FIRST QUANTIFICATION OF PLASTIC INGESTION BY SHORT-TAILED ALBATROSS *PHOEBASTRIA ALBATRUS*

ERICA DONNELLY-GREENAN[1,6], DAVID HYRENBACH[1,3], JESSIE BECK[1], SHANNON FITZGERALD[4], HANNAHROSE NEVINS[1,2,5,6] & MICHELLE HESTER[1]

[1]*Oikonos Ecosystem Knowledge, P.O. Box 2570, Santa Cruz, CA 95062, USA (erica@oikonos.org)*
[2]*Current address: American Bird Conservancy, 190 Benito Ave., Santa Cruz, CA 95062, USA*
[3]*Hawai'i Pacific University, 41-202 Kalaniana'ole Hwy, Waimanalo, HI 96795, USA*
[4]*NOAA, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Bldg. 4, Seattle, WA 98115, USA*
[5]*Karen C. Drayer Wildlife Health Center, School of Veterinary Medicine, One Shields Ave., University of California, Davis, CA 95616, USA*
[6]*California Department of Fish and Wildlife, Office of Spill Prevention and Response, Marine Wildlife Veterinary Care and Research Center, 1451 Shaffer Road, Santa Cruz, CA 95060, USA*

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ABSTRACT

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We investigated the sex, age, body condition, and ingested plastics in six Short-tailed Albatross *Phoebastria albatrus*, bycaught or opportunistically salvaged in US North Pacific groundfish fisheries. Necropsies revealed a 1:1 sex ratio, and a 2:1 juvenile (≤4 years of age) to adult (≥5 years of age) ratio, with five birds in healthy body condition and four in active molt. Of the six birds examined, two females (one adult, one juvenile) and two males (both juvenile), contained ingested plastics. Of the four birds with plastic, the number and mass of total plastic per bird was variable (number: mean 4.75, SD 2.1; mass: mean 0.2921 g, SD 0.3250 g). Plastics were categorized as fragments (n = 11), sheets (n = 4), foam (n = 2), and rubber (n = 2). Fragments were the most numerous type, occurring in all four birds that had ingested plastic and accounting for 57.9% of the plastic items and 90.5% of the plastic mass (dry weight). We documented greater incidence of ingested plastic in the ventriculus (75.0%) than in the proventriculus (16.7%). The overall plastic incidence was 75.0% in juveniles and 50.0% in adults. While this research provides quantitative evidence that Short-tailed Albatross juveniles and adults ingest plastics, additional analyses are needed to fully quantify the prevalence of plastic ingestion and to investigate potential persistent organic pollutants and plasticizers in Short-tailed Albatross.

Key words: Short-tailed Albatross *Phoebastria albatrus*, plastic ingestion, marine debris, bycatch

INTRODUCTION

Plastic ingestion has been reported in an increasing number of marine birds, including many species of North Pacific tubenose species (order Procellariiformes), such as albatrosses, fulmars, petrels, shearwaters, and storm-petrels (Fry *et al.* 1987, Spear *et al.* 1995, Anderson *et al*. 2008, van Franeker *et al.* 2011). A recent global review of seabird plastic ingestion revealed high incidence rates for Black-footed *Phoebastria nigripes* and Laysan *Phoebastria immutabilis* albatrosses, but highlighted the lack of published reports for the Short-tailed Albatross *Phoebastria albatrus* (hereafter referred to as STAL) (Wilcox *et al*. 2015).

STAL is listed as vulnerable by the International Union for Conservation of Nature (IUCN, https://www.iucn.org/), under Appendix 1 of the Convention for the International Trade of Endangered Species (CITES, https://www.cites.org/), and is protected under the national endangered species legislation of several range countries (e.g., Canada, USA, Japan). This species is susceptible to a variety of threats at sea, including longline fishery interactions, plastic ingestion, and other pollutants (McDermond & Morgan 1993, USFWS 2008). Evidence of plastic ingestion in STAL comes from Torishima Island, Japan, where chicks regurgitate plastic debris in the colony (Federal Register 2000). Yet, while STAL are known to ingest plastic, there are no quantitative records of the incidence, loads, and types of the ingested plastics; the impacts of this pollution on individuals and the population are unknown (McDermond & Morgan 1993).

While albatross ingest a wide range of plastics at sea, the types and loads vary by species, location, age class, and potentially by stomach chamber (proventriculus vs. ventriculus) (Auman *et al*. 1997, Robards *et al*. 1997, Young *et al*. 2009, Gray *et al*. 2012, Rapp *et al.* 2017). Thus, studies of plastic ingestion by a given species at a given site should consider different age classes and stomach chambers separately.

