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).

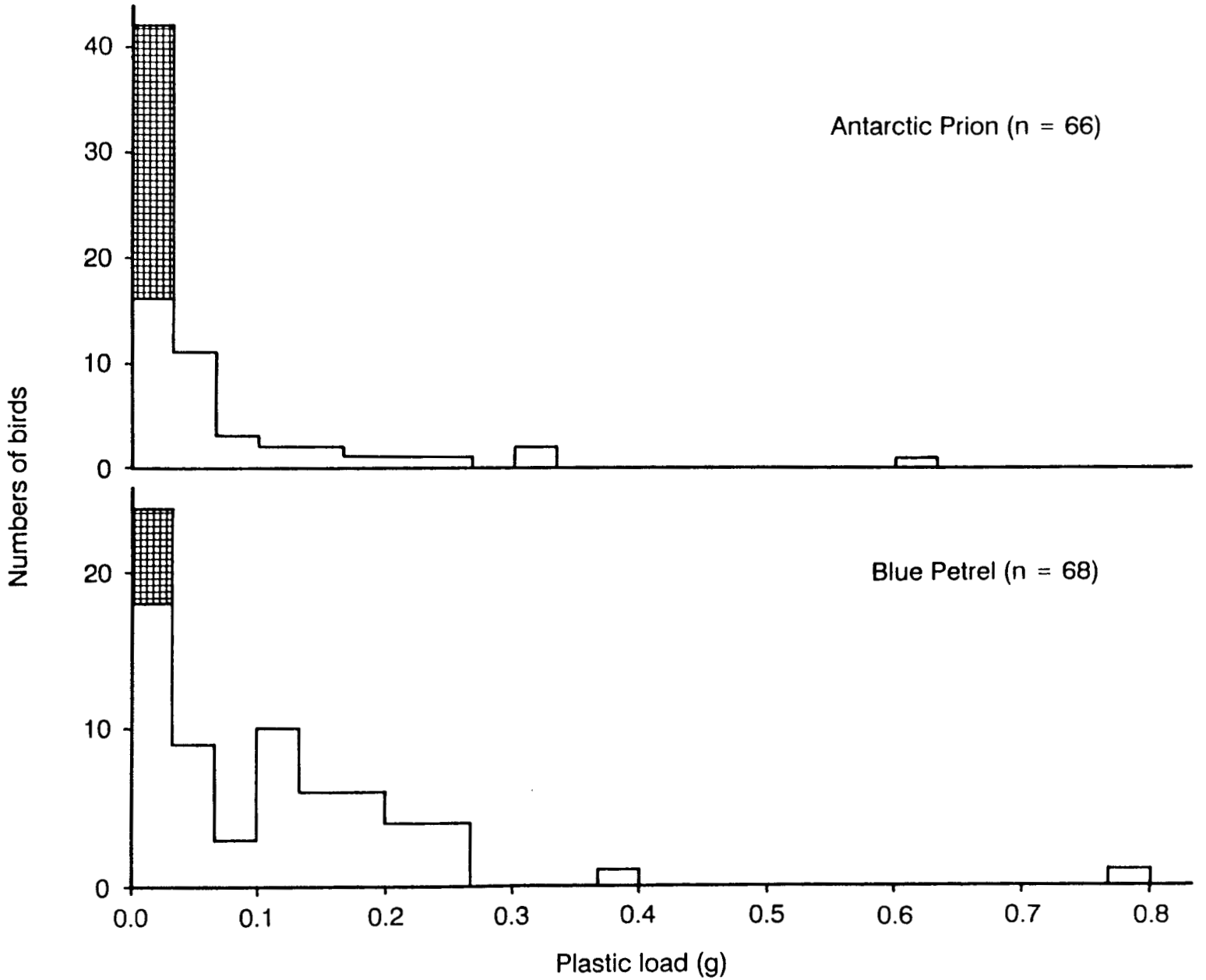

Figure 1.--The total plastic loads (by mass) of individual Antarctic prions, *Pachyptila desolata*, and blue petrels, *Halobaena caerulea*. See Ryan (1987b) for sampling procedures. Hatching depicts birds containing no plastic particles. Note the highly skewed distributions, with relatively few birds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

