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LETTER

Plastic ingestion is an underestimated cause of death for southern hemisphere albatrosses

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Abstract

Albatrosses are among the world's most imperiled vertebrates, with 73% of species threatened with extinction. Ingestion of plastic is a well-recognized threat among three North Pacific species, but lesser known in the southern hemisphere, where it is considered a minor threat. As plastic entering the ocean is increasing while albatross populations decline, the threat of ocean plastic to albatross populations may be underestimated. We present case studies of 107 beach-cast albatrosses of twelve species, received by wildlife hospitals in Australia and New Zealand, and estimate plastic ingestion and mortality rates for albatrosses in the southern hemisphere. Ingested plastic was present in 5.6% of individuals, and the cause of death in half of these cases. We estimate ingestion of plastic may cause 3.4–17.5% of nearshore mortalities and is worth consideration as a substantial threat to albatross populations. We provide clinical findings and "checklist" methodologies for identifying potential cases of foreign-body gastrointestinal obstruction. We suggest practical policy responses, empowering decision makers to reduce albatross mortality from anthropogenic sources.

KEYWORDS

albatross, balloon, bottle, by-catch, conservation, marine debris, plastic pollution, policy, seabird, threatened species

1 | INTRODUCTION

1.1 | Declining ocean wanderers

Albatrosses (Order: Procellariiformes, Family: Diomedeidae) are among the world's most imperiled vertebrate species (Dias et al., 2019; IUCN, 2019; Phillips et al., 2016). More than two-thirds of albatross species are threatened with extinction, listed as either vulnerable, endangered, or critically endangered, and half of species' populations are declining (IUCN, 2019). By-catch in fishing operations and invasive species on breeding islands are recognized as the key threats driving the decline of albatross species (Dias et al., 2019), with mortality from these causes readily observable and quantifiable. However, these encounters alone cannot account for population decline across all albatross species; there is considerable variability in the mortality of adult albatrosses that cannot be explained by fishing effort (Rolland, Weimerskirch, & Barbraud, 2010), leaving a dearth of knowledge surrounding the impact of less visible threats. Mortality associated with emerging anthropogenic threats, including the ingestion of plastic, is not easily observed in species that inhabit the high seas. Among other marine vertebrates, including cetaceans and sea turtles, researchers make use of postmortem examination of stranded animals to investigate at-sea threats to mortality, such as ingestion of plastic (Bairdhz & LangelierL, 1991; Lusher, Hernandez-Milian, Berrow, Rogan, & Connor, 2018; Puig-Lozano et al., 2018). However, few stranded albatrosses are encountered annually, and fewer in suitable postmortem examination condition, even at national scales (Taylor, 2004). Obtaining sufficient sampling power to quantify causes of death in rare and dispersive marine species, such as albatrosses, remains a challenge. Collaboration research linking biologists and wildlife veterinarians would benefit the knowledge of causes of mortality to inform conservation of albatrosses.

Twenty-two species of albatrosses are recognized by the International Union for Conservation of Nature (IUCN, 2019). Three species, Laysan albatross, *Phoebastria immutabilis*, black-footed albatross, *P. nigripes*, and short-tailed albatross, *P. albatrus*, inhabit the northern hemisphere, one species is equatorial, and the remaining 18 species largely inhabit the southern hemisphere (Onley & Scofield, 2007). Ingestion of plastic is well studied among the northern species (Auman, Ludwig, Giesy, & Colborn, 1998; Fry, Fefer, & Sileo, 1987; Gray, Lattin, & Moore, 2012), particularly the Laysan (Auman et al., 1998; Young, Vanderlip, Duffy, Afanasyev, & Shaffer, 2009), and black-footed albatrosses (Gray et al., 2012), for which garbage and solid waste is a recognized threat (IUCN, 2019). However, plastic pollution is not considered a major threat, or not listed, for southern hemisphere albatross species (Dias et al., 2019; IUCN, 2019; Phillips et al., 2016). We pose the question: is ingestion of plastic a conservation issue, which may be worthy of further consideration as a mortality source for threatened southern hemisphere albatrosses?

1.2 | Plastic ingestion mortality—uncommon or unobserved?

