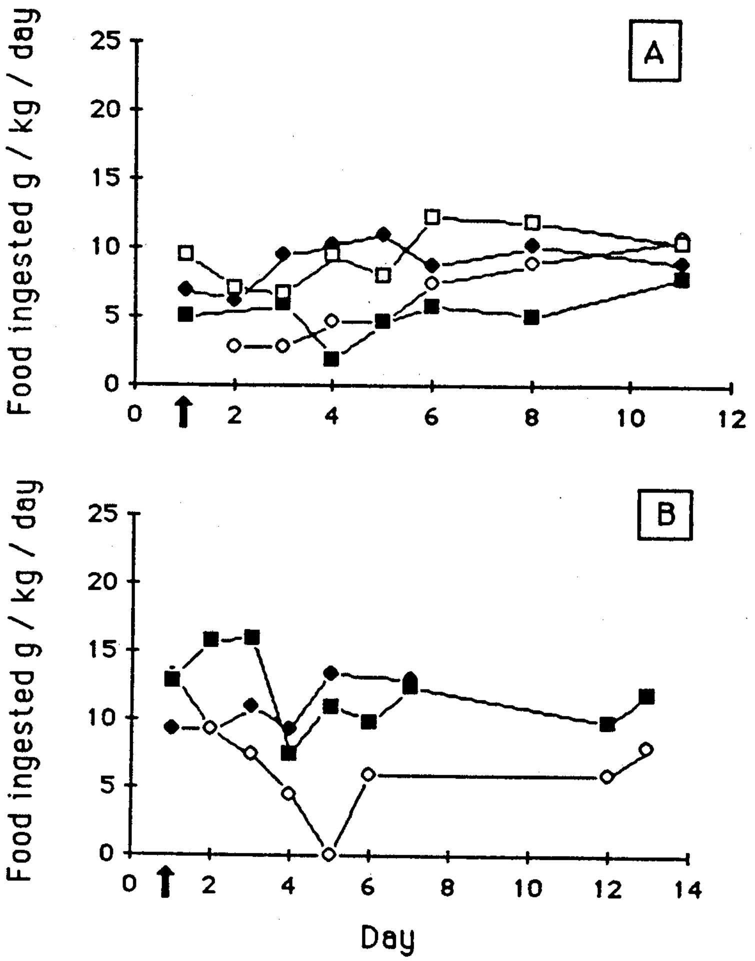

Figure 5.--The effect of plastic ingestion (↑) on food consumption in four individual loggerhead (A) and three green sea turtles (B).

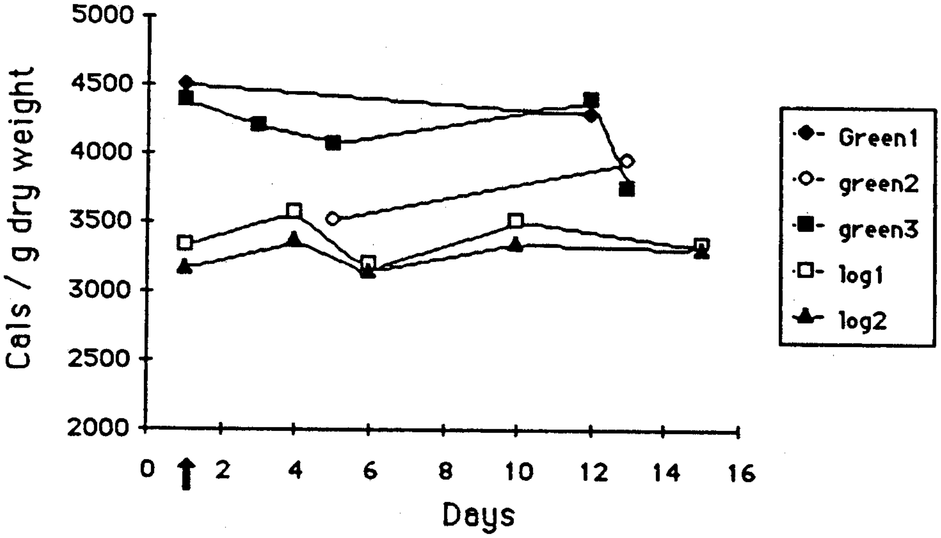

Figure 6.--The calorific value of green and loggerhead turtle feces after being fed plastic (↑).

would have a gross energy content of 51,381 cal, while feces with the same amount of ash would have 12,743 cal. Assuming constancy of ash, this indicates a digestible energy adsorption efficiency of 75.2%.

Stool Culture

In the two control loggerheads, the fecal flora was respectively 99% g positive, 1% g negative; and 98% g positive, 2% g negative. In three turtles that had been fed plastic bags, the fecal floral composition was as follows: 100% g positive; 85% g positive, 15% g negative; 100% g positive. The gut bacterial composition was, therefore, substantially gram positive in nature and this feature was not altered by plastic ingestion.

Occult Blood

No occult blood was observed in any of the fecal samples examined either in the control or the experimental animals. The plastic ingestion, therefore, had not caused intestinal bleeding.

Respiration

Oxygen Consumption

Plastic ingestion had no apparent effect on the oxygen consumption of either the green sea or the loggerhead turtles, and on an individual basis they were remarkably constant over the 2 weeks of monitoring. Metabolic rates for the green sea turtles ranged from 47.9 to 73.8 ml/kg/h, and the loggerhead values showed an almost identical range of from 38.1 to 70.2 ml/kg/h. Similar oxygen consumptions have been obtained for green sea turtles (70.8 ml/kg/h at 25°C, Kraus and Jackson 1985) and loggerheads (62.0 ml/kg/h, Lutz and Bentley 1985) measured in air.

Blood Chemistry and Acid Base Balance

Oxygen

Venous oxygen levels remained relatively constant in both the experimental turtles and in the starved group. There was no significant difference between groups. Since venous oxygen levels are determined by the difference between oxygen supply and tissue use, and since oxygen consumption did not change, it seems likely that the mechanisms for oxygen transport have not been affected by plastic ingestion. The mean venous value for all of the data ($PO_2 = 56.69 \pm 1.59$, $n = 38$) is very similar to that found in an earlier study on the same animals (Lutz and Dunbar-Cooper 1987).

Carbon Dioxide

Venous carbon dioxide remained similarly constant over the course of the experiment, and no statistical difference was found between the control and the experimental groups. The mean value for all of the data is $PO_2v = 24.79 \pm 0.976$, $n = 38$.

Blood pH

For the group of experimental turtles fed plastic, venous blood pH appeared to decline on the first day after feeding plastic ($P \leq 0.5$) and continued to fall in two turtles on day 2 and in one until day 3 (Fig. 7A). No such trend was noted for the starved controls (Fig. 7B). However, the range in pH shifts was very narrow, and for the whole set the average pH was 7.550 ± 0.008, n = 38, close to the predicted normal venous pH for the prevailing body temperature (25°C, pH = 7.442, Lutz et al. 1988).

Bicarbonate

There was no change in venous bicarbonate on the day following plastic ingestion. The overall bicarbonate concentration was 22.6 ± 0.971 mM, n = 38.

Glucose

In the loggerheads fed plastic, blood glucose levels declined for 10 days (Fig. 8), but recovered to initial values by day 14, about the time plastic was expelled from the gut (see below). A least squares linear regression of the relationship between blood glucose (G) and days after plastic ingestion (T) produced the following equation illustrated in Figure 8.

$$G\ (\mathrm{mM}) = 6.683 - 0.445\,T \qquad r = 0.866,\ n = 12$$

The average rate of decline in blood glucose was therefore 0.45 mM/day. Interestingly, starvation by itself caused a marked fall in blood glucose levels (Fig. 9). In both the loggerhead and green sea turtles, blood glucose levels declined sharply on the second day of starvation at much greater rates than the fed loggerheads who had consumed plastic viz., 2.52 mM/day in the green and 2.42 mM/day in the loggerhead.

Glutamic Transaminase

The initial concentration of loggerhead glutamic transaminase plasma (GTP) was 1.67 ± 0.608, n = 7, international units/ml. The GTP values varied somewhat in both the control turtles and the plastic-fed turtles for the first 3 days of the experiment (Fig. 10), but after the fourth day there was a marked decline in values in both groups, possibly related to the fall in plasma glucose.

Cortisol

In all samples tested, the blood cortisol levels were extremely low ($\leq 1.0\ \mu g/dl$), indicating that the turtles were not stressed by the experimental protocol. Blood cortisol levels have been seen to increase in stressed loggerheads from similar low initial levels (1-3 $\mu g/dl$ to as high as 37 $\mu g/dl$ (D. Owens pers. commun.).

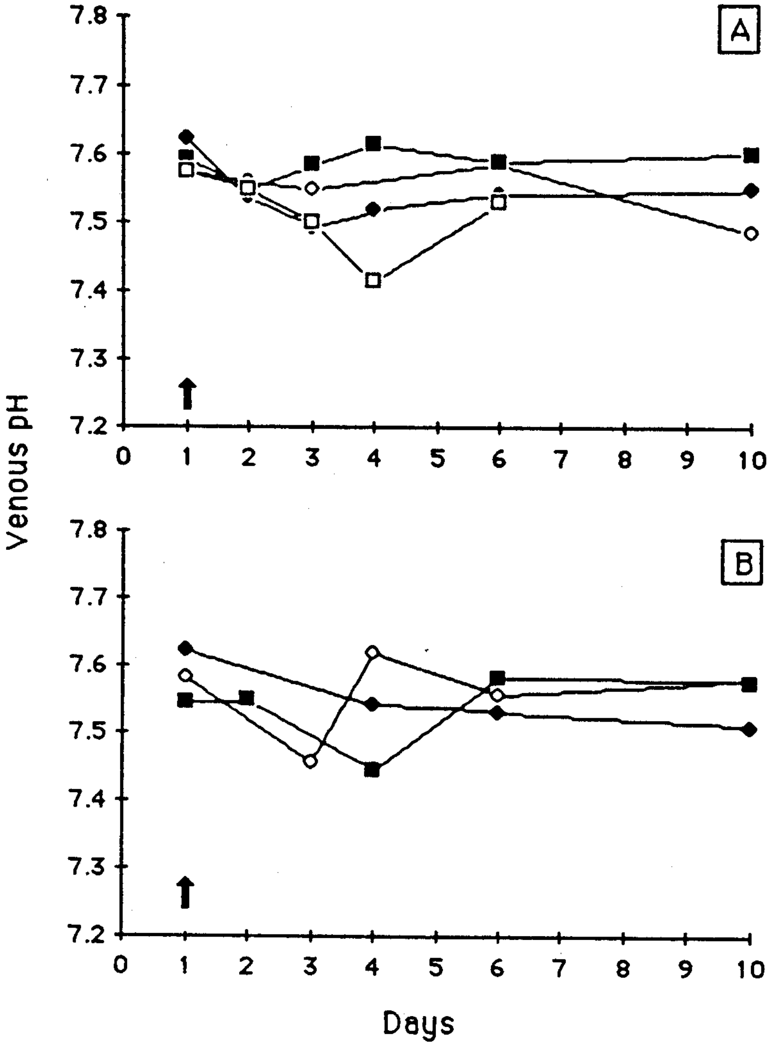

Figure 7.--The effect of plastic ingestion (A, ↑) and starvation (B, ↑) on the loggerhead turtle venous pH.

