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Antipodean wandering albatross population study 2023

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Final report

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Summary

The Antipodean wandering albatross *Diomedea antipodensis antipodensis* has been in decline since a population crash in 2005-07. Declining numbers appear to have been largely driven by high female mortality, but low chick production—with fewer birds breeding and reduced breeding success—has compounded the problem. To tease out the causes of falling numbers of Antipodean wandering albatrosses and identify the effectiveness of potential solutions, research includes an annual visit to the breeding grounds on Antipodes Island. This report describes the results of the field programme in the 2022/23 breeding season, and the preliminary findings from tracking of juveniles since January 2022.

There are some signs that the rate of decline might be slowing. The number of Antipodean wandering albatrosses breeding has been roughly stable for the past four seasons, and female survival shows some suggestion of improving since 2014 (4-year rolling averages), although it is still highly variable year to year. Breeding success in 2022 at 72% approached the average pre-crash nesting success of 74%, although the mean 2006–2022 rate remains comparatively low at 62%. However, the actual number of chicks produced remains small, even in good breeding-success years, since numbers nesting remain low. Recruitment is starting to draw from the (much smaller) cohorts produced since the crash, so population numbers will soon no longer be supplemented by higher recruitment rates seen over the past decade.

The population has been approximately stable for the last four years. However, there is so far no evidence of any sustained improvement in Antipodean wandering albatross demography, as required for the population to recover, with tentative improvements recorded here merely slowing the decline.

Recommendations include ongoing mark-recapture monitoring of demographic and population-size trends; an island-wide population size estimate; and research into causes of declines. More-targeted ongoing engagement is also needed, internationally and domestically, to achieve better bycatch mitigation in line with ACAP best practice.

Contents

Introduction

The Antipodean wandering albatross *Diomedea antipodensis antipodensis* is a biennially breeding seabird virtually endemic to the Antipodes Islands, New Zealand. A few pairs also breed on Campbell and Chatham Islands, but those make up less than 1% of the population. A sister subspecies, *D. antipodensis gibsoni*, breeds in the Auckland Islands and has morphological, distributional, and breeding timing differences with *D. a. antipodensis*. The genomics of both are currently being reviewed as part of a PhD project at Victoria University (I. Foote pers. comm.).

The New Zealand Threat Classification of Antipodean wandering albatrosses is Threatened; Nationally Critical (Robertson *et al.* 2021), with the five qualifiers Conservation Dependent, Climate Impact, Conservation Research needed, Island Endemic and One Location.

Since the eradication of house mice from the Antipodes Islands in 2016 (Horn *et al.* 2022), the island is free of introduced mammals so the current major conservation threats to Antipodean wandering albatrosses are in the marine environment. The species forages mainly in the Pacific Ocean to the east of New Zealand, and to a lesser extent in the Tasman Sea (Walker & Elliott 2006; Bose & Debski 2020; Walker & Elliott 2022). Antipodean wandering albatrosses are caught in New Zealand domestic surface long-line fisheries in small numbers every year (MPI 2023). Forty-seven Antipodean wandering albatross captures were recorded by observers on domestic fishing vessels 2002–2020, with another 26 identified only as wandering albatross, at least some of which will be Antipodean wandering albatrosses (MPI 2023). It is very likely that more Antipodean wandering albatrosses are caught in New Zealand waters than are recorded due to (1) the majority of fishing effort not being independently observed, (2) fisher-reported seabird captures being reported at lower rates than captures with government observers onboard, and (3) a watchkeeping issue identified recently by Maritime New Zealand which means there is little to no observer coverage in some significant fisheries where Antipodean wandering albatrosses forage. Further, potential species misidentification or lack of identification (generic codes like 'Albatrosses; unidentified' frequently used, whereby the seabird species caught remains undetermined) mean more Antipodean wandering albatross captures probably occur but remain unquantified (Edwards *et al.* 2017).

In international waters, Antipodean wandering albatrosses forage in the southern Pacific Ocean (Walker & Elliott 2006; Bose & Debski 2020) in areas where there is a large amount of surface or pelagic long-line fishing effort with no or very little observer coverage (Peatman *et al.* 2019). Antipodean wandering albatrosses are caught in those fisheries, but the lack of observer coverage and fisher-reported captures makes the overall number of annual captures of Antipodean wandering albatrosses impossible to quantify accurately.

