Plastic ingestion by Laysan Albatross chicks on Sand Island, Midway Atoll, in 1994 and 1995.

Heidi J. Auman et al. In Albatross Biology and Conservation, pp239-44, 1997.

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Laysan Albatross chicks from Midway Atoll, North Pacific Ocean, were assessed in 1994 and 1995 for impacts of plastic ingestion. Masses and incidence of plastic in chicks were compared between birds found dead of "natural causes" and those injured by motor vehicles. Naturally killed Laysan Albatross chicks had significantly greater masses of plastic in their proventriculi and gizzards and had significantly lighter body masses and lower fat indices than injured but otherwise healthy chicks. Ingested plastic probably does not cause significant direct mortality in Laysan Albatross chicks, but likely causes physiological stress as a result of satiation and mechanical blockages.

Key words: Laysan Albatross, Midway Atoll, Pacific Ocean, Plastic Ingestion, Physiological Stress

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Pp. 239-44 *in* ALBATROSS BIOLOGY AND CONSERVATION ed by G. Robinson and R. Gales. Surrey Beatty & Sons, Chipping Norton. 1997.

INTRODUCTION

SEABIRDS ingest floating plastic and other foreign matter while feeding on the surface of the ocean. Laysan Albatrosses *Diomedea (Phoebastria) immutabilis* accumulate plastic materials in their proventriculi and gizzards and are reported to have a greater incidence, a wider variety, and larger volume of ingested plastic than any other seabird (Kenyon and Kridler 1969; Sileo and Fefer 1987; Sileo *et al*. 1989). Fledglings normally regurgitate boli or castings of squid beaks, fish bones, and other indigestible matter, but large pieces of plastic may complicate or prohibit this process (Petit *et al*. 1981). At Midway Atoll (28°11'N, 177°22'W), Hawaiian Leeward Islands, Laysan Albatross chicks die by the thousands from disease, abandonment and starvation; chicks may also die of starvation or dehydration even if properly fed due to a build up of plastics in their stomachs (Sileo *et al*. 1990; Sievert and Sileo 1993).

This chapter reports on research to determine if ingested plastic adversely affected Laysan Albatross chicks on Midway Atoll and whether the rates of plastics ingestion have changed since studies conducted in the 1960s. Specifically, the research aimed to compare masses of plastic in Laysan Albatross chicks found dead with plastic

loads in chicks accidentally injured or killed by vehicles, the latter group being assumed to be healthy before collision with vehicles. Although this comparison does not establish that greater plastic loads causes increased death rates (Ryan 1987), collecting plastic from dead chicks alone would have been insufficient to determine the cause of mortality, and since collection of uninjured chicks was considered unethical chicks accidentally injured by vehicles were used in the comparison.

METHODS Collection of chicks

Dead and injured Laysan Albatross chicks were collected from 25 May to 21 July 1994, and 24 May to 30 June 1995 on Sand Island, Midway Atoll. Dead and injured birds were collected at random from populations within the areas of Sand Island populated by humans, since injured birds in uninhabited areas were rarely found. Throughout June of both years at least 10 fresh albatross chick carcasses were collected daily. Only chicks with glossy eyes were selected for necropsy, and only the most recently dead birds were necropsied in order to minimize the effects of desiccation and decomposition. Once the carcass was opened, a visual inspection of the internal organs determined the decomposition state of the birds found dead. Carcasses were judged to be too decomposed to assess critically if the proventriculus was thin, peeling and transparent.

The majority of injured birds had compound fractures of their wings or legs. We assumed that ingested plastics did not contribute to chicks' injuries from collisions with vehicles. We assumed that no chicks had regurgitated their stomach contents as a reaction to their injury as no regurgitated boluses were observed near the site of injury. Chicks that had not collided with vehicles but had drooping wings, thought to be caused by lead poisoning, were excluded from the study since they were not considered healthy, although plastic load has not been correlated with either lead poisoning or droop wing (Sileo *et al*. 1990). Injured chicks were processed within 24 h of collection, but it was not possible to determine when a bird had been injured. Injured birds were restrained and 1-24 ml of blood was drawn from the brachial vein and stored; the birds were then killed by cervical dislocation and a necropsy performed within 10 minutes.