Hematocrit

The hematocrit values did not change over the course of the experiments in either the loggerhead or the green sea turtle. The loggerhead mean value (28.6%) is less than that found for loggerheads sampled in the wild (35.5%, Lutz and Dunbar-Cooper 1987) and less than that found for the green sea turtle (33.3%); the latter difference is significant ($P < 0.01$).

White Blood Cells

No change was seen in white blood cell volume following plastic ingestion. In the loggerheads, the white blood cells initially made up about 0.2% of the whole blood, and with one exception the values were reasonably constant, ranging between 0.2 and 0.4% for 10 days after plastic ingestion.

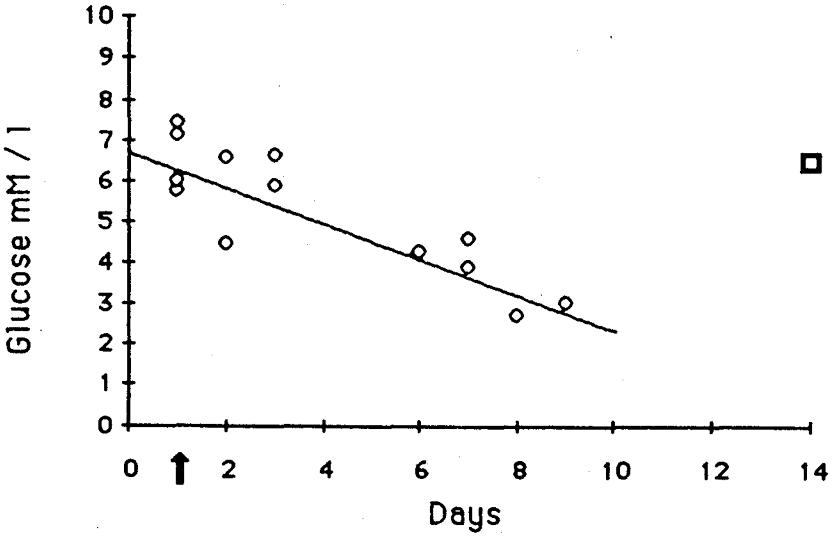

Figure 8.--The effect of plastic ingestion (↑) on blood glucose levels in the loggerhead turtle.

DISCUSSION

We have been able to demonstrate that both green sea and loggerhead turtles do not discriminate against plastic sheeting when they engulf food intermingled with plastic. The experiments with latex ingestion in loggerheads demonstrated that if their appetite is sufficient, they will actively swim towards and ingest latex materials, that all colors are acceptable, and that the amount ingested will depend on their nutritional state. Indeed, it was our impression that hungry sea turtles will swallow almost any material of a suitable size and consistency and will continue to do so until satiation.

No clear evidence of ill effects from plastic ingestion was found in this set of experiments though it should be noted that the turtles were only allowed to consume very small amounts. In fact, the constancy of many of the physiological parameters over the 2 weeks of monitoring is evidence that the experimental setup was not, by itself, a perturbing influence.

Further evidence of a lack of stress is seen in the low blood cortisol levels. The values are similar to those reported for resting blood cortisol levels for vertebrates in general which are around 1-5 µg/100 ml (rainbow trout, 3.8 µg/100 ml, Donaldson 1981; loggerhead, 1-3 µg/100 ml, Owens pers. commun.; dog, 1-5 µg/100 ml, Fraser 1986). For many animals, stress produces a surge in blood corticosteriods, often within hours of the stress, that will persist during the stress and sometimes for days afterwards (Fraser 1986). Compared to resting values, the expected increases in blood cortisol concentrations under stressful conditions can be substantial (16 µg/100 ml in the stressed rainbow trout, Donaldson 1981).

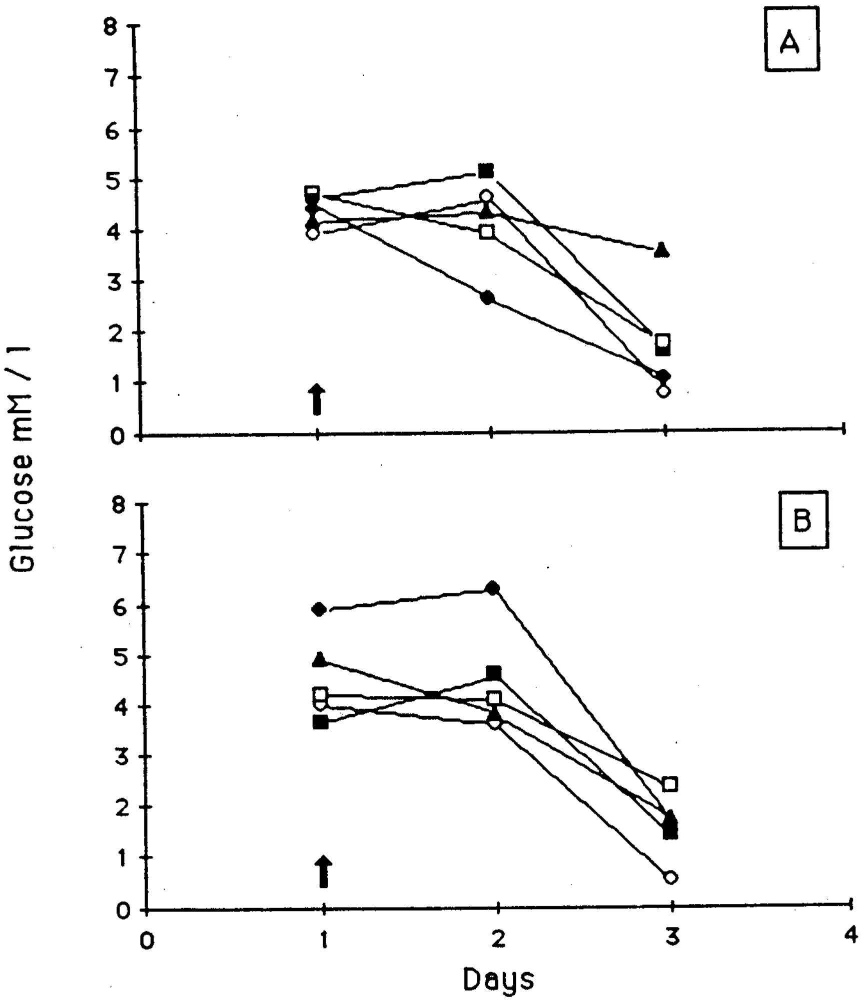

Figure 9.--The effect of starvation (↑) on blood glucose concentrations in the loggerhead (A) and green sea turtles (B).

There was no evidence of plastic ingestion affecting feeding and the handling of food. The rate of food consumption did not change after eating plastic in either the loggerhead or the green sea turtles, and the average daily consumption was similar for both species (9.79 g/kg/day, green; 7.37 g/kg/day, loggerhead). Wood and Wood (1981) found a similar food intake for green sea turtles fed pellets (8 to 12 g/kg/day). The food consumption rates found in this study are equivalent to a calorific intake of 44.2 kcal/kg/day for the green and 33.3 kcal/kg/day for the loggerhead.

The efficiency of food adsorption and the calorific value of the feces were unaltered, and the bacterial composition of the gut was not changed. There was no evidence of blood in the feces, pointing to an absence of mechanical damage as plastic passed through the gut.

No effect of plastic ingestion was detected with respect to any of the measured parameters that are directly associated with respiratory

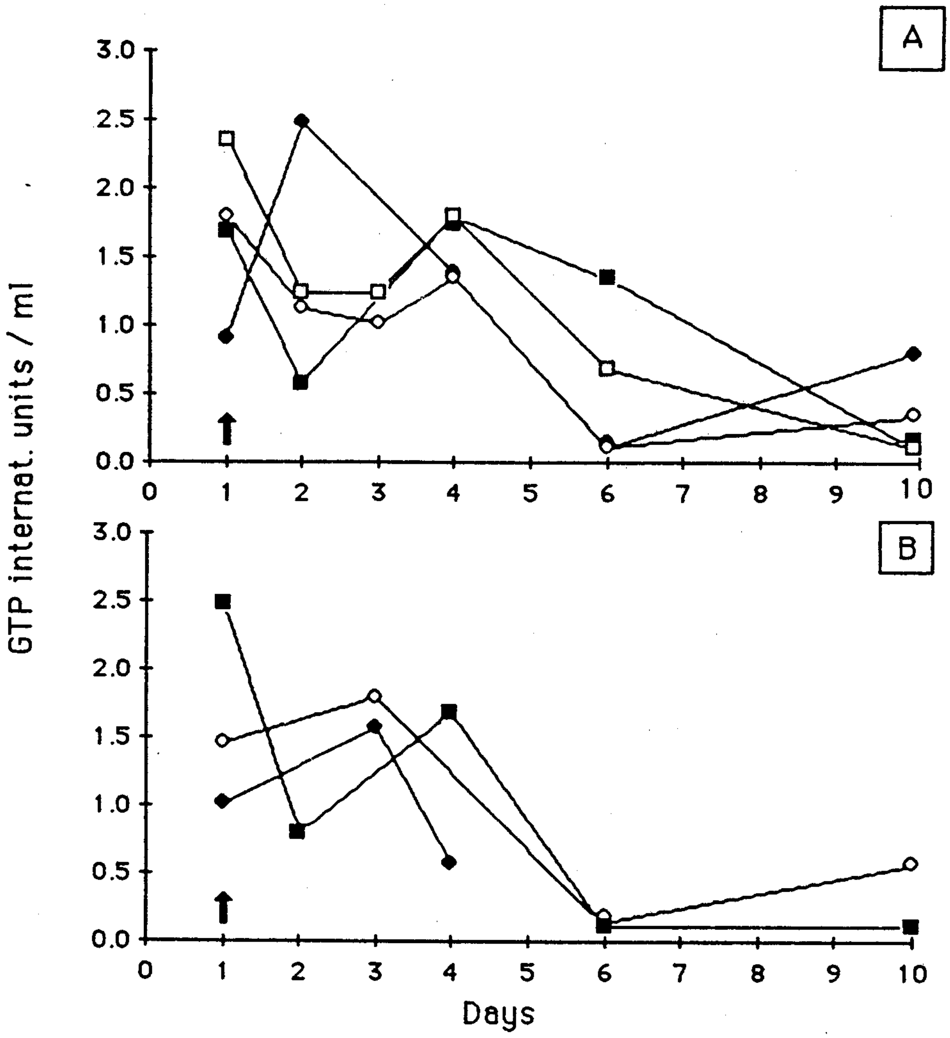

Figure 10.--The effect of plastic ingestion (↑, A) and starvation (↑, B) on glutamic transaminase levels in loggerhead plasma.

physiology, viz., metabolic rate, blood oxygen and carbon dioxide levels, blood acid base status.