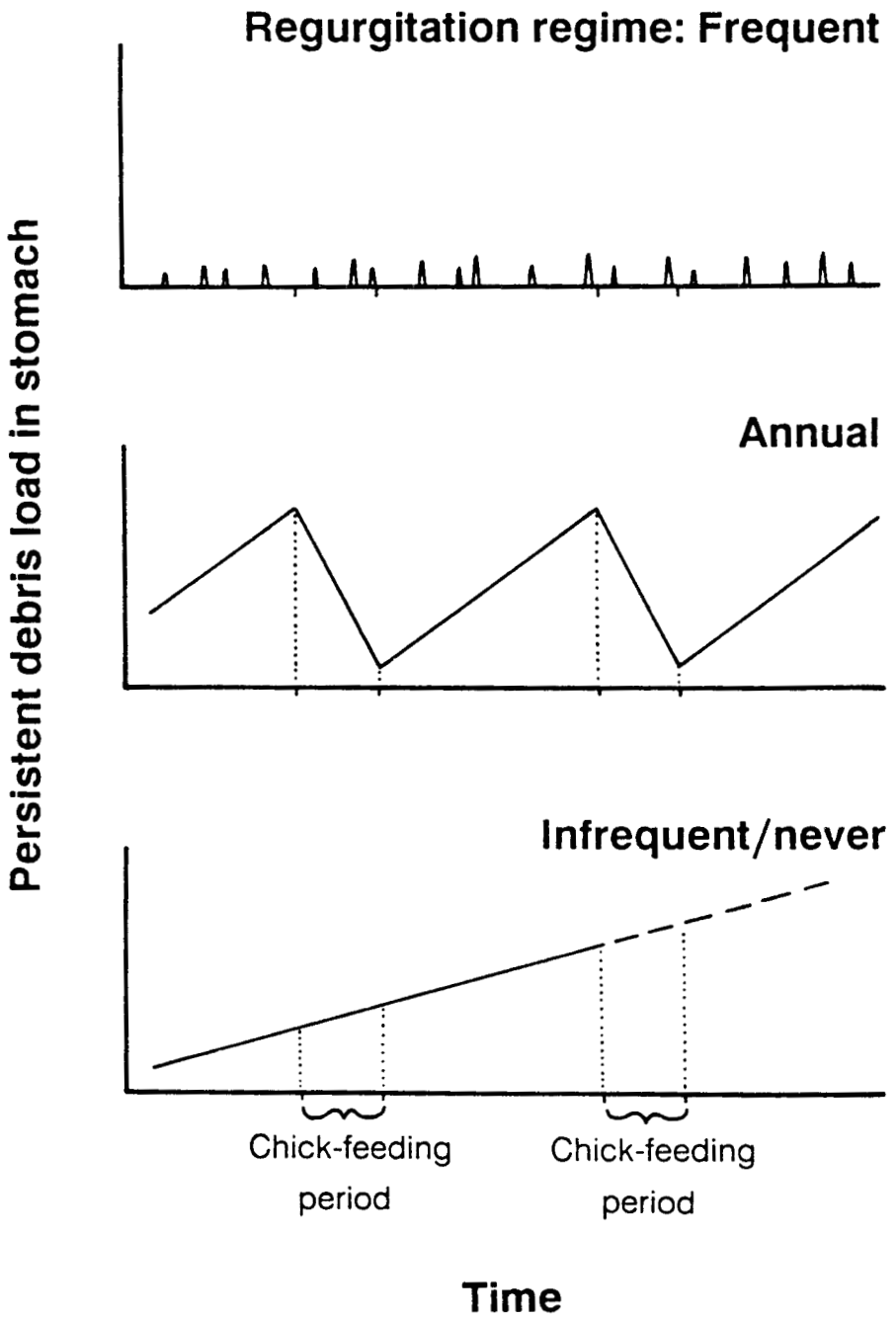

Figure 2.--Diagrammatic representation of the effect of different regurgitation frequencies on the pattern of persistent debris accumulation in seabird stomachs.

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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REFERENCES

Azzarello, M. Y., and E. S. van Vleet.
1987. Marine birds and plastic pollution. Mar. Ecol. Progr. Ser. 37:295-303.

Baltz, D. M., and G. V. Morejohn.
1976. Evidence from seabirds of plastic particle pollution off central California. West. Birds 7:111-112.

Bedard, J.
1969. Adaptive radiation in Alcidae. Ibis 111:189-198.

Bourne, W. R. P.
1976. Seabirds and pollution. *In* R. Johnston (editor), Marine pollution, p. 403-502. Acad. Press, London.

Bourne, W. R. P., and M. J. Imber.
1982. Plastic pellets collected by a prion on Gough Island, central South Atlantic Ocean. Mar. Pollut. Bull. 13:20-21.

Brown, R. G. B., S. P. Barker, D. E. Gaskin, and M. R. Sandeman.
1981. The foods of great and sooty shearwaters, *Puffinus gravis* and *P. griseus*, in eastern Canadian waters. Ibis 123:19-30.

Carpenter, E. J., S. J. Anderson, G. R. Harvey, H. P. Miklas, and B. B. Peck.
1972. Polystyrene spherules in coastal waters. Science 178:749-750.

Conners, P. G., and K. G. Smith.
1982. Oceanic plastic particle pollution: Suspected effect on fat deposition in red phalaropes. Mar. Pollut. Bull. 13:18-20.

Croxall, J. P.
1984. Seabirds. *In* R. M. Laws (editor), Antarctic ecology, p. 533-618. Acad. Press, London, 2.

Day, R. H.
1980. The occurrence and characteristics of plastic pollution in Alaska's marine birds. M.S. Thesis, Univ. Alaska, Fairbanks, 111 p.