Our current knowledge of plastic ingestion in southern hemisphere albatrosses largely comes from the postmortem examinations of birds that have been by-caught in fishing operations. Though the frequency of plastic ingestion is suitably monitored by surveying by-catch birds, such samples are not informative with respect to plastic ingestion mortality, presenting a mortality sampling bias. By-catch records show ingested plastic rates of 0–39% occur across southern albatross species (Jiménez, Domingo, Brazeiro, Defeo, & Phillips, 2015; Roman, Bell, Wilcox, Hardesty, & Hindell, 2019; Ryan, de Bruyn, & Bester, 2016), with higher rates observed in great albatrosses (Genus: *Diomedea*) compared to mollymawks (Genus: *Thalassarche*) (Jiménez et al., 2015; Ryan et al., 2016). Ingested plastic rates in southern hemisphere albatrosses are significantly lower than northern hemisphere albatrosses (Genus: *Phoebastria*), which exhibit ingested plastic frequencies from 52% to 83% (Gray et al., 2012). Albatrosses may ingest and regurgitate/excrete undigestible items without incident through their lifetime, as evidenced by plastic in regurgitated boluses (Nilsen, Hyrenbach, Fang, & Jensen, 2014) and numerous reports of otherwise healthy by-caught birds with ingested plastic. Though most plastic ingestion may not cause harm, even a single item can cause death of an individual seabird if that item causes a gastrointestinal obstruction or perforation (Pierce, Harris, Larned, & Pokras, 2004; Roman, Hardesty, Hindell, & Wilcox, 2019). Large plastic items also have a space occupying effect in the gastrointestinal tract, reducing volume for nutritious food (Pierce et al., 2004; Ryan, 1988), as observed in sea turtles (McCauley & Bjorndal, 1999; Santos et al., 2020). An albatross that has survived many instances of plastic ingestion may still ultimately die from plastic as each exposure presents a new opportunity for potential death (Roman, Hardesty et al., 2019).

Floating plastic density is increasing in the southern hemisphere, following a pole-ward spread of ocean plastic over the past few decades (Barnes, 2005). Consequently, we expect an increasing rate at which foraging albatrosses are expected to encounter and ingest plastic (Roman, Bell et al., 2019). Already, significant plastic accumulation zones occur in association with subtropical gyres in the southern hemisphere (Cózar et al., 2014; Eriksen et al., 2013). For example the South Pacific subtropical gyre, which borders seabird foraging hotspots associated with upwelling zones of the Humboldt current (Weichler, Garthe, Luna-Jorquera, & Moraga, 2004), contains >26,000 plastic particles per km^2, increasing to >396,000/km^2 near the center (Eriksen et al., 2013). Deaths of albatrosses due to plastic ingestion occur at sea and are unlikely to be discovered (Figure 1), especially in remote regions. As albatrosses are highly migratory (Onley & Scofield, 2007) and regional differences in the density of ocean plastic must also be accounted for when considering risk to both taxa and individuals (Wilcox, Van Sebille, & Hardesty, 2015). Among great albatrosses (Genus: *Diomedea*), ingested plastic is absent/rare in individuals by-caught off South Africa (0–2.7%), but common in the same species by-caught off South America (0–39%) (Ryan et al., 2016). Due to the low frequency of encountering dead albatrosses in an unbiased manner, it is difficult to survey and quantify mortality that might result from plastic ingestion encounters.

FIGURE 1 The cause of death of albatrosses that die at sea are unlikely to be realized unless carcasses reach a populated shoreline and a postmortem examination is performed by suitably experienced persons. This black-browed albatross, *Thalassarche melanophris*, was observed dead at sea, with ribbon (typically attached to balloon, indicating likely balloon ingestion) coming from the mouth off Southport, Queensland, Australia, 2015 (Pers. Obs. David Stewart). Specimen was not collected. Photo provided by Todd Burrows.

We aimed to examine cause of death in albatrosses to ascertain the frequency of plastic ingestion and the frequency where death results from plastic ingestion. To quantify death in a "natural" context, we examined cases of beach-cast albatrosses in Australia and New Zealand. We contextualized the frequency of death due to plastic ingestion compared to other threats and provide a checklist for identifying plastic ingestion as a factor in morbidity and mortality. We also discuss potential policy responses in light of this newly identified threat.

2 | METHODS

We collected data from postmortem examinations of beach-cast albatross and mollymawk species (henceforth, albatrosses) presented to veterinary hospitals and pathology services in Australia and New Zealand between 2001 and 2020. All postmortem examinations were conducted by wildlife veterinarians or with a veterinarian present. Cases include albatrosses submitted to The Nest Te Kōhanga, Wellington Zoo, New Zealand between 2010–2020 (n = 5), Wildbase pathology service, New Zealand, from 2001 to 2020 (n = 87) and collected on Fraser Island, Australia between 2012 and 2016 and delivered to Moggill Koala Hospital, Australia (n = 15). These numbers include albatrosses that were found dead, and those that were found alive and received by wildlife carers and/or hospitals but were euthanized or died in care.

Using cause of death frequencies determined by postmortem examination in this study, and the frequency of occurrence (FOO) of ingested plastic from the literature (Table S1), we used Bayesian analysis to estimate the FOO of plastic ingestion in an albatross and the mortality rate due to plastic ingestion.

We asked four questions:

(1) What is the probability that an albatross has plastic in its gut when by-caught? We estimated these probabilities using data from albatrosses that were by-caught in the western South Pacific Ocean (off New Zealand and Australia), the western South Atlantic Ocean (off Uruguay and Brazil) and the eastern South Atlantic/Indian Ocean (off South Africa).