Statistical considerations

To determine a statistically viable sample size for the chicks found dead 30 birds were necropsied and the variance of the mean mass values of plastic in the proventriculus and gizzard was determined. Additional birds were necropsied until the estimate of the parametric variance did not change when plotted against the number of necropsied birds. This indicated that a statistically significant sample size had been reached. The sample size of birds injured by vehicles was determined by the number of chicks injured by vehicles. The non-parametric Wilcoxon tests (Wilcoxon 2-way sample test) were used to compare means of the injured and dead chicks. Samples collected in different years were tested separately.

Sampling protocols

All collected chicks were weighed to the nearest 50 g using a Pesola spring scale. Bill length was measured to the nearest 1 mm to estimate age. The entire digestive tract was examined and subcutaneous fat were estimated visually using the following fat index: 0 = no fat, 1 = low fat, 2 = moderate fat, and 3 = high fat. The proventriculus and gizzard were removed by cutting anterior to the cardiac sphincter and posterior to the pyloric sphincter. Since there is no demarcation between the end of the oesophagus and the proventriculus, to sample consistently between carcasses each cut was made at a point immediately ventral to the caudal tip of the heart, about halfway between the taper of the oesophagus and the proventriculus. The entire proventriculus and gizzard were removed, any fat was peeled off, and both organs were weighed together on an electronic balance to 0.1 g. Contents of the proventriculus and gizzard were categorized as food, plastic, other human-made materials, and rock (mainly volcanic pumice). Plastic and other man-made materials were removed, washed in fresh water, air dried, and weighed to 0.1 g. (Although some authors used volume as the measure of plastics, we chose to measure mass because of the potential connection to chemical contaminants which are measured on a mass basis). The lining of the emptied proventriculus was examined for lacerations, ulcerations and punctures.

Chicks found dead in 1994 contained, on average, 23.8 g of plastic, while injured chicks averaged 11.3 g of plastic. In 1995 dead chicks averaged 18.1 g and the injured chicks 9.5 g; between-year differences in masses of plastics in dead and injured chicks were not statistically significant so the data for both years were pooled.

RESULTS

Ninety-five dead and 39 injured Laysan Albatross chicks were necropsied in 1994 and 76 dead and 41 injured Laysan Albatross chicks were necropsied in 1995. Of these 251 chicks, only six (2.4%) did not contain plastic. Plastic items comprised chips and shards of unidentified plastic, Styrofoam, beads, fishing line, buttons, chequers, disposable cigarette lighters, toys, PVC pipe and other PVC fragments, golf tees, dish-washing gloves, magic markers and caylume light sticks. Non-plastic items included neoprene o-rings, pieces of rubber and a lightbulb (Fig. 1; see also Fig. 9 in Croxall 1997). Natural objects such as Ironwood *Casuarina* spp. cones, peach pits, walnuts, twigs, wood chips and pumice also were found. Squid beaks occurred in all chicks except those with completely empty proventriculi.

Only two chicks found dead had punctures or tears in the lining of their proventriculus. These two birds also had leaking gall bladders and puncture wounds in the livers and breast tissue, probably caused by a pitchfork, which is often used by people to pick up carcasses at Midway Atoll. Between December 1992 and April 1994 62 adult Laysan Albatrosses found injured or dying on Midway included four adults with scars on the proventricular lining (H. Auman, unpubl. data). One bird had an 11.3 cm long piece of plastic wedged crosswise in the proventriculus that projected through all but the last connective tissue layer on the outside of the proventriculus; it also had a conspicuous ulcer.

Fig. 1. Plastic items found in the proventricular bolus of a Laysan Albatross chick.

