



First evidence of mouse predation killing adult great albatrosses

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Abstract Invasive rodents threaten native species in numerous ecosystems, especially oceanic islands. The House Mouse *Mus musculus* is the only introduced mammal species on sub-Antarctic Gough and Marion Islands. Ample evidence exists of mice preying upon seabird chicks on these two islands, but there have been only a few reports of attacks on adult seabirds, none of which has been fatal. We report the first deaths of adult great albatrosses due to mouse attacks. On Gough Island, three Tristan Albatrosses

Diomedea dabbenena (Critically Endangered) brooding small chicks were observed with wounds typical of mouse attacks in March–April 2021; two likely abandoned their chick, causing breeding failure, and the third was found dead eight days after discovery with large blowfly larvae in the wound. On Marion Island, two wounded and eight dead adult Wandering Albatrosses *D. exulans* (Vulnerable) were found in April 2023. Inspection of the wounded individuals, as well as the injuries on the fresh carcasses strongly suggest that mouse predation was the cause of death. Gough Island is home to virtually all Tristan Albatrosses, and Marion Island is the single most important breeding site for Wandering Albatrosses, home to about a quarter of all breeding birds. The death of breeding adults of these long-lived species emphasizes the urgent need to eradicate introduced mice from these islands.

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Introduction

Important biodiversity loss has been attributed to invasive alien species which threaten native species particularly in island ecosystems. Islands are important breeding grounds for seabirds, which are one of the most threatened group of marine species. Invasive species are one of the greatest threats to seabirds, together with bycatch, hunting/trapping, climate/environmental change and disturbance (Dias et al. 2019). In terms of invasive species, rats (*Rattus* spp.) and Feral Cats (*Felis catus*) pose the greatest threats to seabirds, but mice (*Mus* spp. and *Peromyscus maniculatus*) have a severe impact on 22 seabird species (Dias et al. 2019).

The first suspected attack of House Mice (*Mus musculus*) on seabird chicks dates to the 1970s when a chick of the Endangered Ashy Storm-petrel (*Hydrobates homochroa*) was discovered eaten by mice in the Farallon Islands (Ainley et al. 1990). In the 1980s, a Blue Petrel (*Halobaena caerulea*) chick carcass was found on sub-Antarctic Marion Island with deep wounds on the back of the neck suspected to be from mice (Fugler et al. 1987). However, unequivocal proof of predatory behaviour was only obtained in 2004, when video footage was obtained of mice attacking chicks of Tristan Albatrosses (*Diomedea dabbenena*), Atlantic Petrels (*Pterodroma incerta*) and Great Shearwaters (*Ardenna gravis*) on Gough Island (Wanless et al. 2007). Invasive mice have now been reported to prey upon the eggs and chicks of many seabird species, from small storm-petrels, through prions, shearwaters and petrels to albatrosses (e.g. Angel et al. 2009).

The first occurrence of mouse attacks on adult seabirds was recorded on Midway Atoll in the 2015–2016 breeding season, when 42 adult Laysan (*Phoebastria immutabilis*) and Black-footed (*P. nigripes*) albatrosses were killed and 480 wounded (Duhr et al. 2019). The following season, this escalated to 242 adults killed and 1218 injured (Duhr et al. 2019). In the Southern Ocean, the first mouse-related wounds on an adult seabird were observed on Marion Island in 2017, when open wounds were observed on both flanks of an incubating male Northern Giant

Petrel (*Macronectes halli*) (Jones et al. 2019). The bird presumably abandoned its breeding attempt, because the nest failed shortly afterwards, but the bird returned to breed successfully the following year (FIAO unpubl. data). The first mouse attack on a great albatross (*Diomedea* spp.) was recorded on a Tristan Albatross on Gough Island in March 2018 but the adult recovered and successfully raised its chick (Jones et al. 2019). Here, we describe the first instances of introduced House Mice killing breeding adult great albatrosses on two sub-Antarctic islands, Gough and Marion Islands.