(2) What is the probability that an albatross dead on the beach has plastic in its gut? We estimated these probabilities using data from albatrosses that had beach-washed along the western South Pacific coast (New Zealand and Australia) and the western South Atlantic coast (Brazil).
(3) What is the probability that plastic was the cause of death for an albatross found dead at sea/on a beach with plastic in its stomach? We estimated this probability using parameters from this study.
(4) What is the probability that a beach-washed albatross had died from an anthropogenic cause, either a fisheries interaction or plastic ingestion? We estimated these probabilities using data from albatrosses that had beach-washed along the western South Pacific coast (New Zealand and Australia) and the western South Atlantic coast (Brazil), and the posterior probability estimated in question three.
(5) To answer these questions, we used both uninformed uniform priors (Q 1–4) and informed normally distributed priors (Q4, informed by probability of Q3). Parameters were derived from all published literature available on southern hemisphere albatross plastic ingestion rates within the past 20 years, where bycatch and beach-washed data are reported separately, and the results of this study. A detailed Bayesian analysis methodology is available in Supplementary Information.

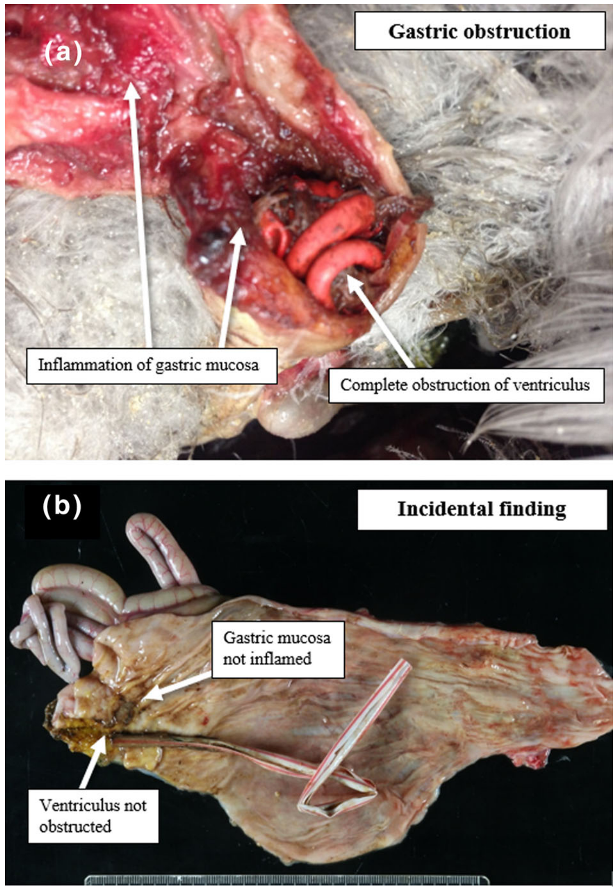

FIGURE 2 Distinguishing gastric obstructionfrom plastic as an incidental finding on postmortem examination. The top image shows gastric obstruction in a light-mantled albatross, *Phoebetria palpebrate*, caused by a rubber balloon (top view, looking into the ventriculus). The lower image shows a plastic straw found in the proventriculus of a juvenile female grey-headed albatross, *Thalassarche chrysostoma*, from a postmortem examination by Wildbase pathology service. The straw was determined to be an incidental finding

3 | RESULTS

3.1 | Plastic patterns among patients

Postmortem examinations were conducted, and the cause of death was determined for 107 individual albatrosses of 12 species (Table S2). Ingested plastic was present in 6 of 107 individuals (5.6%) representing four species, light-mantled albatross, *Phoebetria palpebrate*, Southern royal albatross, *Diomedea epomophora*, grey-headed albatross, *Thalassarche chrysostoma*, and shy albatross, *T. cauta*. In half of the cases where plastic was present ($n = 3$, 2.8%), the plastic foreign body had caused a gastrointestinal obstruction and was determined to be the cause of death. Two albatrosses that died from gastrointestinal obstruction were clinical cases, treated by veterinary staff before death (Case 1: Light-mantled albatross and Case 2: Southern royal albatross). One case where plastic was the cause of death was found at postmortem examination (Case 3: Light-mantled albatross). Plastic possibly contributed to the death of another case at postmortem examination (Case 4: Grey-headed albatross), but this case presented multiple pathologies and the final cause of death was unclear (Tables S2 and S3). Ingested plastic was an incidental finding (Figure 2) in one grey-headed albatross, which had ingested a plastic straw; and one shy albatross, which had eaten a plastic lolly wrapper (Tables S2 and S3). One case of death due to gastric perforation by hook on an ingested long-line snood in a Buller's albatross *T. bulleri* was counted as trauma due to fisheries and not due to ingested plastic.