Here, we quantify plastic ingestion (incidence, number, and mass) by six STAL of varying ages, caught in fishing gear or opportunistically salvaged at sea, and place this information in a broader context using ancillary demographic (age, sex) and ecological (body condition) information collected during necropsies.

METHODS

Necropsy and demography

Five STAL collected by the North Pacific Groundfish Observer Program between 1995 and 2014 were examined by Oikonos biologists, in collaboration with a US Fish and Wildlife Service (USFWS) biologist, a New Zealand Museum taxidermist, and a University of Washington Burke Museum curator (UWBM; Walker *et al*. 2015). The sixth bird was collected alive but in poor condition by a fisheries observer and delivered to a wildlife rehabilitation center (Progressive Animal Welfare Society; PAWS). The bird died after 15 d in captive care.

Albatrosses were measured and examined for injuries, feather molt and bursa, muscle and fat scores, and stomach contents using standardized methods and criteria (van Franeker 2004). The status of feather molt was scored for the primary feathers on both wings. Status of wing, body, head, and tail molt were combined to estimate bird age (Pyle 2009). Additionally, bursa characteristics (size and condition) and gonad size provided ancillary information for age classification. These ageing criteria were compared with the estimated ages for the known-age birds (Torishima Island Colony banding data, as cited in Walker *et al*. 2015) that had been banded as chicks and ranged in age from hatch year to 7.5 years (Table 1).

To quantify body condition, the pectoralis-supracoracoideus (breast) muscle complex was scored from 0 (severely emaciated: muscle significantly below keel-line) to 3 (excellent body condition: muscle at or above keel-line) and subcutaneous and adipose fat stores were scored from 0 (no fat) to 3 (very fat). The codes for the pectoralis muscle complex and the fat stores were combined to generate an overall body condition score for each bird, ranging from 0 to 9.

Stomach processing and sorting

Stomach contents were processed at the necropsy site (Oikonos, UWBM, and PAWS). The contents of the two stomach chambers, the proventriculus and ventriculus, were stored and analyzed separately (van Franeker 2004). Stomach contents were collected in a 0.5 mm mesh sieve and rinsed to remove oil and soft tissues. Hard prey parts were sent to the Alaska Fisheries Science Center, Marine Mammal Laboratory (MML), Seattle, WA, for detailed analysis, as reported in Walker *et al.* (2015).

For the two birds examined at UWBM and PAWS, the non-prey hard parts were sent to Oikonos to standardize the plastic categorization. We used a binocular microscope to sort and classify plastic items into five types, defined by their shape, compressibility, and flexibility: line, sheets, fragments, foam, and rubber (van Franeker 2004).

Incidence of plastic (presence/absence), total number of plastic items, and total plastic dry mass in both stomach chambers were quantified (van Franeker 2004). All plastic samples were air dried in the laboratory and weighed (resolution = 0.0001 g) on a vibration-controlled scale equipped with a draft shield (Mettler-Toledo MS104S). We subsampled nine pieces of plastic (five fragments, two sheet, one foam, one rubber), ranging in mass between 0.0268 and 0.4839 g. The scale was calibrated before weighing the samples (Mettler-Toledo 2012).

Plastic characterization

After plastic fragments were quantified, we characterized their two-dimensional size using their longest dimension (length) and their longest perpendicular dimension (width) (Mallory 2008). Here, we approximated fragments as two-dimensional items due to their mostly flat and planar shape (depths < 1 mm). We scanned the 11 rigid fragments at high resolution (1200 dpi) using a digital scanner (Epson Perfection V37) with a custom-made cover to ensure consistent lighting. We analyzed the resulting images using Fiji's Image J open-source software to determine the length of the longest dimension (with 0.1 mm resolution) (Schindelin *et al.* 2012).

Next, to investigate potential attraction of STAL to highly visible and brightly colored debris, we quantified the fragment colors using the Hue, Saturation, Brightness (HSB) color model in Fiji image processing software. For each fragment, we averaged the color of a 0.5 mm × 0.5 mm square focal area, avoiding overly bright, shadowed, or cracked surfaces. We then quantified the averaged color using Red, Green, Blue (RGB color space) values, which we then converted into HSB values using standard algorithms (Karcher & Richardson 2003).