The hematocrit was remarkably constant, an indicator of health, and no marked changes were seen in the proportion of white blood cells. A very substantial increase in white blood cell numbers (400%) was one of the most notable features of sea turtles affected by oil pollution (Vargo et al. 1986). No evidence of liver malfunctioning was seen in the lack of increase in plasma glutamic pyruvic transaminase (Fraser 1986).

The rates of change in blood glucose are a possible exception to this pattern. The key observation was that blood glucose declined rapidly in loggerheads that were starved and also fell, although at a lesser rate, in turtles that had been fed plastic sheets. The implication is, therefore, that blood glucose levels in sea turtles are especially sensitive to nutrient uptake from the gut and that this process had been interfered with in those animals that had consumed plastic. Interestingly, the blood glucose concentrations for the control fed loggerheads in this study (5.23 mM ± 1.279 mM, n = 10) were much higher than those recorded in the wild from loggerheads sampled in the Port Canaveral ship channel (ca. 1 mM, Lutz and Dunbar-Cooper 1987) evidence perhaps that the Canaveral turtles had not been feeding. Blood glucose levels, therefore, may serve as a sensitive index of nutritional status for turtles both in the laboratory and in the wild.

The study did point to some interesting differences in the physiology of green sea turtles and loggerheads. On average the green sea turtles had a higher hematocrit than the loggerheads (33.3%, green; 28.6%, loggerhead) and a higher proportion of white blood cells (0.2%, loggerhead; 1.02%, green). In the green sea turtles, the average daily food consumption of the pelleted food was about 32% higher. On the other hand, this was offset somewhat by green sea turtles having a higher feces energy content (24% higher in the green) and, therefore, a lower efficiency in extracting energy from the food.

In summary, when hungry, sea turtles will actively consume plastic and latex material. Except for a possible interference in energy metabolism (declining blood glucose levels), at the levels allowed in this study ingestion produced no measurable changes in the physiological parameters that were measured. However, the observation that pieces of latex can gather up in the gut and remain there for considerable periods of time should be viewed with some concern and certainly needs more detailed investigation.

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EFFECTS OF ANTHROPOGENIC DEBRIS ON SEA TURTLES IN THE NORTHWESTERN GULF OF MEXICO

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ABSTRACT

Reports of sea turtles ingesting and becoming entangled in marine debris and the adverse effects associated with these encounters exist worldwide, but the magnitude of this problem has yet to be determined. Data collected from sea turtles stranded on the south Texas coast from 1986 through 1988 indicate that they are significantly affected by ingestion of and, to a lesser extent, by entanglement in marine debris. All five species of sea turtles found in the Gulf of Mexico, both male and female, posthatchling through adult, had eaten or were ensnared by debris. Plastics discarded at sea were involved in the majority of these incidents. The offshore oil industry, cargo ships, research vessels, commercial and recreational fishing boats, and other seagoing vessels are primarily responsible for the trash discarded at sea which threatens sea turtles in the Gulf of Mexico.

INTRODUCTION

Because of their widespread intentional exploitation by man in the past, sea turtle populations in the United States have declined and all species are currently considered either threatened with or in danger of extinction. The greatest threat to their survival today is man's incidental exploitation. Every year thousands of sea turtles are incidentally caught and drowned in the net trawls of shrimp fishermen, beach front development encroaches on valuable sea turtle nesting beaches and threatens their reproductive efforts, newly hatched sea turtles are run over by cars or die from heat and exhaustion after they are enticed to crawl from their nests towards the bright lights of a condominium instead of towards the comparatively dimly lit sea, and an unknown number of sea turtles die when they become entangled in or ingest nonbiodegradable anthropogenic marine debris.

Balazs (1985) was the first to examine the widespread effects and impacts of marine debris on sea turtles. He compiled reports from the literature and through personal communication on the incidences of

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entanglement in and ingestion of marine debris by sea turtles worldwide. Collectively, these reports painted a rather grim picture for the recovery of sea turtle populations. But precisely how much of a threat marine debris poses to sea turtles has not yet been determined. Because sea turtles spend most of their lives at sea and are generally inaccessible to researchers, it has been difficult to assess the magnitude of this problem on any population. The objective of the present study was to determine the extent of entanglement and ingestion for sea turtles found stranded on the south Texas coast.

METHODS

Data were collected from sea turtles found stranded on Mustang Island, North Padre Island, and South Padre Island, Texas, from 1986 through 1988.

Entanglement

Stranding forms submitted to the Texas Sea Turtle Stranding and Salvage Network coordinator were used to obtain information on entangled sea turtles. Information culled from these forms included species stranded, date stranded, condition of the turtle (i.e., alive or dead), size of the turtle (curved carapace length (CCL)), type of entanglement, and fate of the turtle.

Ingestion

Stranded turtles were necropsied following Wolke and George (1981). Prior to necropsy, the species was identified and CCL and width measurements were recorded. During necropsy, the sex of the turtle was determined by visual examination of the gonads. The esophagus, stomach, and intestinal tract were removed from the body cavity and all organs were examined for abnormalities: lesions, ruptures, and parasites. The contents of the digestive tracts were emptied onto a fine-meshed sieve and rinsed with water. Anthropogenic debris was separated from the other food items, catalogued, and saved for later analysis. The remaining food items were preserved in 10% buffered formalin.

RESULTS

Entanglement

Sea turtles became entangled when their head, limbs, or entire bodies accidentally were ensnared in debris or active fishing gear. During the 3-year study, 30 (7.5%) of the 400 sea turtles reported stranded were entangled (Table 1). All of the sea turtle species found in the northwestern Gulf of Mexico had been ensnared. These included 13 Kemp's ridleys, *Lepidochelys kempi*, 7 loggerheads, *Caretta caretta*, 6 hawksbills, *Eretmochelys imbricata*, 3 green turtles, *Chelonia mydas*, and 1 leatherback, *Dermochelys coriacea*. Commercial and recreational fishermen and their lost or discarded gear were responsible for the majority of these incidents. Sea turtles were found entangled in fishing line or hook (9), shrimp trawl (7), net or rope (5), plastic woven produce sacks (4), tar (3), trotline

Table 1.--Incidence of entanglement in sea turtles found stranded on the south Texas coast from 1986 through 1988.

Year	Number of turtles entangled (%)	Total number of turtles stranded
1986	14 (7.8)	179
1987	11 (10.1)	109
1988	5 (4.5)	112
All years	30 (7.5)	400

(1), and crab pot (1). Injuries resulting from their entanglement were responsible for the deaths of seven of these turtles. The remaining 23 turtles were rehabilitated at the University of Texas Marine Science Institute and, with the exception of 1 permanently injured (blind) turtle, were released back into the Gulf of Mexico.

Ingestion

Marine debris was found in the stomachs or intestinal tracts of 60 (54.1%) of the 111 turtles necropsied (Table 2). It was present in 52.3% of the loggerheads, 46.7% of the green turtles, and 87.5% of the hawksbills (Table 3). (No leatherbacks were necropsied during the study.) Shaver (pers. commun.) examined the gut contents of Kemp's ridleys stranded within the same study area and found debris in 29.8% of those turtles (Table 3). Plastic materials were most frequently eaten (Table 4). Most of this material (ca. 60%) was buoyant in nature, but some was not, indicating that sea turtles not only feed on debris floating on the surface of the water, but also feed on debris that is suspended in the water column or is on the bottom.

The incidence of debris ingestion was highest in those turtles stranded during December and lowest in turtles stranded during August (Fig. 1). However, seasonal trends should not be interpreted from these data because recent work by Lutz (pers. commun.) has revealed that sea turtles have the ability to retain plastic in their digestive tracts for prolonged periods of time.

Our ingestion data support Carr (1987), who warned that the young, advanced pelagic stage sea turtles were most vulnerable because they spend the first few years of their life in the open ocean, dependent upon drift lines (areas of high debris concentrations) for their food supply and shelter. Information on the size (carapace length) at which sea turtles become sexually mature (adult) is based upon data collected from females at their nesting beaches. The size at sexual maturity differs among the sea turtle species, varies geographically within a species, and is unknown for male sea turtles. For the purposes of this study, we defined posthatchling

Table 2.--Incidence of debris ingestion in sea turtles found stranded on the south Texas coast from 1986 through 1988.

Year	Number of turtles with debris (%)	Total number of turtles necropsied
1986	10 (40.0)	25
1987	32 (59.3)	54
1988	18 (56.3)	32
All years	60 (54.1)	111

Table 3.--Incidence of debris ingestion by the different sea turtle species found stranded on the south Texas coast from 1986 through 1988.

Species	Number of turtles with debris (%)	Total number of turtles necropsied
Loggerhead, *Caretta caretta*	46 (52.3)	88
Green, *Chelonia mydas*	7 (46.7)	15
Hawksbill, *Eretmochelys imbricata*	7 (87.5)	8
Kemp's ridley, *Lepidochelys kempi*[a]	31 (29.8)	104

[a] D. J. Shaver pers. commun.

Table 4.--Types of debris (and their occurrence) collected from the intestinal tracts of sea turtles found stranded on the south Texas coast from 1986 through 1988.