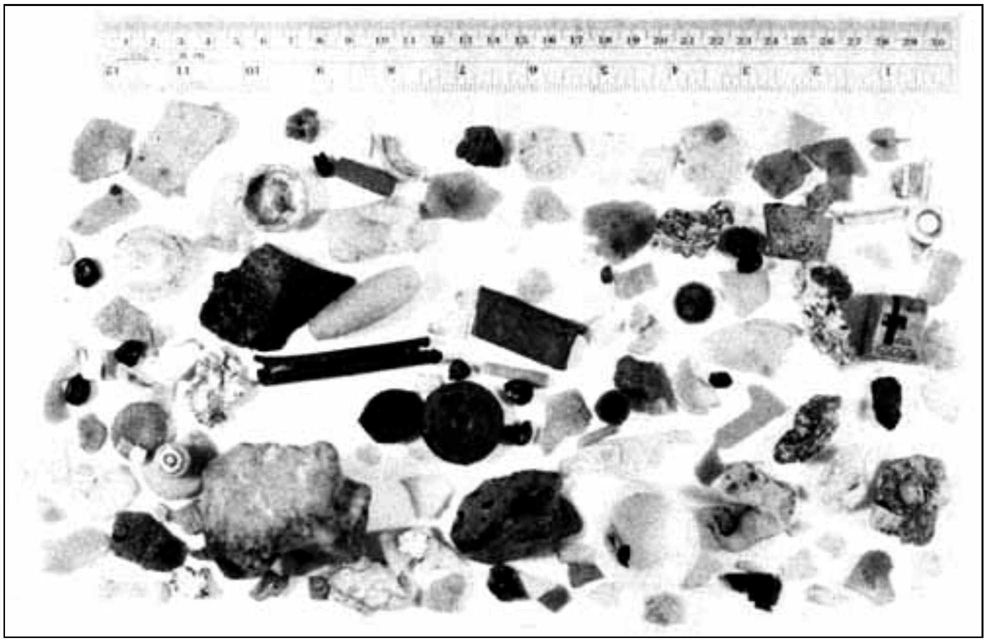

Fig. 2. Frequency of occurrence of plastic masses in 171 Laysan Albatross chicks found dead (black bars) and 80 chicks found injured by motor vehicles (diagonal bars) on Sand Island, Midway Atoll. Numbers for plastic masses represent 5 g increments up to and including the numbers shown.