The Antipodean wandering albatross population at Antipodes Island has been declining since a population crash 2006–07, and is expected to continue doing so unless vital rates recover (Edwards *et al.* 2017; Richard 2021; Walker & Elliott 2022).

The primary objective of this study was to update the key demographic parameters of the Antipodean wandering albatross, and to estimate their island-wide population size. A secondary objective was to collect samples towards describing the diet of Antipodean wandering albatross and assessing signatures of nutritional stress. Additional work included collecting blood and feathers for a Pacific-wide mercury pollution study.

This report summarises the most recent findings on the survival, productivity and population trends for Antipodean wandering albatrosses, collected during a ten-week trip to the island over December 2022–February 2023. We also summarise movements to date of juveniles carrying trackers since January 2022.

Methods

Mark-recapture study

In summer 1994 and every year thereafter except 2006, a 29 ha study area on Antipodes Island (Fig. 1) has been visited to count nests, check nest contents, record the band numbers of previously banded birds, band nesting albatrosses, and band chicks just before fledging.

All nests found within the study area are marked and monitored, so that a year later the nesting outcome (failed or fledged) can be determined for a productivity estimate. All Antipodean wandering albatrosses found nesting within the study area are double-banded with individually numbered metal and large coloured plastic (darvic) bands, one on each leg. Since 1995, most chicks in 60% of cohorts have also been banded. Ideally, all chicks in the study area are banded, but the proportion of chicks that are banded each year depends on the timing of the field trips, which in turn is dependent on the availability of transport. In 19 of the years since 1994 researchers arrived just before, at, or soon after the date at which the first chicks fledge (26 December) when more than 90% of the chicks are still present and can be banded. In nine of the years since 1994 late trips meant up to 45% of the chicks had already fledged without being banded, and no chicks were banded in 2006 (no trip) or 2020 (very late trip). Arrival on Antipodes for the 2023 season was 17 December 2022 so 100% of the chicks produced in 2022 could be banded.

Survival of birds in the study area is estimated using R 4.2.3 (R Core Team 2023) and the package *RMark* v3.0.0 (Laake 2013). For modelling, adult birds are categorised by sex and by breeding status: non-breeders, successful breeders, failed breeders and sabbatical birds taking a year off after a successful breeding attempt. Birds in each of these classes have different probabilities of being seen on the island, and different survival rates, so the models estimate re-sighting probabilities and survival rates separately for each class. The number of birds in the study area in each class is estimated by multiplying the actual counts of birds in each class by their respective estimated resighting probabilities from the best-supported model in mark-recapture analysis. Sabbatical birds are the only class where this calculation cannot using actual in-colony counts, the birds not being present on the island. Instead, the number of sabbatical birds is taken as the number of successful birds in the previous year multiplied by the survivorship of successful birds. The estimated total population of birds that have bred in the study area is the sum of the estimates of all classes.

The survival and re-sighting probability estimates assume no emigration, and even though wandering albatrosses have strong nest site fidelity, Richard (2021) showed there was detectable emigration. In our models birds that emigrate then subsequently return will contribute to low detectability, and birds that permanently emigrate will contribute to low survival and these models will underestimate survival.

Trends in the mark-recapture-based estimates of population size are calculated as annual rates of population growth or decline (λ or lambda), using $\lambda = (\frac{N_{t+y}}{N_t})^{\frac{1}{y}} - 1$ where *N* represents the number of albatrosses, t the first year in the time series, and *y* the number of years in the time series.

Counting nests in two representative blocks

Since 1994, all the nests in two areas (Fig. 1) additional to the study area have been counted most years. The two areas support about 14.9% of all the nests on Antipodes Island (Clark *et al.* 1995; Walker & Elliott 2002; Walker & Elliott 2022).

Counts are carried out between 6 and 12 February, just after the completion of laying, and as close as possible to the same time at each place in each year. A strip search method is used where two observers walk back and forth across the area to be counted, each within a strip about 25 m wide marked in a map on a handheld GPS, and count all the nests with eggs in their strip. Every bird on a nest is checked for the presence of an egg, and each nest found with an egg is marked by GPS. All non- breeding birds on the ground are also counted, and they and most breeding birds on eggs are checked for bands, the number and location of which are recorded. Once the whole block has been counted, the accuracy of the census is checked by walking straight transects at right angles to the strips, checking all nests within 10–15 m of the transect have a GPS point thus have already been counted.