Methods

Gough (40° 21' S, 9° 53' W) and Marion (46° 52' S, 37° 49' E) Islands are in the South Atlantic and Southern Indian oceans, respectively. The only introduced mammals now present on both islands are House Mice. Both islands support a great diversity of birds with at least 24 species breeding on Gough Island (Ryan and Oppel 2022) and 28 species on Marion Island (Preston et al. 2019). Gough Island harbours virtually the entire breeding population of the Critically Endangered Tristan Albatross (1250–1750 pairs; BirdLife International 2023). Marion Island harbours 24% of the breeding population of the Vulnerable Wandering Albatross (~ 2300 pairs; BirdLife International 2023; FIAO unpubl. data). Both these species form part of the Wandering Albatross species complex. The Tristan Albatross is slightly smaller (body length: 100–110 cm vs. 110–135 cm) and lighter (weight: 5–8 kg vs. 6.8–10 kg) than the Wandering Albatross (Ryan 2023). With experience, plumage can reliably indicate sex within each species (Jones et al. 2012; Ryan 2023). Sex assignment can be confirmed by measurements; males have longer and deeper bills (Cuthbert et al. 2003). Both species have similar breeding cycles, with egg-laying from mid-December, hatching in March, and chicks being left unattended from late April until they fledge from November–December (BirdLife International 2023). When successful, individuals of both species typically skip a year between breeding attempts.

Regular population monitoring started in 2001 for Tristan Albatrosses on Gough Island (Oppel et al. 2022) and 1982 for Wandering Albatrosses on Marion Island

(Ryan et al. 2009). This involves annual whole island counts of incubating adults and large chicks shortly before fledging, as well as more frequent monitoring of sub-colonies to identify marked parents and determine breeding success (Dilley et al. 2013; Opperl et al. 2022). The study colonies represent about 14% of each island population, respectively (FIAO and RSPB unpubl. data).

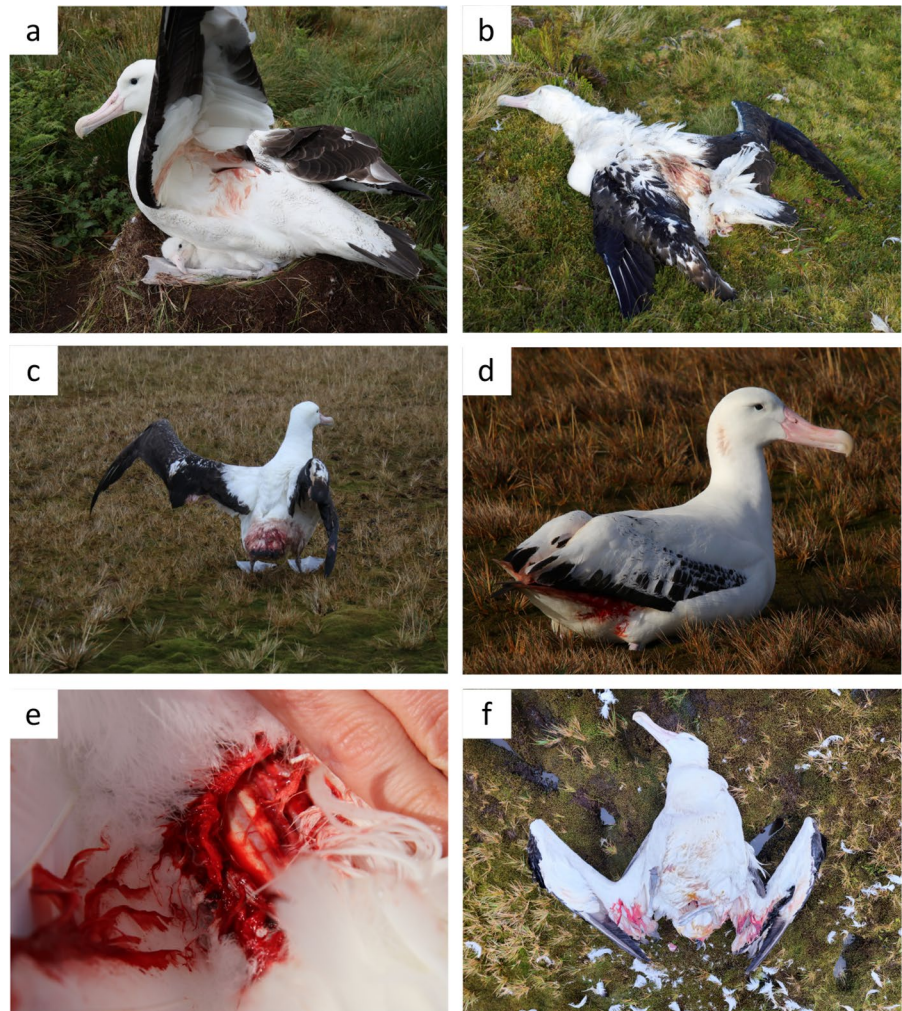
Results

Tristan Albatross

On 30 March 2021, two adult Tristan Albatrosses (a 17-year-old male and a 35-year-old female) brooding small chicks were found with open wounds typical