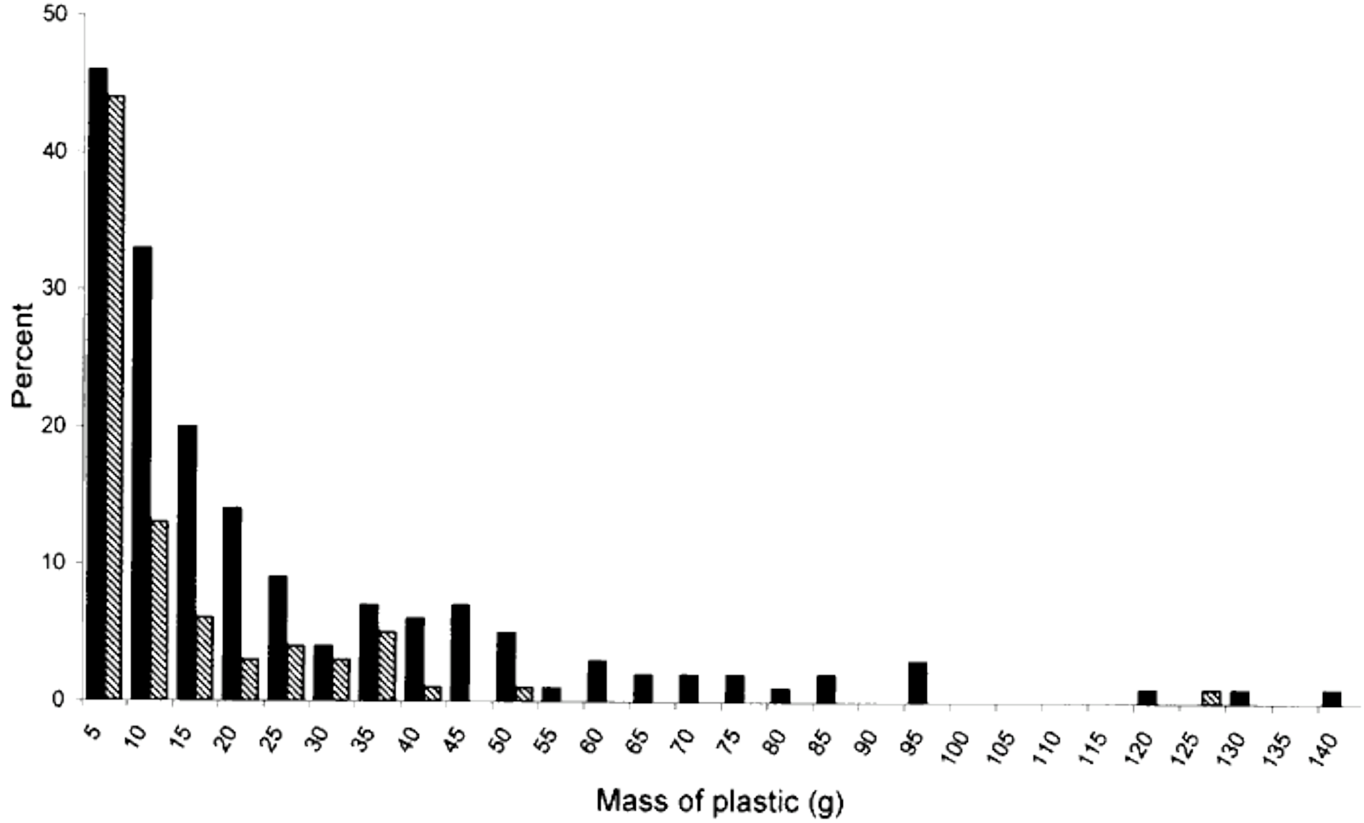

Table 1. Parameters measured in dead and injured Laysan Albatross chicks at Sand Island, Midway Atoll, in 1994 and 1995. Figures in parenthesis indicate sample sizes.

	Mean				Range	
	Dead		Injured		Dead	Injured
Parameter	**1994**	**1995**	**1994**	**1995**	**1994-1995**	**1994-1995**
Body mass (g)	1938	1554	2231	1966	600-2900	1350-2900
	(95)	(73)	(39)	(40)		
Beak length (cm)	10.6	9.8	11	10.0	7.9-11.7	9.2-11.9
	(95)	(74)	(39)	(42)		
Proventriculus length (cm)	13.3	12.4	12	13.2	6.5-21.0	8.5-23.0
	(93)	(71)	(38)	(37)		
Proventriculus width (cm)	5.9	4.9	3.8	4.2	2.1-9.4	1.6-7.8
	(93)	(71)	(38)	(37)		
Proventriculus height (cm)	4.7	3.2	2.9	3.0	0.3-8.3	0.6-6.9
	(93)	(71)	(38)	(37)		
Proventriculus mass (g)	140.4	103.5	85	104.0	15.2-393.7	18.5-313.
	(93)	(73)	(38)	(42)		
Plastic mass (g)	23.8	18.1	11	9.5	0.0-136.3	0.0-122.7
	(95)	(73)	(39)	(42)		
Largest piece (g)	3.7	4.2	1.6	3.3	0.1-34.9	0.0-12.5
	(95)	(50)	(39)	(27)		
Fat index	2.0	1.3	2.5	2.2	1-3	1-3
	(95)	(73)	(39)	(42)		
Pumice mass (g)	30.0	NA	10	NA	0.0-194.8	0.0-121.1
	(95)	(NA)	(39)	(NA)		

However, the mean masses of plastic were significantly greater in the proventriculi and gizzards of birds found dead than injured in both 1994 ($p = 0.0001$) and 1995 ($p = 0.01$). The largest pieces of plastic in the dead chicks were significantly heavier than in injured chicks ($p = 0.0099$) (Table 1). In the sample of chicks injured in 1994 only one bolus of plastic greater than 40.0 g was found. If this 122.7 g sample is removed as an outlier, the mean plastic mass drops from 11.3 g to 8.4 g in the injured birds. The mass of plastic in injured and dead Laysan Albatross chicks is shown in Figure 2.

For both groups in both years there was no significant difference in the number of males and females sampled ($p = 0.50$). Additionally, there were no differences in chick masses ($p = 0.11$), proventricular width ($p = 0.65$), proventricular height ($p = 0.21$), mass of plastic boluses ($p = 0.83$), heaviest piece ($p = 0.87$) or fat index ($p = 0.36$) between male and female chicks. Males had significantly longer proventriculi ($p = 0.03$) and slightly heavier loads of proventricular pumice ($p = 0.08$) than females. Chicks found dead were significantly lighter than chicks found injured, and had greater proventricular lengths, widths and heights, lower fat indices, and greater masses of proventricular pumice (Table 1).