3.2 | Clinical cases

Two clinical cases included an adult male light-mantled albatross (Case 1), found in June 2020 and a juvenile male southern royal albatross (Case 2) found in December 2019. The light-mantled albatross was emaciated, weighing only 1.61 kg, compared to an average weight range of 2 kg (female) to 3.2 kg (male) (Dunning Jr, 2007). Major initial clinical findings were dehydration, weakness, dropped wings, reduced fecal output, anemia, hypoproteinemia (low blood protein) and hyperuricemia (high uric acid in blood). Hyperuricemia returned to normal levels following rehydration, indicating the cause of the increase was reduced renal filtration rate due to dehydration. The southern royal albatross was found severely emaciated, weighing 6 kg compared to an average adult male weight of 8.2 kg (Dunning Jr, 2007), as well as being dehydrated and weak with severe anemia and hypoproteinemia. Radiographs showed no obvious foreign objects for either cases (Table S3). Both cases died in care.

3.3 | Postmortem examinations

Postmortem examinations were performed shortly after death for all four cases, confirming emaciation with minimal pectoral muscle mass and no body fat reserves, and no signs of obvious trauma. In Case 1, an 18 mm green rubber ring was found in the proximal duodenum, 2 cm aboral to the stomach exit, with the central hole filled with another small hard plastic fragment (Table S3). The surrounding intestinal wall was thickened, indicating the foreign object had been present for an extended length of time. In Case 2, the esophagus was filled with a large amount of liquid food, given orally during hospitalization. The proventriculus contained a flattened but intact 500 mL empty plastic bottle with lid, two pieces of balloon, lobster tail remnants, multiple feathers, and plant matter. In Case 3, the gastrointestinal tract was empty except for the knotted end of a latex balloon, which was firmly lodged in the pylorus. The gastric mucosa was inflamed and had a foul odor. Case 4 had ingested several foreign bodies including two rubber latex balloons, a fragment of hard plastic, a plastic straw and body feathers. These foreign bodies were not completely obstructing the ventriculus but may have contributed to death. In Cases 1–3, partial to complete obstruction to the passage of ingesta was determined as the cause of death. This theory was supported by the undigested food in the esophagus of Case 1 and 2, and lack of digesta beyond the foreign body in the intestines in all cases. Case 4 showed several pathologies in addition to ingested foreign bodies. Case 4 was not allocated as plastic cause of death, though plastic may have been a contributing factor. For a detailed description and photographs of each of the two clinical cases and four postmortem cases, please see Supplementary Information.

3.4 | Estimated probability of ingested plastic and plastic-mortality in albatrosses

3.4.1 | Probability of plastic in the gut when by-caught

The posterior probability of ingested plastic in by-caught albatrosses was 0.003 (0.3%) for the western South Pacific Ocean (90% CI ≤ 0.001–0.013), 0.168 (16.8%) for the western South Atlantic Ocean (90% CI = 0.118–0.226), and 0.019 (1.9%) for the western South Atlantic/Indian Ocean (90% CI = 0.013–0.028) (Figure 3).

3.4.2 | Probability of plastic in the gut when beach-washed

The posterior probability of ingested plastic in beach-washed albatrosses was 0.063 (6.3%) for the western South Pacific Ocean (90% CI = 0.033–0.105), 0.412 (41.2%) for the western South Atlantic Ocean (90% CI = 0.330–0.493) (Figure 3) and western South Atlantic/Indian Ocean is unknown. The probability of plastic occurring in the gut of beach-washed albatrosses was higher than the probability of plastic in the gut of by-caught albatrosses, without overlap between the probability distributions in two ocean basins (Figure 3).

3.4.3 | Probability that plastic was the cause of death for beach-washed albatross with plastic in their stomach

Albatrosses found on the beach with plastic in their gut had a posterior probability of 0.441 (44.1%) that the plastic was the cause of death (90% CI = 0.157–0.758) (Figure 4).

3.4.4 | Probability of plastic or fisheries cause of death among beach-washed albatrosses

Albatrosses found dead on New Zealand and eastern Australian beaches had a 0.034 (3.4%) posterior probability that plastic was the cause of death (90% CI = 0.013–0.072), compared to 0.025 (2.5%) for a fishing interaction cause of death (90% CI = 0.008–0.060) (Figure 4). Albatrosses found dead on Brazilian beaches had a 0.175 (17.5%) posterior probability that plastic was the cause of death