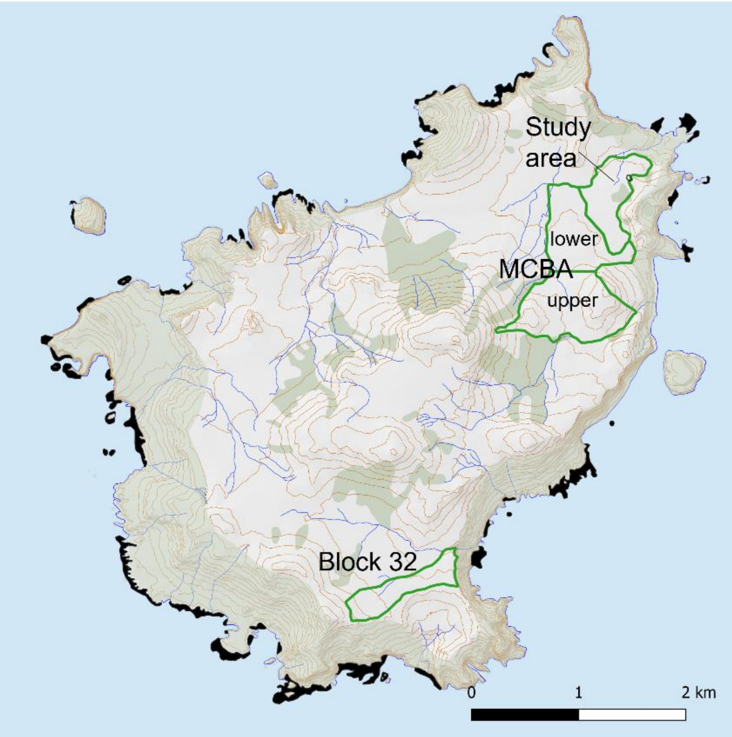

Figure 1. Study area for Antipodean wandering albatross on Antipodes Island, the two census blocks and the area (shaded) in which albatrosses do not nest.

Number of nests on the island

The total number of pairs of wandering albatross nesting on Antipodes Island is estimated from whole island population counts of 1994, 1995 and 1996 (Clark *et al.* 1995; Walker & Elliott 2002) and subsequent annual counts of parts of Antipodes Island (the study area and all or some parts of the two representative blocks described above) (Table 2). The proportion of the total population in 1994–96 that was nesting in those parts of the island counted in subsequent years is used to estimate the total number of nests on the island each year using the following equation:

$$\widehat{total}_i = \frac{pairs_i}{proportion_i}$$

Where:

$\widehat{total}_i$ is the estimated total number of pairs nesting in year *i*.

$proportion_i$ is the proportion of pairs counted nesting in 1994–96 that were in those parts of the island that were counted in year *i* (see column "% of population counted" in Table 2).

$pairs_i$ is the number of pairs counted nesting in year *i*.

This estimate assumes that the relative abundance of nests in the counted blocks is constant from year to year, which is supported by the repeated counts of the study area and census blocks on Antipodes Island (Elliott & Walker 2018).

Developing drone count techniques

In anticipation of a whole-island nest count being undertaken in the next two years the use of a drone to undertake nest censuses on difficult to access parts of the island was explored. While it is cost-effective to count albatross nests on foot where nest densities are high and access is easy, research on Antipodes and Adams islands showed that where nests are sparse and walking difficult, nest counts might be more effectively undertaken using a drone (Rexer-Huber *et al.* 2020; Walker & Elliott 2022). Comprehensive trials to refine a drone-census methodology were conducted in January on Adams Island (Walker *et al.* 2023). Most aspects translate fully to Antipodes Island, so to avoid unnecessary duplication in the limited time available, we checked briefly that flight parameters did indeed work as well for Antipodean as Gibson's wandering albatrosses, then focussed on a major variable that cannot be tested elsewhere: ground-truthing for nest contents.