TABLE 1
Demographics and morphometrics of Short-tailed Albatross carcasses from the North Pacific examined for ingested plastics

Band number	Sex	Age (year)[a]	Gonad length (mm)	Gonad width (mm)	DLF[b] (mm)	Plumage age[c] (year)	Bursa description	Bursa length × width (mm)	Body mass (g)	Plastic found
13D6724	F	<1	30	5	2	–	Not found	–	3260	Yes
13A0853	M	1.4	14	4	–	–	Fleshy	20×4	6990	Yes
13C2597	M	2	20	3	–	2–4	Membranous	22×11	6935	Yes
13B9510	M	3.4	18	5	–	5–11	Not found	–	6790	No
13C2173	F	5.4	22	14	4	5–9	Not found	–	6715	Yes
13B2376	F	7.5	20	24	2	5–9	Not found	–	5670	No

[a] Based on banding data (Walker *et al*. 2015, and R. Suryan, pers. comm.).
[b] Diameter of largest ovary follicle.
[c] Based on Pyle (2009).

RESULTS

Plastic incidence mass and number

Stomach processing revealed ingested plastics and other "natural" items, including prey, fishery offal tissues, pumice, and stones. Non-food natural items included small pumice pieces and stones.

Of the six STAL examined, four (66.7%) contained plastic: two females (one adult, one juvenile) and two males (both juveniles) (Tables 1, 2). When we considered all six birds, plastic incidence was higher in the ventriculus (mean 66.7%, standard deviation [SD] 21.1%) than in the proventriculus (mean 16.7%, SD 16.7), as suggested by the non-overlapping point estimates (2 SDs). However, when stomach chambers were combined, the overall plastic incidence among juveniles (mean 75.0%, SD 25.0%) compared with adults (mean 50.0%, SD 50.0%) was indistinguishable, as suggested by the overlapping point estimates (2 SDs).

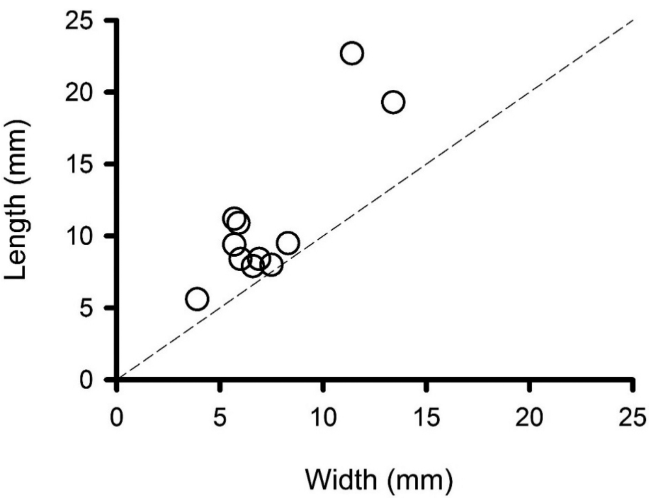

Fig. 1. Dimensions of ingested plastic fragments (n = 12) in the four necropsied Short-tailed Albatross stomachs that contained plastic.

When we considered only the four birds that contained plastic, the total number of plastic pieces and the total mass per bird (stomach chambers combined) were mean 4.75, SD 2.1, median 4.5, range 3–7, and mean 0.2921 g, SD 0.3250 g, median 0.1538 g, range 0.0869–0.7738 g (Table 2). Moreover, the plastic incidence differed between the proventriculus (mean 25.0%, SD 25.0) and ventriculus (100%), as suggested by the non-overlapping point estimates (2 SDs). There was also a greater number of plastic items in the ventriculus (mean 4.50, SD 1.9, median 4.0, range 0–7) than in the proventriculus (mean 0.25, SD 0.5, median , range 0–1) and a greater mass of ingested plastic in the ventriculus (mean 0.2208, SD 0.1855 g, median 0.1538 g, range 0.0869–0.4887 g) than in the proventriculus (mean 0.0713, SD 0.1426 g, median 0.0000 g, range 0.0–0.2851 g; Table 2).

Plastic size and color

STAL ingested fragments in the meso-plastic size class (mean 11.0 mm, SD 5.2, median 9.4, range 5.6–22.7 mm, n = 11; Fig. 1). Overall, the two-dimensional shape of the fragments varied from circular to elliptical, with the ratio of their largest dimension (major axis) divided by their width, defined as the largest perpendicular dimension (minor axis) ranging 1.07–1.99. Most of the fragments (nine of 11) were whitish in color, with hues ranging from 35 (cream) to 106 (pinkish), and with high brightness values (mean 77%, SD 8, median 75%, range 66%–92%). The two remaining fragments were green (hue 153) and red (hue 20). The two foam items and two of four sheet plastic items were yellowish shades of white (hue range 36–39). The two other sheets were green (hue 153). The two rubber items were red (hue 20). Altogether, these results suggest STAL predominantly ingest white items (68.4%), with lower proportions of high-contrast items (red, 15.8%) and low-contrast items (green, 15.8%).