Type of debris	Number of turtles that had ingested that type	Percent (N = 111)
Plastic bag, pieces	39	35.1
Styrofoam	17	15.3
Plastic, hard pieces	15	13.5
Plastic, line or rope	10	9.0
Plastic beads or pellets	8	7.2
Balloons	7	6.3
Tar	7	6.3
Glass	2	1.8
Paper or cardboard	2	1.8
Aluminum	2	1.8
Stainless steel hook	1	0.9
Latex or rubber	1	0.9
Heat-sealed drink tab	1	0.9

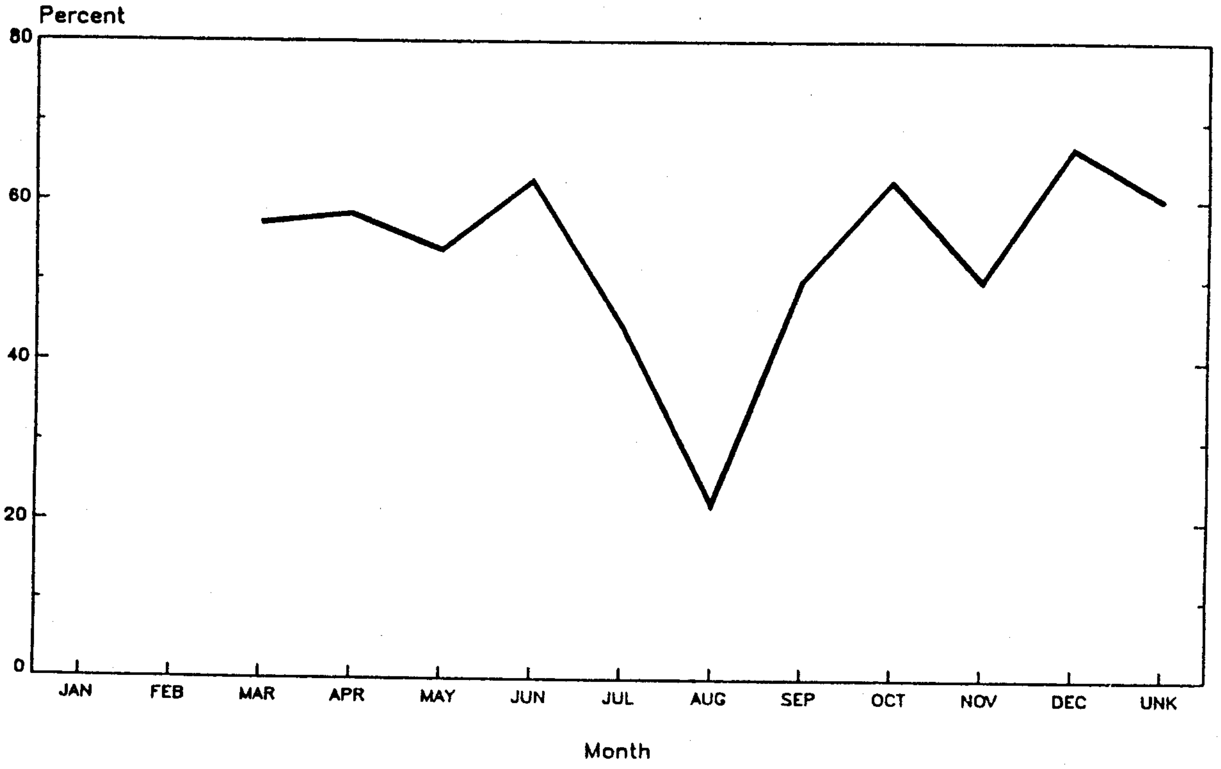

Figure 1.--Percent occurrence (by month) of anthropogenic debris found in the digestive tracts of sea turtles stranded on the south Texas coast.

to 40-cm CCL as advanced pelagic stage turtles, 40-80 cm CCL as subadult turtles, and ≥80-cm CCL or greater as adult turtles. We found debris in 70.8% of the advanced pelagic stage turtles, 55.4% of the subadult turtles, and 31.8% of the adult turtles (Fig. 2).

Debris ingestion resulted in the deaths of four of the turtles necropsied during this study (a noticeable obstruction or blockage in the digestive tract was observed), but could not be implicated in the deaths of the remaining 56 turtles. It was difficult to determine if the debris eaten had caused a turtle's death. For most cases observed, only small quantities of debris were present, and they were usually well mixed in the digestive tracts with the other food items and probably did not contribute to death.

DISCUSSION

A number of the turtles that washed ashore during the study were already missing a limb. Many of these losses were suspected to be the result of a prior entanglement, but because there was no proof, these turtles were not counted as having been entangled. Therefore, we feel that our entanglement numbers may be too small. The reasons why sea turtles become entangled remains unclear. Their natural curiosity towards objects

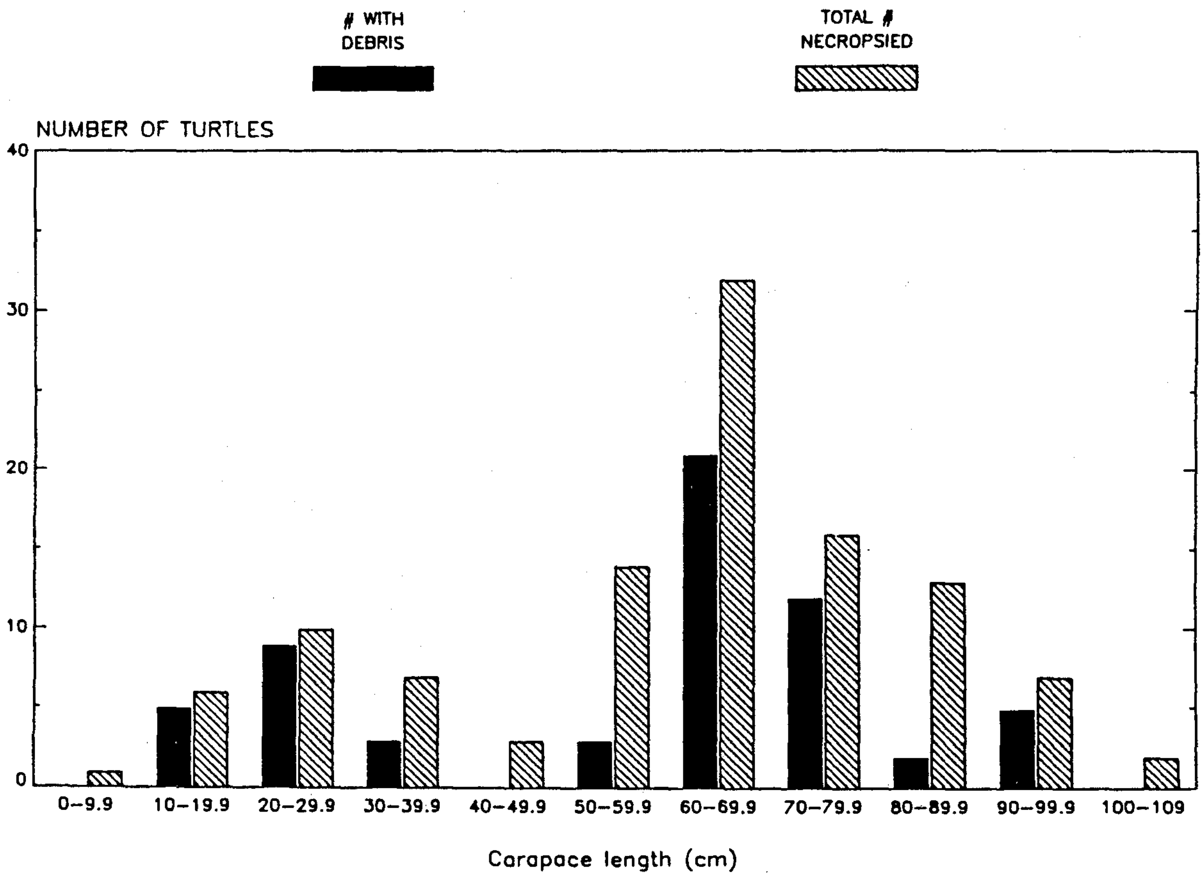

Figure 2.--Occurrence of anthropogenic debris found in the digestive tracts of sea turtles stranded on the south Texas coast from 1986 through 1988 (by carapace length (cm)).

adrift in the water is most often cited as the reason for their propensity for probing near and becoming ensnared in debris. It is likely that sea turtles are attracted to these floating objects because they are seeking food or shelter.

An unusual relationship was found between hawksbills and plastic woven produce sacks (onion sacks). The four incidents of entanglement in those sacks reported here all involved advanced pelagic stage hawksbills (their CCL ranged from 19.4 to 28.5 cm) had their head or limbs caught in the plastic fibers of a produce sack. In addition to our four reports, we know of two other hawksbills that were found entangled in the exact same manner. In 1988, one was found stranded on Galveston Island, Texas (M. Duronslet pers. commun.), and the other was found in April 1989 on the beach at Rancho Nuevo, Mexico (R. Byles pers. commun.). What affinity, if any, hawksbills have for onion sacks is unknown. More behavioral studies of all of the sea turtle species are necessary before we can explain how and why they become involved in these situations.

Debris was eaten by more than half of the turtles necropsied during this study, and while this ingestion did not appear to result in the deaths of the majority of these turtles, its presence in the digestive tracts of so many is indicative of the pervasiveness of anthropogenic debris in the northwestern Gulf of Mexico. It has been suggested that sea turtles eat debris because it resembles their natural prey or perhaps because epizoic or epiphytic growth on the debris has attracted the turtle. Before man began discarding his nonbiodegradable wastes into the oceans, sea turtles did not have to differentiate between what was edible and what was not, because essentially everything was edible. In the Gulf of Mexico, the offshore oil industry, cargo ships, research vessels, commercial and recreational fishing boats, and other seagoing vessels are primarily responsible for the trash discarded at sea which eventually is consumed by many sea turtles. Prevailing currents and winds drive virtually all of the trash that is dumped into the Gulf of Mexico (and to a lesser extent the Caribbean) to the northwestern Gulf of Mexico and onto the Texas coast.

Annex V of MARPOL (implemented domestically by the Act to Prevent Pollution from Ships) came into effect on 31 December 1988. This annex prohibits the dumping of plastics at sea and regulates how far from shore other anthropogenic debris may be discarded. The passage of this law probably will not deter the many who have grown accustomed to dumping their trash overboard. This law needs to be enforced at sea and at the ports, and those who are guilty should be fined as one means of controlling the oceanic debris problem. Most importantly, people need to be educated and convinced to save their refuse until they can properly dispose of it on land.

Certain bodies of water such as the Mediterranean Sea were given special designation under Annex V of MARPOL. These areas have been afforded extra protection because of their unique oceanographic or ecological conditions, and it is now illegal to discard any type of debris in these waters. The Gulf of Mexico was considered a candidate for this special protection, but was not designated as such when Annex V was passed. The semienclosed nature of the Gulf of Mexico, the prevalence of marine debris in these waters and on adjacent beaches, and the importance of this area as a habitat for sea turtles (in particular the critically endangered Kemp's ridley sea turtle) should be enough justification for its designation as a special area. The likelihood that a sea turtle inhabiting the Gulf of Mexico will come into contact with anthropogenic debris is quite substantial.

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ON THE SYNTHETIC MATERIALS FOUND IN THE DIGESTIVE SYSTEMS OF, AND DISCHARGED BY, SEA TURTLES COLLECTED IN WATERS ADJACENT TO JAPAN

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ABSTRACT

It has been recognized that five species of sea turtles are common in waters adjacent to Japan: *Caretta caretta*, *Chelonia mydas*, *Eretmochelys imbricata*, *Lepidochelys olivacea*, and *Dermochelys coriacea*. Stranded, live turtles collected along the coast of central and southern Japan were examined, and most were found to have ingested synthetic materials into their systems during the research period. The main types of plastics found were transparent bags or sheeting, monofilament fishing line, and rope parts. Large plastic sheets were ingested particularly by the leatherback turtle, *D. coriacea*. It is concluded that most of the sea turtles found in waters adjacent to Japan have a high frequency of plastic ingestion.