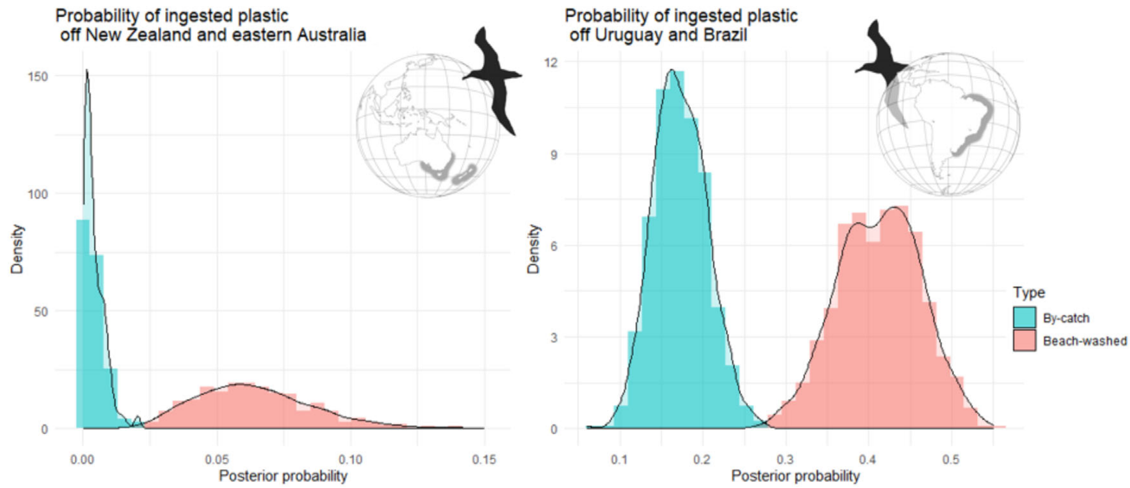

FIGURE 3 The probability of ingested plastic in gut of albatrosses, at the time of by-catch or beach-washing (following at-sea death), was estimated using Bayesian analysis. If there is no link between plastic and death of albatrosses, the probability of ingested plastic in the gut of beach-washed albatrosses should overlap with the probability of plastic in the gut of by-caught albatrosses. However, we found that beach-washed albatrosses had a higher probability of having plastic in their gut than by-caught albatrosses, showing a link between plastic in the gut and the probability of nonfisheries death at sea. Posterior probabilities were generated from plastic ingestion data from by-catch and beach-washed albatrosses collected in New Zealand, Australia (this study and Roman, Bell et al., 2019), Uruguay, and Brazil (Barbeiri, 2009; Jiménez et al., 2015; Petry & Fonesca, 2002; Tavares et al., 2017)

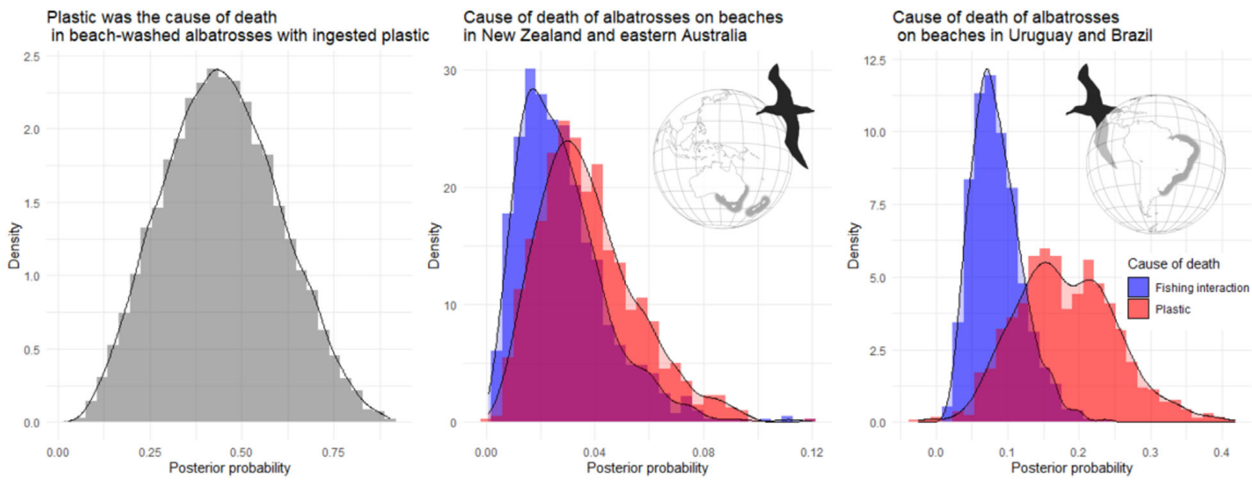

FIGURE 4 How many beach-washed albatrosses with plastic in the gut, have died from plastic, and what is the probability of anthropogenic causes of death: fisheries interaction or plastic ingestion? We estimated the probability of plastic death, given plastic ingestion and the probability of plastic and fisheries cause of death at sea, becoming beach-washed, in New Zealand, Australia, Uruguay, and Brazil using Bayesian analysis. We estimate that there is a similar probability that beach-washed albatrosses had died due to either a fisheries interaction or the ingestion of plastic. This is an important finding given that fisheries interactions are a known cause of albatross population decline, while plastic is not currently recognized as a significant threat. Posterior probabilities were generated from plastic cause of death data from this study and fisheries interaction data from this study and Petry and Fonesca (2002)

(90% CI = 0.078–0.301), compared to 0.080 (8.0%) for a fishing interaction cause of death (90% CI = 0.036–0.152) (Figure 4).