Plastic types

STAL ingested four types of plastic: fragment, foam, sheet, and rubber. Yet fragments were the most common type, accounting for over half (57.9%, 11 of 19) of the ingested items and the majority (90.5%) of the ingested mass (Table 2). Each of the other three plastic types (foam, sheet, rubber) accounted for <5% of the mass (Table 2).

TABLE 2
The number, type, and mass of plastic ingested by four Short-tailed Albatrosses from the North Pacific

Band number	Stomach chamber	Total plastic		Fragment		Foam		Sheet		Rubber	
		Number	Mass (g)	Number	Mass (g)	Number	Mass (g)	Number	Mass (g)	Number	Mass (g)
13C2597	Proventriculus	0	0	0	0	0	0	0	0	0	0
	Ventriculus	3	0.0869	1	0.0601	0	0	0	0	2	0.0268
13C2173	Proventriculus	1	0.2851	1	0.2851	0	0	0	0	0	0
	Ventriculus	5	0.4887	4	0.4839	0	0	1	0.0048	0	0
13D6724	Proventriculus	0	0	0	0	0	0	0	0	0	0
	Ventriculus	3	0.2012	3	0.2012	0	0	0	0	0	0
13A0853	Proventriculus	0	0	0	0	0	0	0	0	0	0
	Ventriculus	7	0.1064	2	0.0273	2	0.0519	3	0.0272	0	0
n = 4	Mean (SD)[a]	4.7 (2.1)	0.2921 (0.3250)	2.7 (1.7)	0.2644 (0.3448)	0.5 (1.0)	0.0130 (0.0260)	1 (1.4)	0.0080 (0.0130)	0.5 (1.0)	0.0067 (0.0134)

[a] Stomach chambers combined.

Demographics

External examinations of the five STAL carcasses collected as bycatch revealed some bodily damage, involving at least one of the following injuries: mandible fracture, wing abrasion and hematoma, and congested/darkened lungs. These are consistent with injuries previously described in other albatross that were fishery bycatch (Darby & Dawson 2000, Oikonos unpubl. data). Four birds in various stages of active molt were assigned estimated plumage ages (Pyle 2009). When these estimates were compared to their known ages, based on banding data, three birds fell within the known age range and one male bird's age was over-estimated (Table 1). While the molt data were not available for two birds, we report the colony-banding ages for all six individuals (Table 1).

Internal examination revealed healthy body condition for the five birds caught during fishery interactions, and poor body condition for the individual salvaged alive. Overall, the five birds in good body condition contained thick fat deposits and good pectoral muscle development. The greatest condition index values were assigned to those STAL with marked subcutaneous and internal fat deposits (score of 3) and healthy pectoralis muscle complex extending above the keel (score of 3). The bird in poor condition had lesser body mass (3260 g; Table 1), no subcutaneous and internal fat (score of 1), a moderate pectoralis muscle complex score (score of 2; tissue not extending above keel), adrenal enlargement, possible splenic reduction, notably pale liver, and reduction in skeletal muscle mass.

Examination of the gonads, diameter of largest ovarian follicle (for females), and bursa size for all birds revealed a 1:1 sex ratio and a 2:1 juvenile to adult ratio (Table 1). The diameter of the largest follicle was 2 mm and 4 mm for the 7.5-year-old and 5.4-year-old females, respectively. While a bursa was present in two males (ages 2 and 1.4 years), none was found in the other individuals, including the hatch-year female (<1 year; Table 1).

DISCUSSION

We report ingested plastics in both juvenile (three of four) and adult (one of two) STAL sampled opportunistically by fisheries observers, providing evidence that birds of both age classes, including individuals in good body condition, ingest plastic. Plastic fragments are routinely documented in the stomachs of immature and adult Black-footed and Laysan albatrosses incidentally caught by commercial fisheries (Robards *et al*. 1997, Gray *et al.* 2012, Oikonos unpubl. data).