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PLASTIC INGESTION IN A PYGMY SPERM WHALE, *KOGIA BREVICEPS*

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ABSTRACT

An adult female pygmy sperm whale, *Kogia breviceps*, (2.9 m body length) and a young male (1.8 m body length) thought to be her calf stranded alive on Galveston Island on 1 January 1984. Both animals were transported to a holding tank for observation and treatment. The female was extremely weak and died on the third day of captivity. Severe multiple mucosal ulcerations were found throughout all stomach chambers during necropsy. In contrast, the calf initially appeared to be thriving. He was able to swim unassisted and eventually began to make shallow dives. Force feeding was begun, and on the eighth and ninth days he voluntarily accepted squid placed in front of him. However, on the tenth day he suddenly weakened, lost interest in feeding, and died. On necropsy, the first two stomach compartments (forestomach and fundic chamber) were found to be completely occluded by a plastic garbage can liner, a bread wrapper, a corn chip bag, and two other pieces of plastic sheeting. The small third stomach chamber (connecting channel) prevented passage of the debris farther along the gastrointestinal tract. A severe inflammation within the abdominal cavity was also found which was diagnosed as the immediate cause of death and thought to be secondary to the gastric obstruction. The primary food item for this species is squid, and it is feasible that suspension of this debris in the water column may have been mistaken as prey by the inexperienced calf.

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INGESTION OF PLASTIC DEBRIS BY STRANDED MARINE MAMMALS FROM FLORIDA

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ABSTRACT

Ocean pollution in the form of plastic debris has been recently recognized as a major threat to marine wildlife. Injuries and fatalities caused by entanglement and ingestion of floating and submerged debris have been documented for an increasing number of marine vertebrates (mammals, birds, turtles, fish). Ingested plastics may cause a false sensation of fullness, decreasing feeding bouts, or may obstruct normal passage of food through the digestive tract.

Ingestion of plastic material is reported here for five species of marine mammals stranded along the Florida coast. These include four cetacean species (bottlenose dolphin, *Tursiops truncatus*; false killer whale, *Pseudorca crassidens*; pygmy sperm whale, *Kogia breviceps*; dwarf sperm whale, *K. simus*) and the sirenian, *Trichechus manatus* (West Indian manatee), from both coastal (*Tursiops truncatus*, *T. manatus*) and pelagic (*P. crassidens*, *K. breviceps*, *K. simus*) habitats. Debris included plastic jugs, disposable surgeon gloves, plastic bags, and monofilament lines. Plastic debris was usually found with food items (vegetation, and fish and cephalopod remains). On at least one occasion (an emaciated *T. truncatus*), ingestion of such material is believed to have contributed to death. With the increasing littering of the Florida coastline, plastic impact on marine mammal populations may be much more widespread than previously reported.

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SURVEY OF MARINE DEBRIS INGESTION BY ODONTOCETE CETACEANS

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ABSTRACT

Odontocete cetaceans are affected to an unknown degree by the ingestion of oceanic debris. Published accounts discuss primarily the sperm whale, *Physeter macrocephalus*.

The pathologic effects of foreign body ingestion on captive cetaceans are well documented, and provide background information on the potential effects of debris ingestion on wild, free-ranging animals. A survey of major institutions reveals 40 incidences of debris ingestion in 16 species of stranded odontocete cetaceans. Plastic debris was prevalent, with a total occurrence of 80.0%. Evidence indicates ingestion of debris may be secondary to the stranding syndrome. A survey of prior food habits analyses on 10 species of odontocete cetaceans was conducted. All species combined, a total of 1,790 stomachs were examined. Marine debris was encountered only in Baird's beaked whale, *Berardius bairdii*, taken at two localities in the coastal waters of Japan. In *B. bairdii* taken off the Pacific coast of central Japan, debris incidence in 86 stomachs was 26.7%. Plastic debris made up 39.1% of the foreign material ingested. Off northern Hokkaido, in the southern Okhotsk Sea, incidence of debris in 20 stomachs was 15.0%. Food habits data indicate that the lower frequency of debris ingestion is related to differences in feeding strategy in the northern region.

In the wild state odontocete cetaceans are probably discriminating feeders. Evidence indicates that the high occurrence of debris in *Physeter macrocephalus* and *B. bairdii* is due primarily to incidental ingestion along with benthic prey.

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INTRODUCTION

The quantity of increasingly diverse marine litter discarded into the world's oceans is reaching enormous proportions. Billions of pounds of debris are dumped into the sea each year (Carpenter and Smith 1972; Venrick et al. 1973; Wong et al. 1974; Morris 1980a, 1980b; Van Dolah et al. 1980; Eldridge 1982; O'Hara et al. 1988). Recent studies reveal this to be more than an aesthetic problem. Debris, particularly nonbiodegradeable plastics, is accumulating in the marine environment and causing significant mortality in some marine animals (Wallace 1985).

In 1984, the first Workshop on the Fate and Impact of Marine Debris was held in Hawaii. Papers presented confined their data on ingestion of marine debris largely to marine birds (Day et al. 1985) and turtles (Balazs 1985; Cawthorn 1985). The potential problem of debris ingestion by marine mammals was not addressed, with only anecdotal accounts appearing in the proceedings (Cawthorn 1985; Mate 1985).

Ingestion of debris by cetaceans does occur. Early accounts of an impressive array of nonfood items ingested by the sperm whale, *Physeter macrocephalus*, are well known (Turner 1903; Millais 1906; Hollis 1939; Pike 1950; Sleptsov 1952; Clarke 1956; Berzin 1959, 1971; Caldwell et al. 1966). Berzin (1971) discusses accounts of "several vinyl chloride bags" found in North Pacific sperm whale stomachs as early as 1961. More recent accounts of debris ingestion involve stranded cetaceans (Wehle and Coleman 1983; Cawthorn 1985; Mate 1985; Cowan et al. 1986).

It is evident that there is a need for research on the occurrence and potential impact of cetacean debris ingestion. This study, though confined to the toothed cetaceans (odontoceti), begins to address this subject. It is divided into three major areas of inquiry. 1) Investigate the effects of foreign body ingestion by captive cetaceans maintained by marine aquariums in order to assess the potential effects of debris ingestion in the wild. 2) Conduct a survey on incidences of debris ingestion in stranded cetaceans. 3) Survey incidence of marine debris in food habits analyses conducted on free-ranging cetacean populations.

METHODS OF DATA COLLECTION

Information on the pathologic effects of captive cetacean foreign body ingestion was derived from the literature and the senior author's personal experience as biologist and curator at Marineland of the Pacific during the period 1968-74.

Records of debris ingestion in stranded odontocete cetaceans were solicited from institutions and persons known to include stomach content examination as part of a coordinated stranded animal recovery program. Due to variation in recordkeeping and necropsy techniques imposed by a 24-year time frame (1963-86), frequency of occurrence data on debris ingestion could not be reliably derived. Accounts from the literature were not included unless sufficient information on time frame, locality, and nature of ingested debris was available.

Data on evidence of debris ingestion in free-ranging odontocete cetaceans were obtained from food habits studies conducted on animals collected at sea as a result of incidental fisheries interactions or directly taken for research or commercial purposes. In each case, personnel directly involved in the preliminary stomach content sorting procedures were interviewed. Unusual items encountered during this stage tend to be remembered (though not necessarily recorded). An "I don't recall" response during the interview resulted in elimination of the study from the data base.

In some instances determinations as to whether ingested objects constitute debris directly ingested or introduced secondarily through prey species presented a problem. Tiny bits of plastic and isolated fishhooks are particularly suspect. Fish are well known to be attracted to and ingest man-made objects. Recently ingestion of plastic particles by oceanic squid has been documented (Araya 1983; Machida 1983). For purposes of this study, animals containing only isolated fishhooks were noted but not included in the frequency data presented.

As this study progressed, it became apparent that there are probably more isolated incidences of debris ingestion in odontocete cetaceans than we were able to locate in the time allowed. We welcome any oversights brought to our attention so the records may be included in a future revision of this report.

RESULTS

Captive Cetacean Foreign Body Ingestion

Mortality in marine parks and zoos due to foreign body ingestion is well documented in the literature. Brown et al. (1960) described causes of mortality in a major oceanarium, Marineland of the Pacific, during the first 5 years of operation. Three of those years were summarized as follows: "The losses occurring during the years 1955 to 1958 were, with few exceptions, caused by animals swallowing indigestible foreign material and resulting in gastric and enteric impactions." Nakajima et al. (1965) reported that 18 of 92 (19.6%) dolphin casualties at Enoshima Aquarium in Japan between 1958 and 1965 had foreign material in their stomachs. Caldwell et al. (1965) described a simultaneous mortality of three trained bottlenose dolphins at Gulfarium in Florida. They died from ingesting plastic strips from the tank enclosure. "Balls of plastic up to four inches in diameter were found in the first stomach of these animals."

During the senior author's tenure at Marineland of the Pacific, numerous cetaceans died as a result of ingestion of foreign material. One trained Pacific bottlenose dolphin was particularly noteworthy in that it had ingested a piece of a polyethylene plastic bag ca. 0.19 m (2 ft square). Necropsy findings revealed that while the major portion of the bag remained in the forestomach, a small section extended through the sphincter and into the gastric stomach. Tissue pathology was extensive. Approximately one-half of the forestomach lining and submucosa had eroded away, with necrotic tissue and inflammation extending deep into the musculature of the stomach wall. The stomach wall and serosa adjacent to this lesion were edematous and thickened five to six times beyond normal. It was surmised that the effect of the plastic protruding through the sphincter into the gastric stomach caused an excess of digestive fluids to be released into the forestomach, severely injuring those portions of stomach lining insulated by plastic.

Captive cetaceans have been known to ingest a wide variety of foreign material. Objects such as cotton gloves, tin cans, plastic bags, bottles, pens, coins, flashbulbs, plastic combs, nails, steel wool cleaning pads, plastic toys, and women's jewelry are some of the articles reported (Brown et al. 1960; Amemiya 1962; Caldwell et al. 1965; Nakajima et al. 1965; Ridgway 1965, 1972; Brown et al. 1966).

The reasons for the high incidence of foreign body ingestion in captive cetaceans are not clear. The captive environment, due to its obvious spatial limitations, is at best an abnormal one. The social behavior of these animals has been severely altered (Caldwell et al. 1968). Ridgway (1972) suggested that since captive animals are taught to consume dead fish, they may consider any object entering the pool as edible. Excitement of training, performing, play behavior, and competition for food may also be contributing factors (Nakajima et al. 1965).