4 | DISCUSSION

Plastic mortality occurred in half of albatrosses that had ingested plastic, causing the death of three individuals (2.8%). This high frequency of mortality among plastic-ingestion cases indicates that plastic-eating behavior is associated with a considerable risk of death if the consumed item causes an obstruction. Death from plastic occurred at a higher frequency than other serious anthropogenic threats among wildlife hospital patients, including two individuals from confirmed/suspected fisheries interaction (1.8%) and one from oiling (0.9%). The estimated probability of plastic deaths at sea, near

TABLE 1 Clinical signs associated with gastric obstruction: checklist for veterinarians and wildlife carers

Clinical sign	Notes
✓ Low body condition	Ensure volume of food fed to bird is not included in body mass calculation. Be wary of daily weight increases equal to volume of food fed. Note it can be difficult to detect poor body condition in albatrosses given the thick feather coverage, so comparing the measured weight with the expected species weight range is recommended.
✓ Dehydration	Due to lack of intake or reduced intestinal absorption.
✓ Regurgitation/vomiting	Regurgitation or vomiting is common with gastric obstruction. Sometimes the bird will repeatedly stretch the neck due to gastric discomfort.
✓ Scant, less, or abnormal feces	Food that is not passing (or not normally digesting) results in minimal solids in feces. Ingesta in albatrosses is initially carried in the proventriculus, within the ribcage, so increased distension cannot always be seen or palpated.
✓ Normal radiograph	Plastic can be difficult to appreciate radiographically and only dense plastic can usually be detected. Distension of the proventriculus due to increased gastric contents may be seen radiographically.
✓ Weak and lethargic	A lack of digesta in the intestines leads to reduced nutrient absorption, causing hypoglycemia and weakness.
✓ No signs of trauma	If bird is weak from emaciation, they may experience secondary trauma (crash landing, washed up by waves, etc.), but most will not show signs of obvious trauma.
✓ Anemia and hypoproteinemia	Low nutrient intake/absorption causes reduced production of red blood cells and proteins. The severity of these findings can be underestimated initially due to dehydration.
✓ Halitosis	Undigested food in the upper digestive tract can begin to smell foul.

to the coast and becoming beach-cast, is at least as likely as mortality due to fishing interactions in two ocean basins (Figure 4). We suggest that albatross mortality from plastic ingestion may be underestimated by veterinarians, biologists, and decision makers. Here we show the benefit of detailed reporting by wildlife hospitals, which may help to identify emerging conservation issues such as plastic impacts on threatened and endangered fauna.

4.1 | Clinical signs of plastic obstruction

Common clinical signs of gastrointestinal obstruction in birds include loss of condition, lethargy, vomiting, regurgitation, coelomic distension, and scant or abnormal feces (Miller, Bischoff, & Hoff, 2009; Morishita & Harr, 1999; Perpiñán & Curro, 2009; Pierce et al., 2004; Shwaluk & Finley, 1995) (Table 1). Birds are often emaciated when presenting at veterinary clinics, with no obvious trauma, unless secondary to weakness (such as being damaged in the surf). As plastic is often radiolucent, it may not be detected on radiographs. Obstruction of the gastrointestinal tract prevents or slows the absorption of nutrients, causing dehydration, weakness, lethargy, and hypoglycemia, even when fed. Weight gain may be noted from accumulation of food, in conjunction with a decrease or absence of fecal output. Furthermore, low nutrient intake/absorption causes reduced production of red blood cells and proteins resulting in anemia and hypoproteinemia. The severity of these findings can be underestimated due to dehydration. If a bird presents with the clinical signs detailed in Table 1, we suggest the clinic uses endoscopy to investigate whether a foreign body obstruction may be present.

4.2 | Diagnosing foreign body gastric obstruction on postmortem examination

Gastric obstructions as the likely cause of death can be determined on postmortem examination of suitably fresh carcasses. Signs include emaciated body condition, presence of ingested foreign body, sometimes firmly lodged, undigested ingesta oral to the obstruction, lack of digesta aboral to the obstruction, and possible inflammation/ulceration of the gastric mucosa adjacent the blocking object (Pierce et al., 2004) (Table 2, Figure 2). We recommend routine postmortem examination of albatrosses where the cause of death is unknown to better grasp the scale of causes of mortality.

4.3 | Coincidental cases or symptoms of a larger problem?