of mouse attacks in the Gonydale study colony on Gough Island. The 196 pairs breeding in the study colony had been monitored since January. However, no signs of mouse attacks on adults were detected until these two birds were photographed. On raising their wings to check their wing moult, blood was visible on their flanks from wounds on their lower backs (Fig. 1a). When the colony was next visited, on 7 April, the wounded male had abandoned its nest, and there was no sign of its chick. At the other nest, the wounded female was found dead near the nest (Fig. 1b). The carcass had been scavenged by Brown Skuas (*Catharacta antarctica*), but the fresh wounds inflicted by these birds contrasted with the older wound on its back, which contained blowfly larvae (12–15 mm long). The chick in the nest of the bird

Fig. 1 Wounded (a 30 March 2021; picture Peter Ryan) and dead (b 7 April 2021; picture Roelf Daling) female Tristan Albatross on Gough Island. Injured adult female (c 27 April 2023) and male (d 28 April 2023) Wandering Albatrosses with close-up of his wound (e 28 April 2023), and freshest adult carcass found with typical elbow wounds (f 27 April 2023) observed on Marion Island (pictures C–F: Christopher Jones)



killed by mice was supported by its father until June 2021, when it died. The father returned to the study colony in January 2022, but has not been recorded nesting again. The male that abandoned its nest survived the mouse attack and was seen in January 2022, but there was no sign of its mate, and neither bird has been recorded since then.

On 28 April 2021, a brooding 30-year-old male from a third nest was observed with a fresh mouse wound on the elbow, which was not observed the previous day. Mouse wounds were also first recorded on its chick on 10 April on the scalp, later extending to the back of its head and neck (27 April). Although the chick's wound had healed by 22 May, the nest failed by 17 June. The adult male survived the attack, and in 2022, the pair bred unsuccessfully. In 2023, the pair was breeding with its chick still alive in May 2023.

Wandering Albatross

On 27 April 2023, a wounded adult female Wandering Albatross was found with mouse-related wounds on the elbows of both wings on the northern side of Marion Island (Fig. 1c). She appeared weak and was unable to fully extend her right wing, but was able to walk. She was not seen again the next day, and her fate remains uncertain. Of the chicks nearby, one had a mouse-related wound, and one appeared to have regurgitated stomach oil (the main defence of albatross chicks against predators). On 28 April, a second injured Wandering Albatross, which was not present the day before, was observed near the injured chick. This male also presented typical mouse-related wounds on the elbows of both wings (Fig. 1d, e), and when being caught to observe the injuries, he displayed the typical resistance to manual capture of a healthy adult. Carcasses of eight adult Wandering Albatrosses were found within a 6 ha area around where these wounded birds were found (Online Resource 1). The two carcasses that were relatively fresh both showed signs of mouse-inflicted wounds on the elbows of the wings (Fig. 1f); the other six were too decomposed to detect wounds.

A total of 111 nests were recorded in the area in late January 2023 during the incubating count. On 28 April 2023, 74% of nests were still active (Online Resource 1). This failure rate was similar to the other, more intensely monitored, Wandering Albatross colonies on the north-eastern coast of the island. In the

following days, most of the colonies around the island were checked for wounded or dead adult Wandering Albatrosses; there were no signs of attacks. Further visits to the area where carcasses were initially found (8 May, 20 May and 7 June) did not reveal further evidence of mouse attacks. However, 39% of nests had failed in this area by 7 June, while only 28% had failed at the more intensely monitored colonies. The injured chick observed on 27 April was still alive on 20 May, but the nest had failed by 7 June.

Discussion

These are the first reported deaths of adult great albatrosses resulting from House Mice. The primary cause of death for the nine carcasses is unknown but two hypotheses exist: (a) mouse attacks resulted in death (Davies et al. 2015) by preventing the adult from flying if the elbow wounds were too severe; (b) adults would have succumbed to secondary infection as seen on Midway Atoll (Work et al. 2021). Secondary infection is the suspected cause of death for the Tristan Albatross, where the attack was on the back rather than the elbow. Mouse attacks have been observed on seabird chicks at Gough and Marion Islands for 20 years (e.g. Jones and Ryan 2010; Wanless et al. 2007), but attacks on breeding adults is a new phenomenon (Jones et al. 2019). This is particularly concerning given the high adult survival, delayed sexual maturity and low rate of reproduction typical of albatrosses (Moloney et al. 1994). Angel et al. (2009) and Holmes et al. (2019) acknowledged that mouse impacts on island ecosystems are less well understood than the impacts from larger invasive mammals and may be underestimated. Our observations provide new evidence of the considerable impacts mice have on island ecosystems and threatened species, and also suggest that no species or life stages are too big for attacks from the 20 g (35 g for Gough Island; Cuthbert et al. 2016) invasive mammal.