Day, R. H., D. H. S. Wehle, and F. C. Coleman.
1985. Ingestion of plastic pollutants by marine birds. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 344-386. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

Dickerman, R. W., and R. G. Goelet.
1987. Northern gannet starvation after swallowing Styrofoam. Mar. Pollut. Bull. 18:293.

Fry, D. M., S. I. Fefer, and L. Sileo.
1987. Ingestion of plastic debris by Laysan albatrosses and wedge-tailed shearwaters in the Hawaiian Islands. Mar. Pollut. Bull. 18:339-343.

Fry, D. M., and L. J. Lowenstein.
1982. Insults to alcids: Injuries caused by food, by burrowing and by oil contamination. Pac. Seabird Group Bull. 9:78-79.

Fry, D. M., J. Swenson, L. A. Addiego, C. R. Grau, and A. Kang.
1986. Reduced reproduction of wedge-tailed shearwaters exposed to single doses of weathered Santa Barbara crude oil. Arch. Environ. Contam. Toxicol. 15:453-463.

Furness, R. W.
1985a. Ingestion of plastic particles by seabirds at Gough Island, South Atlantic Ocean. Environ. Pollut. (Ser. A) 38:261-272.

1985b. Plastic particle pollution: Accumulation by procellariiform seabirds at Scottish colonies. Mar. Pollut. Bull. 16:103-106.

Gregory, M. R.
1978. Accumulation and distribution of virgin plastic granules on New Zealand beaches. N.Z. J. Mar. Freshwater Res. 12:399-414.

Harper, P. C., and J. A. Fowler.
1987. Plastic pellets in New Zealand storm-killed prions (*Pachyptila* spp.) 1958-1977. Notornis 34:65-70.

Koth, T., and E. Vauk-Hentzelt.
1988. Influence of plumage and oiling on body and organ growth in young Kittiwakes. Mar. Pollut. Bull. 19:71-73.

Ohlendorf, H. M., and C. S. Harrison.
1986. Mercury, selenium, cadmium and organochlorines in eggs of three Hawaiian seabird species. Environ. Pollut. (Ser. B) 11:169-191.

Ohlendorf, H. M., R. W. Risebrough and K. Vermeer.
1978. Exposure of marine birds to environmental pollutants. U.S. Fish Wildl. Serv., Wildl. Res. Rep. 9.

Parslow, J. L. F., and D. J. Jefferies.
1972. Elastic thread pollution of puffins. Mar. Pollut. Bull. 3:43-45.

Pettit, T. N., G. S. Grant, and G. C. Whittow.
1981. Ingestion of plastics by Laysan albatross. Auk 98:839-841.

Rothstein, S. I.
1973. Plastic particle pollution of the surface of the Atlantic Ocean: Evidence from a seabird. Condor 75:344-345.

Ryan, P. G.
1986. Seabirds as water quality monitors. Mar. Pollut. Bull. 17:435-436.

1987a. The effects of ingested plastic on seabirds: Correlations between plastic load and body condition. Environ. Pollut. 46:119-125.

1987b. The incidence and characteristics of plastic particles ingested by seabirds. Mar. Environ. Res. 23:175-206.

1988a. Effects of ingested plastic on seabird feeding: Evidence from chickens. Mar. Pollut. Bull. 19:125-128.

1988b. Intraspecific variation in plastic ingestion by seabirds and the flux of plastic through seabird populations. Condor 90:446-452.

1990. The marine plastic debris problem off southern Africa: Types of debris, their environmental effects, and control measures. *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. [See this document.]

Ryan, P. G., A. D. Connell, and B. D. Gardner.
1988. Plastic ingestion and PCBs in seabirds: Is there a relationship? Mar. Pollut. Bull. 19:174-176.

Ryan, P. G., and S. Jackson.
1987. The lifespan of ingested plastic particles in seabirds and their effect on digestive efficiency. Mar. Pollut. Bull. 18:217-219.

Sileo, L., P. R. Sievert, and M. D. Samuel.
1990. Causes of mortality of albatross chicks at Midway Atoll. J. Wildl. Dis. 26:329-338.

Sileo, L., P. R. Sievert, M. D. Samuel, and S. I. Fefer.
1990. Prevalence and characteristics of plastic ingested by Hawaiian seabirds. *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. [See this document.]

Van Franeker, J. A.
1985. Plastic ingestion in the North Atlantic fulmar. Mar. Pollut. Bull. 16:367-369.

Van Franeker, J. A., and P. J. Bell.
1988. Plastic ingestion by petrels breeding in Antarctica. Mar. Pollut. Bull. 19:672-674.

Wirka, J.
1988. Wrapped in plastics: The environmental case for reducing plastics packaging. Environmental Action Foundation, Wash., D.C., 159 p.

Zonfrillo, B.
1985. Petrels eating contraceptives, polythene and plastic beads. Br. Birds 78:350-351.