To confirm that the drone trial findings on Adams can indeed be reasonably applied to Antipodes, the flight parameters refined in January on Adams Island were tested in February on Antipodes Island on two occasions. A drone was set up for programmed grid flights at 60 m flight height, flying at 12 m/s and taking photos in swathes to get overlap of 65% front and 59% side (Pix4DCapture in a DJI Mavic 2 Pro drone). Careful disturbance monitoring was conducted throughout flights, to ensure the lack of disruption noted in earlier Antipodean albatross drone trials (Walker & Elliott 2022) was not a coincidence. Coverage, image quality and nest detection were assessed in images taken over the 29-ha study area, and the exercise repeated.

However, with limited time available we considered it more urgent to quantify the proportion of apparently nesting birds that are actually breeding, a variable that is necessarily site-specific. Even though trials confirmed that loafing birds not on nests could be distinguished from birds sitting on well-formed nests in aerial photos, it is clear that nest contents (whether or not there is an egg present) cannot be determined in aerial images. To quantify the proportion of "pretend" nesters out of all apparently nesting birds on Antipodes Island in early–mid February (around the time when whole-island counts would take place), counts of apparently nesting birds which did not, in fact, have an egg were made 1015–1900 hrs at four different sites on four occasions over a six-day period from 7 February.

Satellite tracking in 2022

In January and February 2022 satellite transmitters (TAV 2630 by Telonics, and GPS/Argos by Microwave Telemetry) were taped to the back feathers of 40 Antipodean wandering albatrosses (Walker & Elliott 2022). These comprised a mixture of male and female breeding birds, non-breeding birds, birds that had failed in their breeding attempt and young birds about to fledge (Table 1). A preliminary analysis of the flight paths of these birds and their possible interactions with fishing boats was undertaken. Possible interactions with fishing boats were examined using data from Global Fishing Watch. A thorough analysis of the tracks of these birds and birds previously satellite tagged on Antipodes Island has yet to be undertaken.

Table 1: Breeding status and age of 40 birds to which satellite transmitters were attached during January and February 2022.

	female	male	Total
non-breeder	5	0	5
breeder	9	9	18
failed breeder	3	4	7
fledgling	5	5	10
Total	22	18	40

Collecting Antipodean wandering albatross feces, feathers and blood

For a new approach to assessing changes in diet that is being planned, using corticosterone and stable isotope analysis (Brendon Dunphy, University of Auckland), feather samples were taken from 20 fledglings, 12 adult females and 14 adult males. Birds were mainly sampled in areas where they are not regularly visited to minimise research impacts on study-area birds.

For an ongoing effort to understand the diet of Antipodean wandering albatrosses using genetic identification of prey species detected in their faeces, fresh faecal material was collected opportunistically during albatross work. Diet is expected to vary with age and breeding status, so most samples were collected in the study area from banded birds.

To aid exploration of Pacific-wide mercury contamination in seabirds (PhD student Akiko Shoji, University of Tsukuba, Japan), we collected blood and feathers from 20 albatrosses (10 males and 10 female). Since known-identity is not needed for that study we only sampled birds in areas where they are not regularly visited.

All samples and data derived thereof will be managed and stored with the kaitiakitanga and rangatiratanga of Kāi Tahu in the forefront, as set out by a sample and data management agreement between the Department of Conservation and Te Rūnanga o Ngāi Tahu.

Results

Population size estimate from mark-recapture

The size of the breeding population in the study area estimated by mark-recapture (Fig. 2) was increasing up until 2005 at an average rate of about 5% per annum for both sexes (1996–2005). The increase was initially slow, then rapid in 2002–2005. After 2007 the population of breeding pairs declined, initially very rapidly with an average 2008–2012 of 5% per annum (males) and 14% per annum (females). In recent years the rate of decline has abated to an average of 1% per annum decline for both sexes (2013–2021), and the population of breeding females has been roughly stable for the last 4 years (Fig. 2). The sex ratio before 2005 was about 1:1 but for the following decade averaged 1.5 times as many males as females (average 2008–2018). The sex ratio appears to have improved a bit since 2019, sitting around 1.3 times as many males as females for three successive years.