What is clear from the accounts on captive cetacean ingestion of foreign objects is that it has the potential for being a direct cause of mortality, or at least debilitating to a degree which could predispose animals to disease or predation in the wild state.

Stranded Animal Debris Ingestion

Case descriptions of stranded animal debris ingestion by species are presented in Table 1. A total of 43 accounts were available, spanning a period of time from 1963 to 1986. Sixteen species of odontocete cetaceans were involved.

Reports on debris ingestion came primarily from the east and west coasts of North America (37 and 58%, respectively). Only one record each was obtained from the Gulf of Mexico (Texas) and Hawaii. The differences in frequency probably reflect regional variation in stranded cetacean recovery and detailed necropsy techniques rather than true geographic differences in abundance of marine debris.

The kinds of debris ingested varied considerably. Plastic bags and plastic sheeting were the most prevalent items (62.5%). Other miscellaneous plastic articles such as drinking straws, bottle caps, discarded fishing net, synthetic rope, and a small container occurred in 17.5% of the cases. The total occurrence for all plastic debris was 80.0%. Nonplastic debris such as rubber balloons, asphalt, cellophane, cloth, paper, and metal articles (excluding fishhooks) was encountered in 37.5% of the cases reported. Fragments of marine plants, which are also abnormally ingested, were encountered in 32.6% of the stomachs examined.

Table 1.--Records of the ingestion of marine debris by stranded odontocete cetaceans.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
			Physeter macrocephalus, sperm whale			
--	6/79	Florence, OR	--	--	About 1 L of tightly packed trawl net in stomach. One of 38 stomachs examined from a mass stranding of 41 animals	Mate 1985.
Sp-1	6/7/79	Purgatory Bay, Bonavista Cove, Newfoundland, Canada	1,030	F	Small length of nylon rope and unidentified debris	U.S. National Museum.[a]
MME01362	7/1/85	Seaside, NJ	510	--	Mylar balloon	U.S. National Museum.[a]
			Kogia simus, dwarf sperm whale			
USNM504132	12/4/74	Corolla, NC	178	F	Plastic Wonderbread bread wrapper	U.S. National Museum.[a]
			Kogia breviceps, pygmy sperm whale			
CMNH0216	4/27/76	Sullivan's Island, SC	318	F	Two small pieces of thin plastic	Charleston Museum.[b]
MME00549	1/1/84	Galveston, TX	182	M	Pounds of plastic bags clogging its stomach chambers	U.S. National Museum;[a] Wehle and Coleman 1983.
MME01263	5/17/85	Brevard Co., FL	320	M	Plastic bag	U.S. National Museum.[a]

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
Ziphius cavirostris, Cuvier's beaked whale						
JRH-087	11/20/80	San Diego, CA	526	M	Piece of asphalt	Southwest Fisheries Science Center.[c]
USNM550111	1/7/81	Assawaman, VA	580	F	Large plastic bag and plastic wrappers	U.S. National Museum.[a]
USNM550734	1/27/86	Seaford, VA	512	F	Plastic straw and a horse chestnut	U.S. National Museum.[a]
Mesoplodon europaeus, Gervais' beaked whale						
USNM550018	11/22/80	Hatteras Island, NC	311	M	Large piece of clear plastic bag	U.S. National Museum.[a]
USNM550362	12/28/83	Cape May, NJ	371	F	Stomach filled with plastic bag	U.S. National Museum.[a]
Mesoplodon densirostris, Blainville's beaked whale						
USNM550754	2/14/86	East Hampton, NY	420	M	One plastic bottle cap	U.S. National Museum.[a]
Globicephala macrorhynchus, short-finned pilot whale						
USNM550310	5/18/83	Corolla, NC	275	M	Small plastic container	U.S. National Museum.[a]
Steno bredanensis, rough-toothed dolphin						
USNM504462	6/28/76	Maui, HI	215	F	Plastic bag in stomach. This animal was one of nine mass stranded on 6/28/76.	U.S. National Museum.[a]

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
USNM504486	10/12/76	Sandbridge, VA	206	M	Two pieces of heavy black plastic. This animal and one below are part of mass stranding of 13 on 10/12/76	U.S. National Museum.[a]
USNM504494	10/12/76	Sandbridge, VA	233	M	One large fishhook loose in stomach	U.S. National Museum.[a]
Lagenorhynchus obliquidens, Pacific white-sided dolphin						
--	8/29/63	Santa Monica, CA	165	M	Piece of paper wadded into a 5.1 cm (2-in) ball along with seaweed, squid beaks, and roundworms.	Caldwell et al. 1965.
WAW-130	8/15/71	Santa Monica, CA	167	M	Stomach contained numerous small plastic bags, pieces of cardboard, and waxed paper. Numerous kelp fronds (*Macrocystis pyrifera*) also present. This animal had been observed inside a yacht harbor for 10 days prior to stranding. Necropsy diagnosed parasitic central nervous system pathology and hepatitis as cause of death.	W. Walker, unpubl. data; Cowan et al. 1986.
WAW-174	9/21/72	Long Beach, CA	176	F	Forestomach half full of four plastic bags, two plastic bottle caps, and numerous small sticks, twigs, leaves, and kelp fronds	W. Walker, unpubl. data. Pathology data from Cowan et al. 1986

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
					(*Macrocystis* and *Egregia*). One No. 4 fishhook snagged in stomach lining. Necropsy diagnosed central nervous system pathology due to parasitism by the trematode, *Nasitrema* sp.	
WAW-192	7/18/83	Santa Monica, CA	188	F	Three small plastic bags, one plastic drinking straw, one Calif. Dep. Fish Game mackerel fish tag No. M-11283. Tag is 5.1 cm (2 in) long, yellow, spaghetti type. Necropsy diagnosed central nervous system pathology due to parasitism as cause of stranding.	W. Walker unpubl. data. Pathology data from Cowan et. al. 1986.
			Delphinus delphis, common dolphin			
WAW-148	2/12/72	Malibu, CA	173	F	One 15 * 15 cm plastic bag, several kelp fronds (*Macrocystis pyrifera*). Cause of stranding diagnosed as parasitism of central nervous system.	W. Walker unpubl. data. Pathology data from Cowan et al. 1986.
WAW-172	9/8/72	Will Rogers State Beach, Los Angeles County, CA	190	M	Two 20-cm^2 pieces of cellophane; one small piece of black plastic plastic (approximately 3 cm^2), and portions of marine plants (*Macrocystis*, *Egregia*, and	W. Walker unpubl. data. Pathology data from Cowan et al. 1986.

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
					Phyllospadix). Cause of stranding diagnosed as parasitism of central nervous system.	
LACM72286	11/24/80	Hermosa Beach, CA	197	F	One rusted fishhook embedded in stomach wall. Necropsy revealed an apparently unrelated massive tumor or abscess in abdomen adjacent to left kidney.	Los Angeles County Museum of Natural History.[d]
JEH331	4/25/86	Will Rogers State Beach, Los Angeles County, CA	193	F	Stomach contained one partial red balloon (3 × 13 cm), one piece of clear plastic (8 × 13 cm), and kelp fronds (*Macrocystis pyrifera*).	Los Angeles County Museum of Natural History.[d]
Tursiops truncatus, bottlenose dolphin (All southern California coastal population)						
WFP-559	2/5/77	La Jolla, CA	302	M	One rusted metal bottle cap beach sand, fragments of kelp fronds	W. Walker unpubl. data.
WAW-141	12/26/71	Huntington Beach, CA	207	F	Three approximately 20-cm^2 pieces of heavy clear plastic approximately 3 mil thick; several littorinid snail shells	W. Walker unpubl. data.
WFP-535	8/9/76	La Jolla, CA Diego County, CA	313	M	Two cellophane cigarette wrappers one rusted fishhook, kelp fronds (*Egregia* sp.)	W. Walker unpubl. data.

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
WFP-537	8/31/76	Encinitas, CA	--	F	One blue vinyl plastic strip (3 × 30 cm); kelp frond fragments, one gastropod operculum.	W. Walker unpubl. data.
WFP-565	1/27/77	Del Mar, CA	267	M	One black rubber "bungie cord" with metal hooks at ends (2 × 1 × 40 cm), sand, mollusc shell fragments	W. Walker unpubl. data.
WAW-553	9/2/78	Huntington Beach, CA.	231	F	One partial shoelace, beach sand, mollusc shell fragments	W. Walker unpubl. data.
JRH-057	5/13/80	La Jolla, CA	251	F	Two plastic bags, one 20 × 20 cm, other partial 40 × 15 cm; kelp fronds (*Macrocystis pyrifera*), beach sand, gravel, shell fragments	W. Walker unpubl. data. data.
LJH-006	11/14/81	San Diego, CA	236	F	Metal spring (2.0 × 20 cm)	Southwest Fisheries Science Center.[d]
HJB-036	9/3/86	Solana Beach, CA	U	M	Two fishhooks ca. 2.5 cm (1 in) long	Southwest Fisheries Science Center.[c]
Grampus griseus, Risso's dolphin						
SEAN7595	5/6/82	Martha's Vineyard, MA	230	M	Plastic bag in throat	New England Aquarium and U.S. National Museum of Natural History.[a]

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
LACM47145	12/8/84	Manhattan Beach, CA	225	--	Blue balloon, partial (20 × 2.5 cm)	Los Angeles County Museum of Natural History.[d]
Stenella coeruleoalba, striped dolphin						
DAP-001	3/22/83	Cape Point, NC	220	M	Plastic bag in stomach	U.S. National Museum[a] of Natural History, Smithsonian Institution, Wash., D.C.
Lissodelphis borealis, northern right whale dolphin						
WAW-194	8/2/73	Will Rogers State Beach, Los Angeles County, CA.	211	F	One partial plastic bag in mouth, remainder 25 × 30 cm in forestomach; fronds of marine plants *Macrocystis*, *Cystoseira*, and *Egregia*; one honey bee (hymenoptera); three white bird feathers. Necropsy diagnosed parasitism of central nervous system as cause of stranding *Cystoseira*, and *Egregia*; one honey bee (hymenoptera); three white bird feathers. Necropsy diagnosed parasitism of central nervous system as cause of stranding	W. Walker unpubl. data.