The low rates of mortality investigations may bias perception of threats to populations (Norris & Pain, 2002), meaning that threats and conservation opportunities for seabird species may be overlooked. Observable causes of

TABLE 2 Postmortem examination findings associated with gastrointestinal obstruction: checklist for veterinarians, wildlife carers, and biologists. If the cadaver displays all or most of these findings, gastric obstruction may be suspected as cause of death

Postmortem finding	Notes
✓ Emaciated body condition	No fat under the skin or around the intestines. Pectoral muscle atrophy, often extreme, with very low body weight (may be as low as half healthy body weight).
✓ Ingested foreign body	Can be a large object, mass of objects, or smaller object causing blockage/obstruction. Larger objects may fill the volume of the proventriculus/ventriculus. In this study, objects were found blocking the pylorus or proximal duodenum, but obstructions in the jejunum/ileum or large intestine could also occur.
✓ Undigested food oral to foreign body	If the bird ate or was fed after the foreign body obstruction occurred, ingesta is prevented from passing the blockage and will be oral to the blocking object. Lack of food does not necessarily mean that obstruction has not occurred, as appetite may be impaired by the obstruction. *Note: Food may be present in the GI tract of birds that have died due to acute trauma, as fisheries by-catch, or fed in care. Traumatic and fisheries-related deaths can usually be identified by good body condition, acute physical trauma, and for by-catch, freshly ingested "bait" or commercial fish species. Presence of food from care can be evaluated based on care history and time between last feeding and death.*
✓ Lack of intestinal content aboral to foreign body	Commonly, the GI tract between the blocked site and cloaca is empty. Empty GI tract aboral to the object is an indicator that a gastrointestinal obstruction may have occurred, and a very good indicator if paired with undigested food oral to the blockage. A partial obstruction may result in some digesta being present aboral to the foreign body.
✓ Inflammation and/or ulceration of the gastric mucosa	Especially adjacent to the obstructive object. Inflammation appears grossly as a reddened appearance, with a thickened wall or ulcerations.
✓ Abnormal gastric odor	When opening the gastrointestinal tract, a strong abnormal odor can sometimes be detected. This odor differs to the normal odors of the gut or those associated with autolysis of the body.

mortality such as fishery interactions, oiling, and predation of chicks on islands are perceived as greater threats to seabird populations than less observable threats, such as marine debris, disease, and trauma (Table S2) (Croxall et al., 2012; Dias et al., 2019; Lieske, Tranquilla, Ronconi, & Abbott, 2019). Consequently, conservation actions are prioritized toward more visible threats (IUCN, 2019). Correct identification of potential causes of population decline are essential for appropriate planning of remedial conservation decisions (Norris & Pain, 2002). In one example of misattribution, the decline of Atlantic yellow-nosed albatross *Thalassarche chlororhynchos*, on Amsterdam Island attributed to long-line fisheries, was found to be caused by disease (Weimerskirch, 2004). We do not suggest that ingestion of plastic is a larger threat than fisheries interactions or predation on islands overall. For example, fatal fishing interactions that occur offshore are less likely to become beach-cast and detected than fatal plastic interactions in plastic-dense nearshore regions (Reisser et al., 2013). However, given the frequency observed in this study of plastic mortality compared to fishing interaction, known to cause population-level consequences (Moloney, Cooper, Ryan, & Roy Siegfried, 1994), we suggest that plastic warrants further consideration as a threat.

4.4 | Population-level risks

The timing and high ratio of deaths among albatrosses expressing plastic-eating behavior presents a warning for future population consequences. Albatrosses are long-lived and slow to reproduce (Moloney et al., 1994). Population models show that for threatened albatross populations, just a few percent increase in mortality can cause population decline (Moloney et al., 1994). The probability of plastic-death varied by ocean basin, with posterior probability estimations ranging from 3.4% off east Australasia to 17.5% off Brazil. The mortality rates for South Africa likely fall in between these two figures, given ingested plastic rates in by-caught individuals were higher than Australasia but lower than Brazil. The models presented in these analyses are for a simplified albatross, and do not consider interspecific heterogeneity in foraging range or plastic-eating behavior. However, even the mortality scenarios for less polluted regions, such as Australasia, are within limits expected to cause decline in populations that are vulnerable or near a knifes edge of stability.

All plastic-mortality cases that we examined had occurred within the most recent 5 years of this 20-year dataset. This recent increase in observed plastic-mortality cases likely reflects the increase of plastic entering the southern hemisphere, which has experienced increases of 1–2 orders of magnitude in the higher latitudes from the 1980s to 2000s (Barnes, 2005). Recent increases in the debris in the southern oceans are reflected by increased abundance of user plastic in the regurgitated boluses of some species breeding on sub-Antarctic Marion island (Perold, Schoombie, & Ryan, 2020). The risk that plastics pose to southern hemisphere albatrosses is significantly higher now than in the past and will continue to increase without significant reduction of input of plastic into oceans. The potential population-level threat is heightened for species whose foraging regions overlap with plastic-dense areas of the southern hemisphere, such as near to gyres and populated coastlines. As the habitat range of most albatross species includes these regions (Onley & Scofield, 2007), most species are at risk. For example, we did not record plastic ingestion among the Northern royal albatrosses *Diomedea sanfordi*, an endangered species with a decreasing population trend (Table S2). Though plastic exposure is low in New Zealand's marine territories, Northern royal albatrosses are exposed to high densities of plastic in other parts of their range, and 39% of Northern royal albatrosses by-caught off Uruguay had ingested plastic (Jiménez et al., 2015). Black-browed albatrosses, *T. melanophrys*, and Atlantic yellow-nosed albatrosses were not investigated in this study, but plastic ingestion has been recorded among 73% and 44% of individuals, respectively, found beach-cast in Brazil (Barbieri, 2009). The proportion of albatrosses that engage in plastic-eating behavior may be underestimated, particularly among lesser-studied species.