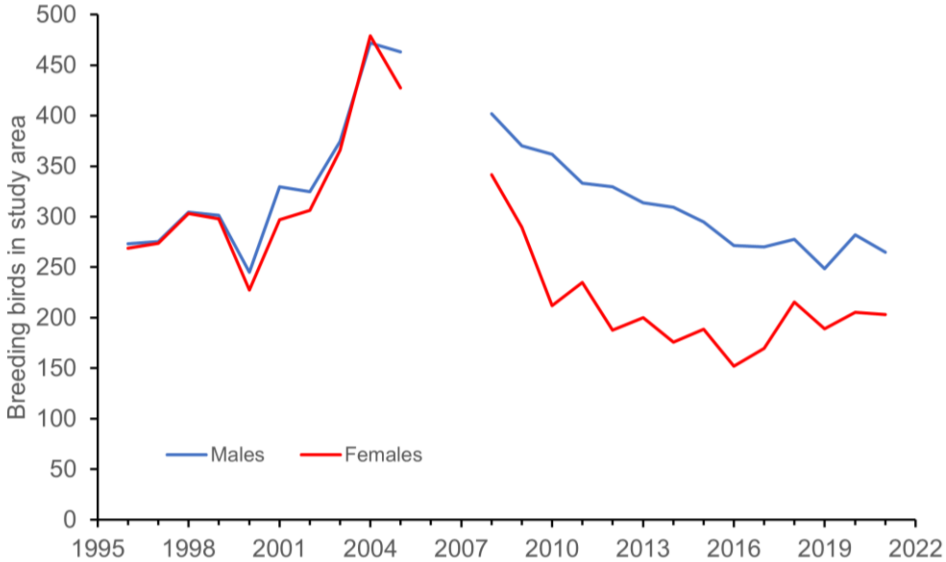

Figure 2. The number of breeding birds in the study area on Antipodes Island estimated by mark-recapture. Note: population estimates via by mark-recapture are not reliable for the last year's data, so results are only up to 2021

Survival

Adult survival varied around a mean value of about 0.96 up until 2004 and during this period male and female breeder and non-breeder survival was not significantly different. Since 2004 annual survival of both males and females has declined, with female survival significantly lower and more variable than that of males (Fig. 3). Since 2014 female annual survival has been particularly variable with both the lowest and second highest female survival occurring in that period. When that volatility is smoothed by calculation of 4 year rolling averages, average female survival appears to have increased since 2010 to approach male survival rates. However, although average female survival has reached 89% (average 2010-present), this remains lower than the pre-crash average of 95% (Fig. 3).

Not only have male and female survival rates differed substantially since 2005 (best-supported survival by sex model), but survival of breeding and non-breeding albatrosses has differed, along with confidence in those estimates (Fig. 4; survival by sex by status model). Male breeders have fared worse than non-breeding males since 2005, while breeding and non-breeding female survivorship has see-sawed since 2005 (Fig. 4).

Figure 3. Estimated annual survival of male (blue) and female (red) Antipodean wandering albatross on Antipodes Island since 1996. Dashed lines represent 4-year rolling means. Mark-recapture estimates of survival for 2023 are unreliable and are not presented.