DISCUSSION

Effects of plastic ingestion

The differences in plastic masses between the dead and injured chicks in 1994 and 1995 were remarkable. However, the results are not evidence of a cause-and-effect link between plastic ingestion with chick death. While it is possible that the death of healthy chicks may result from ingested plastic, it is also possible that unhealthy chicks eat greater amounts of plastic from the ground as a result of their poor condition. It is also possible that unhealthy chicks have difficulty regurgitating indigestible matter. The appearance of glass shards, copper wire and other manmade items that do not float confirm that chicks ingest foreign items off the ground at Sand Island, where plastic brought to the island by previous albatross generations is abundant.

The possible effects of ingestion of plastics include starvation (Dickerman and Goelet 1987), suppressed appetite and reduced growth (in domestic chickens) (Ryan 1988), lower fledging masses (Sievert and Sileo 1993), decreased fat deposition (Connors and Smith 1982), increased PCB and other organochlorine assimilation (Ryan *et al*. 1988; Carpenter *et al*. 1972; Colton *et al*. 1974) and obstruction in the gut *(Fry et al*. 1987). In a trial involving White-chinned Petrels *Procellaria aequinoctialis* birds fed plastic had similar assimilation efficiencies and rates of plastic mass loss as did control birds, suggesting that plastic does not hamper digestive efficiency (Ryan and Jackson 1987). In a study on Sand Island, Midway Atoll, in 1987, no Laysan Albatross chick deaths, impactions or ulcerations in proventricular linings were attributed to ingested plastic (Sileo *el al*. 1990). Further, no conclusive evidence of negative effects from plastic consumption was reported by either Day (1980) or Furness (1985) in several seabird species; however, these authors considered that Procellariiformes may be more vulnerable than other seabirds due to their surface-seizing feeding methods, poor regurgitation capacity and smaller gizzards.

Thus it appears that plastics may add considerable stress to individuals, but probably have little or no direct impact at the population level. Satiation and reduced resistance to the effects of lead poisoning and avian pox virus may eventually contribute to death in birds with heavy plastic loads.

Satiation, or appetite suppression, is potentially caused by distention of the proventriculus, gizzard and intestines, dehydration, warm temperatures, and physical activity (Day 1980). Laysan Albatross chicks with plastic in their stomachs may experience all of these sensations in the hot summer months prior to fledging. Dehydration was considered to be the most common cause of death in Laysan Albatross chicks at Midway Atoll in 1987 (Sileo *et al*. 1990). The displacement of ingested food by plastic may be enough to starve or dehydrate chicks that are already in poor condition. Displacement of food may also reduce the mass and size of fat reserves of fledglings. The uninjured dead chicks in the present study were significantly lighter than the injured chicks. The mean fat indices for dead and injured chicks were 2.0 and 2.5, respectively, in 1994, and 1.4 and 2.2, respectively, in 1995; this difference may account for some of the mass difference between years. Plastic ingestion may also cause blockages in the digestive tract (Fry *et al*. 1987). Three (1.2%) of the chicks found dead contained a solid piece of plastic that completely blocked the junction of the oesophagus and proventriculus; however, it could not be determined if the blockage caused the death of the bird.

Plastic particles in the digestive system of seabirds may last for at least two years (Ryan and Jackson 1987) and radio transmitters inadvertently fed by Laysan Albatross adults to chicks lasted for over 40 d before being regurgitated (Petit *et al*. 1981). Only the smallest (<0.1 g) plastic pieces can enter the narrow gizzard opening. Interestingly, no plastic has been observed in seabird faeces (Day 1980; Petit *et al*. 1981), yet plastic in the intestine was noted in 39% of Laysan Albatrosses in 1986 and 1987 (Sileo *et al*. 1990). Presumably plastic that is not regurgitated is broken down in the digestive tract of Laysan Albatrosses.