The lack of overlap between the probability of plastic occurring in the gut of by-caught and beach-washed albatrosses (Figure 3) shows that plastic is linked to death and beach-washing, rather than incidental to death, as in fisheries interactions. In both Australasia and Brazil, beach-washed albatrosses with plastic in their gut occurred at thrice the rate of fisheries interactions, and more frequently than oiling (Petry & Fonseca, 2002). Though not all of these plastic-eating individuals would have died from plastic, our estimations (Figure 4) show that plastic in nearshore seas is, at a minimum, of equivalent concern as a source of mortality as fisheries. The chance of death likely reflects the types of plastic debris available to foraging albatrosses. For example, among by-caught albatrosses, ingested items typically include fragments of hard plastic, nurdles, and nylon (Jiménez et al., 2015). In our study, the debris recovered was mostly soft and/or large items, which are more likely to cause gastric obstructions (Roman, Hardesty et al., 2019). This pattern also occurs among albatrosses found dead on beaches in previous studies, where soft plastic was the most common debris item found in the gut during postmortem examination (Tavares, de Moura, Merico, & Siciliano, 2017). It is probably not a coincidence that soft/large items are seldom found in by-caught albatrosses; ingesting these items may carry a low rate of survivability due to high risk of fatal gastrointestinal obstruction. The variation in the frequency and type of ingested plastic may be an artifact of the overlap of foraging ranges with plastic-dense oceanic regions or the composition of prey species (Roman, Bell et al., 2019).

4.5 | Where are potential policy responses?

Immediate action to reduce the impact of anthropogenic activities known to cause albatross mortality, especially among threatened species, is required to prevent future breeding populations declining to unsustainably low levels (Moloney et al., 1994; Norris & Pain, 2002). Preventing the decline of endangered species is of international concern given the global nature of the plastic pollution problem and multinational agreements that seek to protect migratory albatrosses, such as "The Agreement on the Conservation of Albatrosses and Petrels (ACAP)," to which 13 nations are signatory. If populations decline to critically endangered levels, intensive remediation may be required to prevent species extinction (Norris & Pain, 2002), which might be avoided by simpler interventions undertaken sooner.

Policy interventions include adjusting the allowable albatross by-catch take to account for mortality due to other sources, such as plastic ingestion. Policies that reduce plastic entering the ocean will decrease wildlife–plastic encounters. For albatrosses, rubber debris, especially balloons, are highly represented among plastic cause of death cases. This presents an opportunity for the management of items identified among these cases (Table S3). Latex balloons contribute just 1% of debris found on beaches globally, and plastic beverage bottles contribute 8% of items on the coasts and seafloor (Roman et al., 2020). As balloons enter the environment through intentional and accidental release, prohibitions on intentional balloon release and restricting their use in circumstances with high risk of accidental release into the environment will undoubtedly reduce wildlife balloon-ingestion deaths. Plastic bottles enter the environment typically through littering. To encourage bottle recycling as an alternative to littering, incentivized schemes such as container deposit legislation (CDL) have been available in some states and countries (Schuyler, Hardesty, Lawson, Opie, & Wilcox, 2018). The success of CDL schemes at reducing marine litter is evident in coastal debris surveys, which show 40% lower whole bottle litter than sites without CDL (Schuyler et al., 2018). Consistent national legislation that limits the use of, incentivizes the recycling of, or prohibits the sale of plastic bottles would reduce input to the marine environment. We recommend policy expansion of such schemes to reduce wildlife–plastic interactions and mortality.

5 | CONCLUSION

Plastic ingestion is likely an underestimated threat to endangered and declining albatrosses. To ensure sustainable populations of these ocean wanderers, adding plastic pollution as an internationally recognized threat may bring opportunity for governance changes in fisheries, island, and land-based waste management. We have provided an improved methodology, which enables veterinarians, wildlife carers, and biologists to identify and consistently report findings to improve our understanding of how significant a threat plastic ingestion may be to albatross populations.

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AUTHOR CONTRIBUTIONS

All authors conceived of the manuscript. LR, RGB, DS, SH, MJ, PK, and BL conducted the clinical care and/or performed postmortem examination of the albatrosses in this study. LR analyzed the data. All authors wrote the manuscript.

ETHICS STATEMENT

This manuscript employed retrospective data records from wild albatrosses received and treated by veterinary hospitals in Australia and New Zealand. No live animals were captured, received, or utilized for research purposes.

DATA ACCESSIBILITY STATEMENT

All data used in this manuscript is available in the supplementary information.

CONFLICT OF INTEREST

The authors report no conflict of interest, financial or otherwise, that a reasonable person could construe as possibly influencing the objectivity of the report.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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