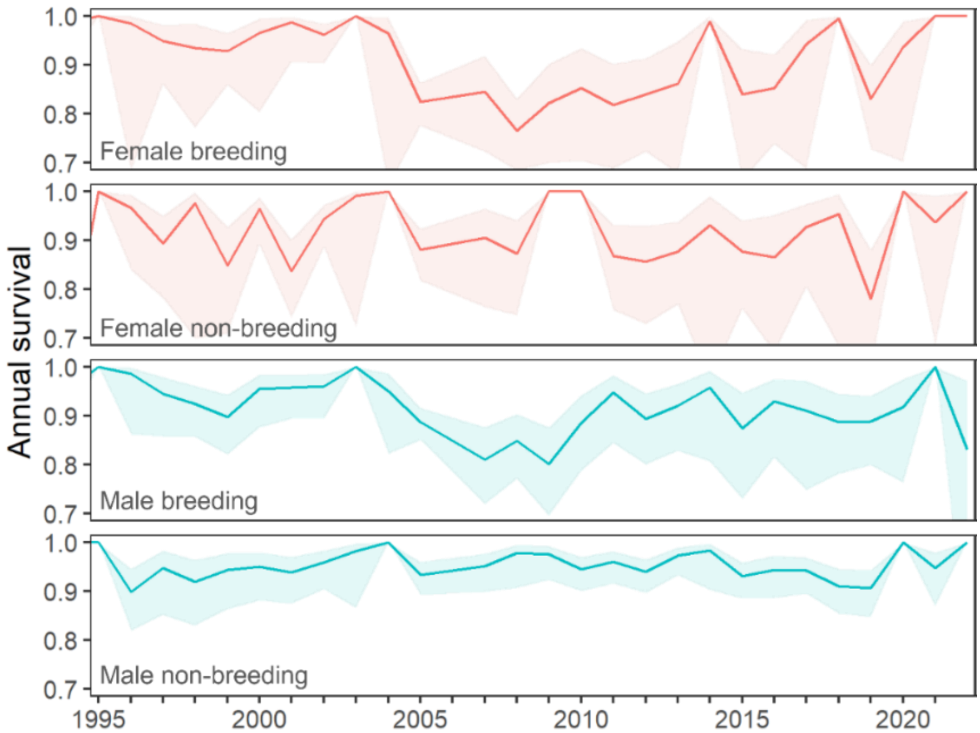

Figure 4. Estimated annual survival of breeding and non-breeding male and female Antipodean wandering albatross since 1996 with 95% confidence limits (shaded). Confidence intervals were not estimated when survival estimates were 1. Mark-recapture estimates of survival for 2023 are unreliable and are not presented.

Productivity

Nesting success in 2022 was 72%. Although nesting success was higher than it has been for several years, this spike has not improved the average nesting success since the 2006 crash; the current average remains 62%, notably lower than the average pre-crash nesting success (Fig. 5). The number of chicks produced in the study area continues to be much lower than that before the crash (Fig. 5) mostly because of the much smaller size of the breeding population.

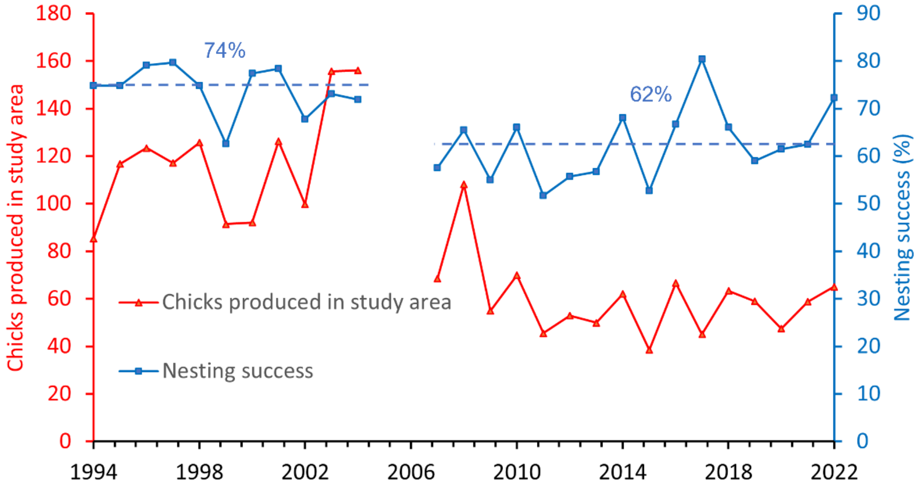

Figure 5. Nesting success and the number of chicks fledged from the study area on Antipodes Island since 1994. The dashed lines indicate average nesting success in two periods, 1994–2004 and 2007–22.

Recruitment

The number of birds breeding in the study area for the first time—that is, recruiting into the breeding population—has remained (on average) steady since 2007 (Fig. 6), despite the declining number of breeding pairs over that period. The average age of known-age recruits (breeding for the first time) in 2022 was 14.75 years (range 8–23), so many of the new recruits hatched before the population crash in 2006.