Until now, mouse-related wounds have been found on the body, wings and head of albatross chicks at Gough (Wanless et al. 2007; Davies et al. 2015, PGR pers. obs.) and Marion Island (Jones et al. 2010, Dillely et al. 2016), whereas mouse wounds on the head have yet to be observed on adults at either island. The observations on both islands suggest that it is easy to overlook attacks on the rump or elbows when adult

albatrosses are sitting. On Gough Island, injuries recorded in March would likely have been missed had the wings not been raised to check their moult. Similarly, injuries on both live birds on Marion Island were less visible until the birds stood up or extended their wings. The finding of dead adult great albatrosses is very rare on islands, so any carcasses should be investigated to try to infer the cause of death. One indication of attacks might be clusters of failed nests; failed nests were clustered at Marion Island (Supp. Mat. Fig. A1), typical of mouse-attacks on seabirds (e.g. Cuthbert et al. 2016; Jones et al. 2019). However, indirect information like this would need confirmation because giant petrels have been found preying upon albatrosses (e.g. Dilley et al. 2013).

In terms of determining when attacks on adults first started, attacks could have easily been missed outside of core study areas on Gough and Marion Island, and the discovery of carcasses and injured birds was mostly opportunistic. On Gough Island, the first two wounded adults would have likely been overlooked if they had not been handled to inspect their moult pattern, but the third one was discovered as part of the regular colony check. At Marion Island, the discovery of wounded adults was incidental as they occurred in an area where Wandering Albatross nests are normally only checked twice per year (incubation, and shortly before fledging). Nonetheless, due to the research effort on both islands by various research teams, it is unlikely that fatal attacks could have been overlooked for many years and they are likely a recent phenomenon. On Marion Island, environmental changes have caused mice to breed earlier each summer, resulting in higher mouse densities in late summer and reducing the availability of their main food, invertebrates and plant seeds (Smith et al. 2002; McClelland et al. 2018). Mice are forced to search for alternative food sources, initially attacking the more vulnerable seabird chicks and now breeding adults. This predatory behaviour may become heritable after a few generations (Hämäläinen et al. 2022).

The ecological traits of albatrosses (long-lived, delayed breeding, low fecundity) mean that the removal of breeding adults from the breeding population will have a considerable demographic impact (Moloney et al. 1994). The long-term monitoring of breeding success of Wandering Albatrosses on Marion Island indicates a slow decreasing trend over the last 15 years (FIAO unpubl. data), and a cryptic

population decrease of Tristan Albatrosses on Gough Island has been attributed to chick predation by mice (Oppel et al. 2022). Mouse-induced mortality of breeding adults will have dire consequences for the conservation of both species. Records on Midway Atoll indicate that the learning and transfer of this new behaviour of attacking breeding adults can happen extremely quickly (Duhr et al. 2019). Our observations thus provide further impetus for the urgent eradication of House Mice from islands, particularly where they are the sole introduced mammal (Wanless et al. 2007).

An attempt to eradicate mice from Gough Island in 2021 was unsuccessful; mice were observed on the island six months after baiting (Samaniego et al. 2023). The successful eradication of mice from Antipodes and other islands (DIISE 2018) highlights that successful mouse eradications are possible. However, recent failures and the generally lower probability of success of mouse eradications highlight that fundamental research into effective eradication strategies should continue to develop the best strategy adapted for every site (e.g. Birand et al. 2022, Livingstone et al. 2022). A mouse eradication is planned for Marion Island in 2026, should sufficient funding be secured. The sooner mice are removed from these fragile island ecosystems, the sooner they will recover (e.g. Brooke et al. 2018).

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Author contribution MC, PGR conceived the idea for this paper. MC, LKS, CWJ, MMR made the observations on Marion Island, PGR, SO, VP, RD, KLS made the observations on Gough Island. VP made the online resource. MC wrote the first draft of the manuscript. All authors contributed critically to the drafts and gave final approval for the manuscript.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article and its supplementary material.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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