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
WAW-209	10/4/73	Santa Monica, CA	225	F	Several small bits of blue vinyl plastic (ca. 2 cm^2); one rusted metal bottle cap; 10-12 pieces of kelp fronds (*Macrocystis pyrifera*). Cause of stranding undetermined.	W. Walker unpubl. data.
					Phocoena phocoena, harbor porpoise	
USNM504220	3/1/75	Corolla, NC	--	--	Piece of cloth and plastic in stomach	U.S. National Museum.[a]
					Phocoenoides dalli, Dall's porpoise	
LACM54739	7/2/73	Venice Beach, CA	222	M	Stomach jammed with debris as follows: 13 pieces of clear plastic sheets ranging in size from 4 × 9 cm to 35 × 41 cm; 1 piece black plastic 5 × 16 cm; 3 heavy, clear plastic bags 20 × 39 cm; 2 sandwich bags both 14 × 20 cm; 2 plastic bread bags both 23 × 47 cm; 1 plastic drinking straw; 2 pieces of crumpled cardboard approximately 10 × 13 cm; kelp fronds (*Macrocystis pyrifera*). Necropsy not performed due to autolysed condition of tissues. Cause of stranding undetermined.	Los Angeles County Museum of Natural History[d] and Walker unpubl. data.

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
WAW-197	8/10/73	Santa Barbara Yacht Harbor, CA	190	F	One blue plastic bottle cap; one 20 × 20 cm plastic bag. The remainder of the forestomach is jammed with kelp, *Macrocystis pyrifera*. Necropsy diagnosed parasitic central nervous system disorder as cause of stranding. Animal had been observed in the harbor 3 days prior to stranding.	W. Walker unpubl. data; Cowan et al. 1986.
SBMNH 78-47	11/8/78	Carpenteria State Beach, Santa Barbara County, CA	204	M	Pieces of plastic bags and kelp in stomach	Santa Barbara Museum of Natural History, Santa Barbara, CA.

[a] Charleston Museum of Natural History, Charleston, S.C.
[b] U.S. National Museum of Natural History, Smithsonian Institution Washington, D.C.
[c] Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, Calif.
[d] Los Angeles County Museum of Natural History, Los Angeles, Calif.

In one case (WAW-192), a small spaghetti-type mackerel fish tag was found in the stomach. This item was undoubtedly introduced secondarily through ingested prey (*Scomber japonicus*).

Autopsy data were available in eight (18.6%) of the cases (WAW-130, 174, 192, 148, 172, 194, 197, and LACM 72286). Chronic pre-existing disease was present in all instances. In seven of these cases, brain parasitism by the trematode *Nasitrema* sp. was diagnosed as the primary cause of stranding. All these cases occurred in southern California. In two isolated instances (WAW-130 and 197), the animals were observed for up to 10 days inside a boat marina breakwater prior to stranding.

In the southern California area, brain parasitism due to *Nasitrema* sp. has proven to be a common pathologic factor in individual strandings of small cetaceans (Ridgway 1965; Ridgway and Dailey 1972; Dailey and Walker 1978; Cowan et al. 1986). Cowan et al. (1986) found 91% parasitized brains in 44 brains examined in 4 species of stranded cetaceans. No marine debris-related gastrointestinal pathology was evident in any of the 23 southern California strandings summarized in Table 1.

Naturally occurring disease factors may predispose these animals to ingest abnormal objects. The high incidence of pre-existing brain parasitism and the absence of debris-induced gastrointestinal pathology suggest that the significance of marine debris in stranded cetaceans should remain questionable unless accompanied by related pathologic changes and a complete necropsy and tissue analysis of all major organ systems.

Marine Debris Encountered in Food Habits Analyses of Free-Ranging Animals

Data on 10 species of odontocete cetaceans were available (Table 2). All species combined, a total of 1,790 stomachs had been examined. The geographic regions covered in the sample are diverse. Localities in the North Pacific and Bering Sea represented 81.5% of the sample. The Okhotsk Sea represented 5.9% and the remaining 12.6% were collected off the coast of Uruguay in the South Atlantic. Of the 10 species of cetaceans reported, only the Baird's beaked whale, *Berardius bairdii*, taken at 2 different localities in the coastal waters of Japan had ingested debris. In 86 *B. bairdii* taken off Chiba Prefecture, central Japan, the frequency of debris ingestion was 26.7%. A lower incidence of debris was evident in 20 *Berardius* examined from the southern Okhotsk Sea, where frequency of ingestion was 15.0%. Overall frequency for both areas sampled was 24.5%.

The nature of debris material ingested by *B. bairdii* from both regions was diverse (see Tables 3 and 4 for detailed accounts). Occurrence of plastic bags and sheeting was 30.8%. Other plastic articles including discarded fishing gear had a frequency of 11.5%. All plastic material combined was 42.3%. Miscellaneous nonplastic material such as vegetable refuse, wood boards, concrete fragments, pieces of glass, cigarette filters, cellophane, rubber material, a roof tile fragment, bottle caps, rusty hinge, aluminum can pull tabs, and a metal butane lighter top had an occurrence of 76.0%. Observations made during collection of stomach content samples revealed no debris-associated lesions or evidence of impaction.

Examination of the data in Tables 3 and 4 reveals that the major portion of debris found in *B. bairdii* stomachs were negatively buoyant items probably ingested at or near the ocean bottom.

Differences in the frequency of debris ingestion between the Pacific coast of central Japan (26.7%) and the southern Okhotsk Sea (15.0%) are probably due to regional differences in feeding strategy. Off the Pacific coast of central Japan, *Berardius* are known to feed primarily on benthic prey. In this region they are documented to be feeding on bottom-dwelling morid and macrourid fishes (81.7%). Cephalopods represented only 18.0% of the consumed prey. In addition, stones and gravel were encountered in all stomachs examined and were undoubtedly consumed incidentally during bottom feeding (Walker and Mead 1988). In the southern Okhotsk Sea, *Berardius* feeding strategy changes considerably. In this region, cephalopod prey are dominant (87.6%) in the food habits sample. The predominantly benthic morid and macrourid fishes represent only 8.2% of the prey. Stones and gravel were encountered in only 10.0% of the stomachs examined (W. A. Walker unpubl. data).

The other nine species of cetaceans summarized in Table 2 are known to feed primarily in the epipelagic and mesopelagic zones in the upper water column. Debris occurrence in all 1,684 stomachs examined was 0. The stomach sample for these nine species is small compared to conservative, stock-level, population estimates. As a result, the absence of marine debris in the species summarized in Table 2 is inconclusive. However, some inference can be made from the Dall's porpoise, *Phocoenoides dalli*, samples from the northern North Pacific and Bering Sea. Both these regions are documented to have a high density of marine debris (Venrick et al. 1973; Feder et al. 1978; Shaw and Mapes 1979; Dahlberg and Day 1985). Eight hundred fifteen *Phocoenoides* stomachs were examined from these regions and no debris items were encountered.

DISCUSSION

Accounts of mortality and pathology caused by foreign body ingestion in captive cetaceans leave little doubt as to the potential effects of marine debris in wild, free-ranging cetaceans.

Most of the available records of debris ingestion are from stranded odontocete cetaceans. However, debris ingestion in singly stranded animals may be, in a large percentage of cases, part of the stranding syndrome. Pre-existing disease factors related to parasitism occurred in almost all cases accompanied by complete necropsy observations.

Debris ingestion data on free-ranging animals derived from previously conducted food habits studies were, with the exception of Baird's beaked whale, negative. Of the 10 species summarized in Table 2, *B. bairdii* is the only species of cetacean known to demonstrate regionally varying degrees of deepwater bottom-feeding strategy. All the remaining nine

Table 2.--Summary of ingested marine debris encountered in food habits analyses of free-ranging small cetaceans.

Species	Date	General location	Collection method	Sample size	Debris occurrence	Information source
Berardius bairdii	1988-89	Taken in the southern Okhotsk Sea off northern Hokkaido, Japan	Shore-based harpoon fishery	20	15.0%	W. Walker unpubl. data. For detailed summary see Table 4.
Berardius bairdii	1985-87	Taken off the Pacific coast of central Japan	Shore-based harpoon fishery	86	26.7%	W. Walker and J. G. Mead unpubl. data. Food habits data in Walker and Mead 1988. For detailed summary see Table 3.
Steno bredanensis	1977-87	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna fishery	16	0	W. Walker and J. G. Mead unpubl. data.
Lagenorhynchus obliquidens	1979-72	Collected off the coasts of Washington and California	Collected at sea for research purposes	44	0	C. Fiscus, food habits data presented in Stroud et al. 1981.
Delphinus delphis	1977-80	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna pursue seine fishery	32	0	Southwest Fisheries Science Center, La Jolla, CA, unpubl. data.
Tursiops truncatus	1972 87	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	35	0	W. Walker unpubl. data; food habits data presented (in part) in Walker 1981.
Stenella attenuata	1968-77	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	231	0	Southwest Fisheries Science Center, La Jolla, CA, food habits data (in part) published in Perrin et al. 1973.

Table 2.--Continued.

Species	Date	General location	Collection method	Sample size	Debris occurrence	Information source
Stenella coeruleoalba	1977-80	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	104	0	Southwest Fisheries Science Center, La Jolla, CA, unpubl. data.
Stenella longirostris	1968-80	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	78	0	Southwest Fisheries Science Center, La Jolla, CA, published (in part) in Perrin et al. 1973.
Phocoenoides dalli	1988	Okhotsk Sea, Japan ca. lat. 44#10'N, long. 144#30'E	Shore-based hand-harpoon fishery	86	0	W. Walker unpubl. data.
Phocoenoides dalli	1979-86	Northern North Pacific and Bering Sea	Incidental take of Japanese high seas salmon gillnet fishery	815	0	T. Crawford and L. Tsunoda, Northwest and Alaska Fisheries Center, National Marine Mammal Laboratory, Seattle, Wash. Food habits data presented (in part) in Crawford 1981.
Phocoenoides dalli	1958-72	Collected off the coasts of Washington and California	Collected at sea for research purposes	17	0	C. Fiscus; food habits data in Stroud et al. 1981.
Pontoporia blainvilli	1969-75	Off the coast of Uruguay, South America (ca. lat. 34#30'S)	Incidental take in local shark gillnet fisheries	226	0	R. Brownell, Jr. and W. Walker. Prey species accounts on 11 animals in Fitch and Brownell 1971.

Table 3.--Summary of ingested marine debris in 86 *Berardius bairdii* taken at Wadaura, Chiba Prefecture, Japan, 1985-87.