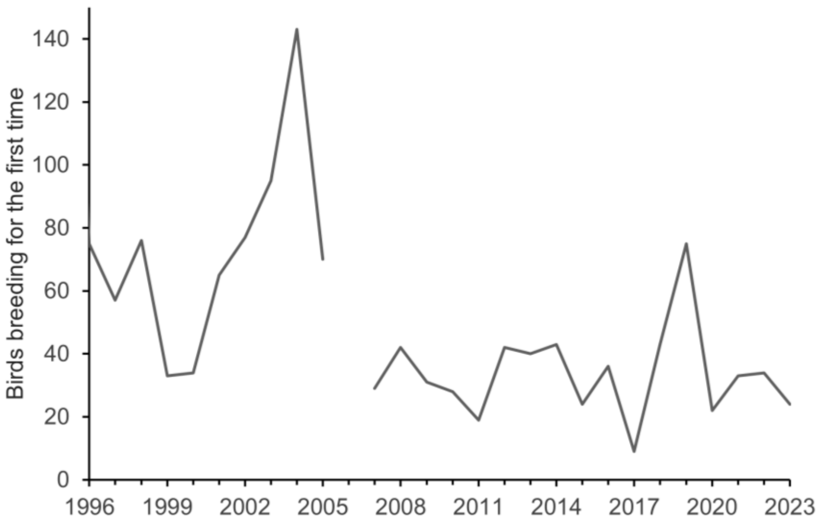

Figure 6. Recruitment of Antipodean wandering albatrosses. Numbers recruiting, or breeding for the first time, in the study area on Antipodes Island.

Nest counts

Nests were counted in the study area, Block 32 and MCBA (Fig. 1) in 2023. From these counts the total number of breeding pairs on the island were estimated (Table 2). After an increase between 2000 and 2005, the number of nests dropped sharply by about 38% between 2005 and 2007 (Fig. 7). In the following decade this reduction slowed, and since 2017 the numbers of pairs nesting have remained fairly similar from year to year (Fig. 7). There is no sign of recovery.

Table 2: Antipodean wandering albatross nests with eggs in February in three areas on Antipodes Island in 1994–2023, and the estimated number nesting on the island in 1998–2023, based on the proportion nesting in those areas relative to island-wide totals in 1994–97.

Year	Study area	Block 32	MCBA (total)	Lower MCBA†	% of population counted	Total counted	Estimated nests on island
1994	114	125	544*		15.0	783	5233
1995	156	185	482*		15.0	823	5500
1996	154	133	418*		15.0	705	4712
1997	150		464*		12.1	614	5073
1998	160		534		12.1	694	5733
1999	142		479		12.1	621	5130
2000	119	130	462		15.0	711	4752
2001	160	141	443		15.0	744	4972
2002	148	178	605		15.0	931	6222
2003	214	187	608		15.0	1009	6743
2004	216	249	755		15.0	1220	8153
2005	211	186	613		15.0	1010	6750
2006							
2007	119	127			5.6	246	4368
2008	165	135			5.6	300	5327
2009	98	120			5.6	218	3871
2010	106	101			5.6	207	3676
2011	88	108			5.6	196	3480
2012	95	104	345	145	15.0	544	3629
2013	88	93	297	127	15.0	478	3195
2014	91	103	341	130	15.0	535	3576
2015	73	86	291	124	15.0	450	3007
2016	100	92	291	97	15.0	483	3228
2017	57	82	230	85	15.0	369	2466
2018	97	97	315	136	15.0	509	3402
2019	99	96	276	107	15.0	471	3148
2020	75				2.8	75	2714
2021	94	89		124	9.6	307	3196
2022	90	74	274	113	15.0	438	2927
2023	90	87	310	112	15.0	487	3255

* estimated (see Walker & Elliott 2002)
† Lower MCBA is a subarea of the overall MCBA count block, shown to enable comparison when only a part-count of MCBA was possible