Plastic ingestion may also lead to contamination by organochlorines. Polychlorinated biphenyls (PCBs) accumulate on the surfaces of plastic in the ocean and may reach five parts per million on polystyrene spherules (Carpenter *et al*. 1972). Phospholipid foam also forms on the sea surface and this can hyperconcentrate airborne contaminants such as PCBs (Hardy 1982; Napoliatano and Richmond 1995). Plastics may serve as adsorbent surfaces for these toxicants. Additionally, the colorants, softeners, and antioxidants used in the conversion to user-friendly

plastic may be harmful toxicants (van Franeker 1985). It is possible that large masses of plastic ingested by albatrosses may increase their PCB concentrations in addition to PCBs derived from dietary sources (Day 1980; Bourne and Imber 1982; van Franeker 1985). Positive correlations were reported between PCBs concentrations and masses of plastic in Great Shearwaters *Puffinus gravis* (Ryan *et al*. 1988) and PCBs, Polychlorinated dibenzo-p-dioxins, furans and naphthalenes have been found in adult Laysan Albatrosses from Midway Atoll (Jones *et al*. 1995). The dioxin-furan congener pattern Jones *et al*. (1995) found in albatross eggs and fat was unusual, but resembled the patterns found in incinerator ash and airborne emissions. It is quite likely that burned and melted plastics serve as a transport vehicle for these toxicants to albatrosses. Presumably, albatrosses extract dioxin and furan residues when the partially burned and melted particles are consumed at sea.

Trends in plastics ingestion

The incidence and mass of plastic ingested by Laysan Albatross chicks appears to be increasing. In 1966 74% of 91 Laysan Albatrosses sampled at Pearl and Hermes Reefs (north-west Hawaiian Islands) contained, on average, 1.87 g of plastic, with eight pieces being the greatest number found in any individual (Kenyon and Kridler 1969). In 1983 on Sand Island, Midway Atoll, plastic contents in live and dead Laysan Albatross chicks averaged 35.7 g (39.3 cc) and 76.7 g (85.0 cc), respectively *(Fry et al.* 1987). An average of 46 cc of plastic was collected from Laysan Albatross chicks in 1986 and 5 cc in 1987, and the frequency of occurrence in both these years was 90% (Sileo *et al.* 1990). In the current study plastics were found in 97.6% of chicks sampled, and the masses recorded (23.8 g in dead chicks in 1994 and 18.1 g in 1995) are in the same order as those for the 1980s, which suggests an upward trend in concentrations of plastic debris on the surface of the north central Pacific Ocean since the mid-1960s.

Sources of plastic

The majority of plastic refuse is generated from municipal solid waste disposal at sea, coastal landfills and runoff, and from sea-going vessels (Colton *et al.* 1974). Ocean currents, winds and the location of disposal influence the abundance and distribution of plastic in the North Pacific Ocean. The warm Kurishio current, which flows north-east near Japan, and the North Pacific current, which flows across the north central Pacific Ocean, move through the main feeding areas of North Pacific Ocean albatrosses and are probably responsible for transporting most plastic material from sources further to the west *(Fry et al.* 1987; Harrison 1990). In 1979-1980, 108 of 109 items found in Laysan Albatross regurgitates and carcasses at Midway Atoll were of Japanese origin (Petit *et al.* 1981). Increasing knowledge of the atmosphere as a transport medium for organochlorine toxicants from third world users to the oceans (Iwata *et al.* 1995), and the concentration processes in the phospholipidenriched sea surface (Hardy 1982; Napolitano and Richmond 1995) lend a sense of urgency to the continuing task of monitoring plastics in seabirds since plastics may be another surface to which organochlorines may adhere. The effects of plastics may be far more subtle than mechanical blockage or reduced food consumption.

ACKNOWLEDGEMENTS

This research was made possible by a grant from the U.S. Environmental Protection Agency through the World Wildlife Fund (#CR 820227-01-0). We thank C.P.O. Gregg Diefenderfer, Darcy Bromley, Cheryl Summer and Katie Swift for their assistance with necropsies, Dr Scott Winterstein for statistical advice, and the U.S. Navy and the U.S. Fish and Wildlife Service for allowing our research to proceed on Midway Atoll.

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