Specimen No.	Date	Length (m)	Sex	Age (year)	Description of debris
85-008	7/23/85	10.10	M	23	Vegetable refuse--approximately 1 dozen coffee beans.
85-015	7/28/85	9.85	M	73	Three small glass fragments (two clear, one brown) approximately 1.5 × 2 × 0.5 cm, edges worn; two cigarette filters.
85-017	7/29/85	10.05	F	23	One cigarette filter and a piece of tree bark.
85-018	7/30/85	10.43	M	31	One No. 2 size rusted fishhook.
85-021	8/1/86	10.00	M	51	One piece of wadded-up longline approximately 15 cm diameter with 15-20 rusted No. 2 size hooks. The main lines and branch lines are made up of braided No. 7 nylon net twine with hooks set approximately 120 cm apart. Condition of this object suggests recent ingestion of discarded fishing gear.
85-022	8/1/85	9.90	M	21	One piece of black plastic (25 × 15 cm) approximately 1.5 mil thick and vegetable refuse--two corn kernels, *Zea maise*.
85-023	8/2/85	10.70	F	54	One fishhook--only rusted shank and small portion of leader remain.
85-024	8/2/85	9.90	M	84	One piece of black vinyl plastic (130 × 135 × 0.3 cm).
85-026	8/3/85	9.65	M	8	One 45 × 3 cm mahogany stick with staples.
85-033	8/6/85	9.62	M	70	One 20 × 15 cm thin plastic sheet (food wrapper?); cellophane package material (8 × 6 cm). Vegetable refuse--one undigested potato (5 × 6 × 3 cm) two pieces of tree bark (3-4 × 5-6 cm).

Table 3.--Continued.

Specimen No.	Date	Length (m)	Sex	Age (year)	Description of debris
85-031	8/5/85	9.50	M	60	One 8 × 10 × 0.5 cm irregular-shaped piece of clear plastic (PVC?).
86-004	7/27/86	10.75	F	22	One 10 × 15 × 1.0 cm piece of pine board.
86-011	7/29/86	10.40	F	53	One 12 × 2 × 1 cm piece of wood; one 20 × 30 cm black plastic sheet approximately 3 mil thick.
86-012	7/30/86	9.70	M	17	Two fragments of clear plastic 4 × 3 cm and 6 × 2 cm, both approximately 3 mil thick.
86-020	8/7/86	9.10	F	8	One 5 × 6 × 2 cm fragment of blue glazed roofing tile, two cigarette filters.
86-026	8/9/86	10.20	M	26	One 10 × 10 cm piece of concrete; one bottle cap; one 6 × 6 × 2 cm piece of tree bark.
86-028	8/10/86	9.70	M	38	One fragment of 20 × 15 × 0.3 cm rubber mat and 3-4 bird feathers.
87-013	7/29/87	10.32	M	56	Vegetable refuse--25-30 soybeans; one badly rusted metal hinge.
87-014	7/29/87	10.80	F	40	One 3 × 4 × 3 concrete fragment; two pieces of cellophane (both approximately 8 × 15 cm).
87-015	8/1/87	10.60	F	19	Vegetable refuse--10-15 soybeans, 8 corn kernels, *Zea maise*; 1 aluminum pull tab.
87-016	8/1/87	10.20	F	17	One corroded fishhook; one metal portion (top) of a butane cigarette lighter.
87-017	8/2/87	10.35	M	68	Four clear glass fragments 2 to 4 cm^2 and approximately 0.3 cm thick, all worn smooth on edges.

Table 3.--Continued.

Specimen No.	Date	Length (m)	Sex	Age (year)	Description of debris
87-021	8/10/87	10.40	F	51	One piece of wood with nail (not protruding) 17.5 × 4.5 × 7.0 cm (weight 130 g).
87-023	8/13/87	10.30	F	44	One large concrete fragment 9.5 × 6.5 × 3.0, weight 230 g; one piece of 3 mil thick black plastic 18 × 23 cm.
87-024	8/14/87	10.58	M	41	One fragment of brown glass, 4 × 2 × 0.3 cm, edges smooth, one piece of brown plastic sheet 30-35 cm^2.

species summarized are known to feed primarily in the epipelagic and mesopelagic zones.

Experimental evidence suggests that odontocete cetaceans are probably very discriminating feeders. Mistaken ingestion of oceanic debris due to its resemblance to preferred prey species is unlikely because of odontocete cetacean echolocation capabilities. In captive experiments, the bottlenose dolphin, *Tursiops truncatus*, has been shown to be capable of making fine discriminations in size, shape, texture, and composition of objects (Kellogg 1958, 1959a, 1959b; Norris et al. 1961; Evans and Powell 1967; Norris 1969). Kellogg (1959a) demonstrated the use of echolocation by *T. truncatus* to locate preferred food fish but avoid inedible objects. Selection between a water-filled 2-cm gelatin capsule and an equal-sized piece of cut fish has been demonstrated (Norris et al. 1961). Evans and Powell (1967) determined that *T. truncatus* could discriminate between identical-sized sheets of different metals, or even between sheets of the same metal but of different thicknesses. Monofilament about 1 mm in diameter was determined to be at the threshold of detection for a captive harbor porpoise, *Phocoena phocoena* (Busnel et al. 1965).

The two species of free-ranging odontocete cetaceans documented to ingest marine debris are the sperm whale *Physeter macrocephalus*, and the Baird's beaked *B. bairdii*. Both these cetaceans are known to spend some time feeding at or near the bottom, particularly in coastal waters. This is verified by the behavior of preferred prey species and by the common occurrence of stones and gravel in examined stomachs (Betesheva and Akimushkin 1955; Nemoto and Nasu 1963; Tomilin 1967; Berzin 1971; Walker and Mead 1988). Ingestion of debris in these two species of cetaceans is very likely to be incidental, the debris being consumed along with bottom-dwelling prey.

Table 4.--Summary of ingested marine debris in 20 *Berardius bairdii* taken at Abashiri, Hokkaido, Japan, 1988-89.

Specimen No.	Date	Length (m)	Sex	Description of debris
Ab-88-03	8/28/88	10.70	M	One No. 2 size fishhook with short, approximately 15 cm, portion of leader attached.
Ab-88-08	9/7/88	10.10	M	Two No. 2 size fishhooks.
Ab-88-18	9/24/88	10.20	F	One badly rusted, partial No. 2 size fishhook.
89-HK-101	9/1/89	9.40	M	One cotton sleeve from rubber glove, black rubber fragments still attached to anterior edges.
89-HK-102	9/2/89	10.78	F	One No. 2 fishhook and three ca. 30 cm^2 portions of clear plastic sheeting. All appear to be portions of the same material and are ca. 3 cm thick. Vegetable refuse--three pieces of citrus fruit (orange?) peels.
89-HK-104	9/9/88	10.20	M	One ca. 10-cm diameter wad of thin, clear plastic sheeting ca. 1.5 mil thick.

Records presented in this report of marine debris ingested by *Berardius* off central Japan all came from off the Boso Peninsula, Chiba Prefecture, an area extending from the northern edge of the entrance to Tokyo Bay north to Choshi off the Pacific coast of Japan (lat. 34°39'-35°57'N). The animals were taken primarily along the 1,000-m depth contour line. Due to the proximity to Tokyo Bay and Choshi (a major fishing port), the entire area is subject to extremely heavy merchant and commercial fishing vessel traffic. The *Berardius* stomach samples from off northern Hokkaido were from two general areas in the southern Okhotsk Sea: 1) The immediate vicinity of the major commercial fishing port of Abashiri (ca. lat. 44°30'N, long. 144°30'E) and 2) Nemuro Strait between the Shiretoko Peninsula (Japan) and Kunashir Island (U.S.S.R.) (ca. lat. 44°15'N, long. 145°30'E). Both these areas are also subject to heavy commercial fishing activity.

Debris encountered in *Berardius* stomachs from both the Pacific coast of Japan and the southern Okhotsk Sea consisted almost exclusively of negatively bouyant material. The varied nature of the debris (e.g., broken glass, vegetable refuse, aluminum pull tabs, bottle caps) and the deep offshore location strongly suggest shipboard refuse as the primary source of the ingested debris.

It should be noted that the absence of debris-related pathology in the Baird's beaked whale sample does not rule out the occurrence of debris-related mortality in the study areas. To the contrary, the high incidence of ingested debris, the varied nature of the debris material, and records of debris-related mortality in captive cetaceans permit some speculation on the potential for incidental debris ingestion as a mortality factor in this species. *Berardius* is a large animal (up to 12.8 m in length). Death or debilitation through gastrointestinal impaction would probably require a relatively large volume of indigestible material. However, some of the debris material summarized in Tables 3 and 4 has considerable pathologic potential. Ingestion of relatively small items such as sharp metallic objects or freshly broken glass poses a real identifiable hazard and is a well-documented factor in human as well as veterinary disease. Complications through mechanical trauma to the gastrointestinal tract by such objects range from laceration and hemorrhage to perforation of the gut wall and acute bacterial peritonitis. These conditions are eminently life threatening. In the wild state, the elapsed time from onset to death would probably be short and accompanied by marked behavioral alterations. As a result, the probability of encountering these acute states in the fisheries sample would be very low. In the commercial fisheries sample we should expect only chronic, prolonged disease conditions to be manifest. Some bias toward the taking of chronically ill whales in commercial harpoon fisheries is suspected. Walker (1988) suggested, on the basis of a parasite survey, that the prolonged chase procedure in the Japanese *Berardius* fishery may involve selection toward the taking of some physically infirm individuals.

Wallace (1985) raised the question of whether sinking truly constituted debris removal. Results of this study indicate that negatively buoyant debris are not neutral, but still may pose a potential hazard to large predators feeding on benthic prey.

RECOMMENDATIONS

The worldwide trend toward curtailment of the commercial take of marine mammals restricts opportunities for future food habits sampling. In the future, food habits studies are likely to become more reliant on samples obtained from incidental fisheries' interactions and strandings. The following recommendations should be incorporated into future research:

- Develop and incorporate a consistent format for recording the presence as well as the absence of marine debris in stomach content analyses conducted on both free-ranging and stranded marine mammals. The recording of negative findings should also be emphasized, as they are crucial in establishing reliable information on the frequency of debris occurrence in future studies.

- Whenever possible, occurrence of ingested debris should be of the debris should also be kept (e.g., size, shape, consistency). In the case of stranded animals, the necropsy should include examination and evaluation of all major organ systems. Data presented in this report suggest that ingestion of debris may be secondary to other naturally occurring disease factors.

- The filter-feeding strategy of the baleen whales, Mysticeti, may make them particularly vulnerable to incidental debris ingestion in both the benthic zone and zones of the upper water column. Researchers should be encouraged to take advantage of the few remaining commercial fisheries to record evidence of ingested debris. The stomachs and oral cavities of stranded baleen whales should be examined whenever possible. Individuals involved in past food habit studies of baleen whale species should be interviewed.

- Research on marine mammal food habits as well as debris ingestion should continue in order to establish preferred prey species and feeding behavior, and increase the data base on debris ingestion.

- The data presented in this report are limited to gross observations on the acute effects of ingested debris (e.g., gastrointestinal impaction, ulceration). Research into the potentially insidious effects of absorption of hydrocarbon contaminants such as plasticizers should be conducted.

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