Bycatch birds are considered good indicators of diet and pollutant loads, due to their good health and body condition, compared with the likely biased samples from beachcast birds, which tend to be in poor health. In fact, the good body condition of albatrosses and other seabirds taken as bycatch has been attributed to their consumption of fishery discards (Phillips *et al.* 1999, van Franeker *et al*. 2011). On the other hand, diet and plastic samples from bycaught birds may not be representative, if they rely heavily on fishery discards, consume plastic debris originating from fishing vessels, or regurgitate their stomach contents when hooked (Phillips *et al.* 1999, Hyrenbach 2001, Gray *et al*. 2012). Thus, our results need to be interpreted with caution when considering population-level rates of plastic ingestion and the associated contaminants.

While we did not examine STAL chicks, there is evidence that they regurgitate plastic debris at the breeding colony (Federal Register 2000). In other North Pacific albatrosses, chicks ingest and accumulate plastics provisioned by foraging parents (Fry *et al.* 1987, Sileo *et al.* 1990, Young *et al.* 2009, Rapp *et al*. 2017). For instance, necropsy of 251 Laysan albatross chicks revealed that 97% contained plastics (resin fragments, beads, toys, fishing line, light sticks, and other anthropogenic items; Auman *et al*. 1997). More recently, significantly greater plastic loads were reported in Laysan and Black-footed albatross chicks, compared with their adult conspecifics (Rapp *et al*. 2017). Based on evidence from other North Pacific albatrosses, we would predict greater plastic incidence and loads in STAL chicks, compared with adult and immature birds.

We also report greater incidence and mean mass of ingested plastic in the ventriculus, which is the grinding chamber of the stomach, than in the proventriculus, the elastic chamber where food is initially digested. Because the ventriculus naturally retains indigestible prey hard-parts and non-prey items, it would be expected to concentrate those plastic items small enough to pass from the proventriculus. Conversely, larger fragments and other plastic items (such as line or foam) may remain in the proventriculus for long periods (van Franeker 2004, van Franeker *et al*. 2011, Hyrenbach *et al*. 2017). In North Pacific albatross adults, the plastic incidence in the two stomach chambers varies by species, with greater incidence in the proventriculus of nine Black-footed albatross (88.9% proventriculus, 66.7% ventriculus) but greater incidence in the ventriculus of 11 Laysan albatross (72.7% proventriculus, 90.9% ventriculus) (Rapp *et al*. 2017).

We report that STAL predominantly ingested hard plastic fragments of meso size class (5.8–15.2 mm). While STALs also ingested foam, sheets, and rubber, we did not document any line or pellets (nurdles) (Table 2). The ingested fragments were whitish in color and of high brightness values (Fig. 1). While most of the fragments (81.8%; nine of 11) ingested by STAL were white, we also documented pink, red, and green fragments. Interestingly, at-sea surveys in the eastern North Pacific (30–45°N) indicate that most (89.0%) floating plastic items are white, with substantially lower numbers of green (2.7%) and pink-red (0.6%) items (Titmus & Hyrenbach 2011).

The preponderance of hard white fragments likely reflects their bioavailability and durability in the marine environment (Ryan 2008, van Franeker *et al.* 2011, Donnelly-Greenan *et al.* 2014, Rapp *et al.* 2017). While the majority (56.5%) of the fragments ingested by Black-footed Albatross chicks from Kure Atoll were white, fragments of 10 other colors (including transparent) were ingested (n = 1 200 fragments). Low-visibility colors (blue, green, grey, black) and high-visibility colors (red, orange, brown, yellow) contributed 27.0% and 16.4% of the ingested fragments, respectively (Hyrenbach *et al*. 2017).

In summary, we provide the first quantitative evidence that STAL ingest plastic. Yet, due to our small sample size, our findings underscore the need for more research to fully document the types, sizes, and colors of the material ingested by this species. Additionally, despite growing concern about the potential impacts from plastic ingestion or the associated pollutants on STAL, we are not aware of any published studies addressing this growing threat (McDermond & Morgan 1993, USFWS 2008, Wilcox *et al*. 2015). In particular, there is concern about reduced chick survival due to depressed resistance to the effects of lead poisoning and the avian pox virus (Auman *et al.* 1997), and other indirect effects involving the ingestion of contaminants adhered to the ingested plastic. The latter include polychlorinated biphenyls (PCBs), which are found in seabird tissues and have been positively correlated with the mass of ingested plastic pellets (Tanabe *et al.* 2004).

Our results indicate that both juvenile and adult STAL ingest plastic. While the concentration at which contaminants would adversely affect individual birds is unknown, any potential population-level impacts would be expected to disproportionately affect the smaller colonies (Senkaku Island group) (USFWS 2008). Thus, further research is warranted to quantify ingested plastics, contaminant exposure, and the potential effects of this pollution on the recovering STAL population.

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