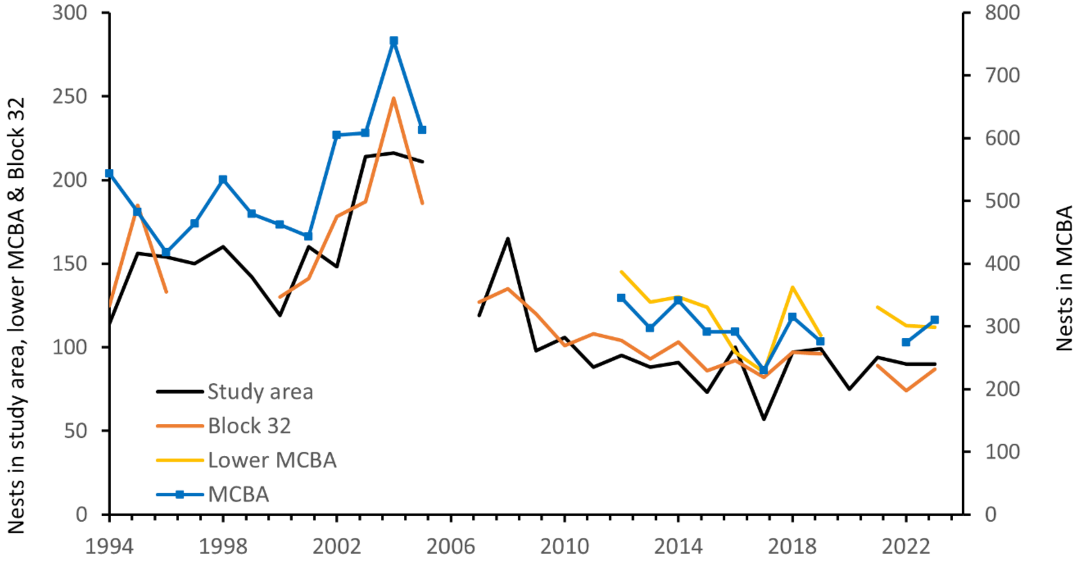

Figure 7. The number of Antipodean wandering albatross nests in three blocks on Antipodes Island since 1994. The MCBA subarea 'lower MCBA' is shown to enable comparison in years when only a part-count of MCBA was possible.

Developing drone techniques: ground-truthing

Checking that drone methodology for Gibson's can indeed be reasonably applied to Antipodean wandering albatrosses, we found that flight parameters used for Gibson's provided images with enough overlap for subsequent creation of orthomosaics of sufficient quality to clearly detect Antipodean wandering albatrosses and nests. Careful disturbance monitoring throughout flights detected no animal responses, as expected given similar lack of disruption in Antipodean wandering albatross drone trials in 2022 (Walker & Elliott 2022).

Since nest contents cannot be seen in images of nesting birds, and nest-contents correction could substantially influence estimates from drone images, we mostly focussed on assessing the potential influence of Antipodean wandering albatross nest contents on photo-counts of apparently nesting birds. An average of 25% of nests with apparently incubating birds did not contain eggs (135 pretending out of 531 apparently incubating) in the four distinct areas counted between 7 and 13 Feb, around the time when whole-island counts would take place. Pretend-nester rates were spatially variable, ranging from 16% (9 pretend-nesters out of 56 apparently incubating, Pipit Peak) to 29% (36 out of 123 in Block 32). More pretend-nesters were present on days when winds were blustery to strong (westerlies and nor-westerlies) than on the day with light winds.

Counts from aerial photographs will need to be corrected so the number of breeding birds is not overestimated. Such calibration is ideally based on nest-contents data from a sample of nests inspected concurrently with drone flight, but could also be derived from repeat flights over an area.

Satellite tracking in 2022

Forty satellite transmitters provided locations for an average of 209 days (32–425 days) before stopping. The batteries in the transmitters normally last about 12 months, so those stopping earlier were assumed to have fallen off when the feathers to which they were taped were moulted or broke off, or—less often—that the bird had died. The fate of birds wearing transmitters in 2022 was explored by checking whether returned to Antipodes Island in the summer of 2022-23 and whether their nesting attempts were successful.

Of the 30 adults, 25 were either detected on Antipodes Island during the summer of 2022–23 (n=11) or their nesting attempts were successful (n=14) which suggests they were still alive a year after satellite transmitter deployment. Of the five adults that might have died, two stopped transmitting within 250 km of fishing boats. One was 218 km from a Spanish longliner off the east coast of the North Island when it stopped transmitting and another was 163 km from a Japanese longliner west of North Cape.

The tagged fledglings will not visit the island again for at least three years, so it is unknown whether any of them are still alive. The transmitters of five of the fledglings stopped transmitting within 250 km of fishing boats. The 10 juvenile birds tracked in 2022 had a similar distribution to 30 juveniles tracked a year earlier (Fig. 8), with the apparently wider dispersal of birds in 2021 probably attributable to the larger sample size.

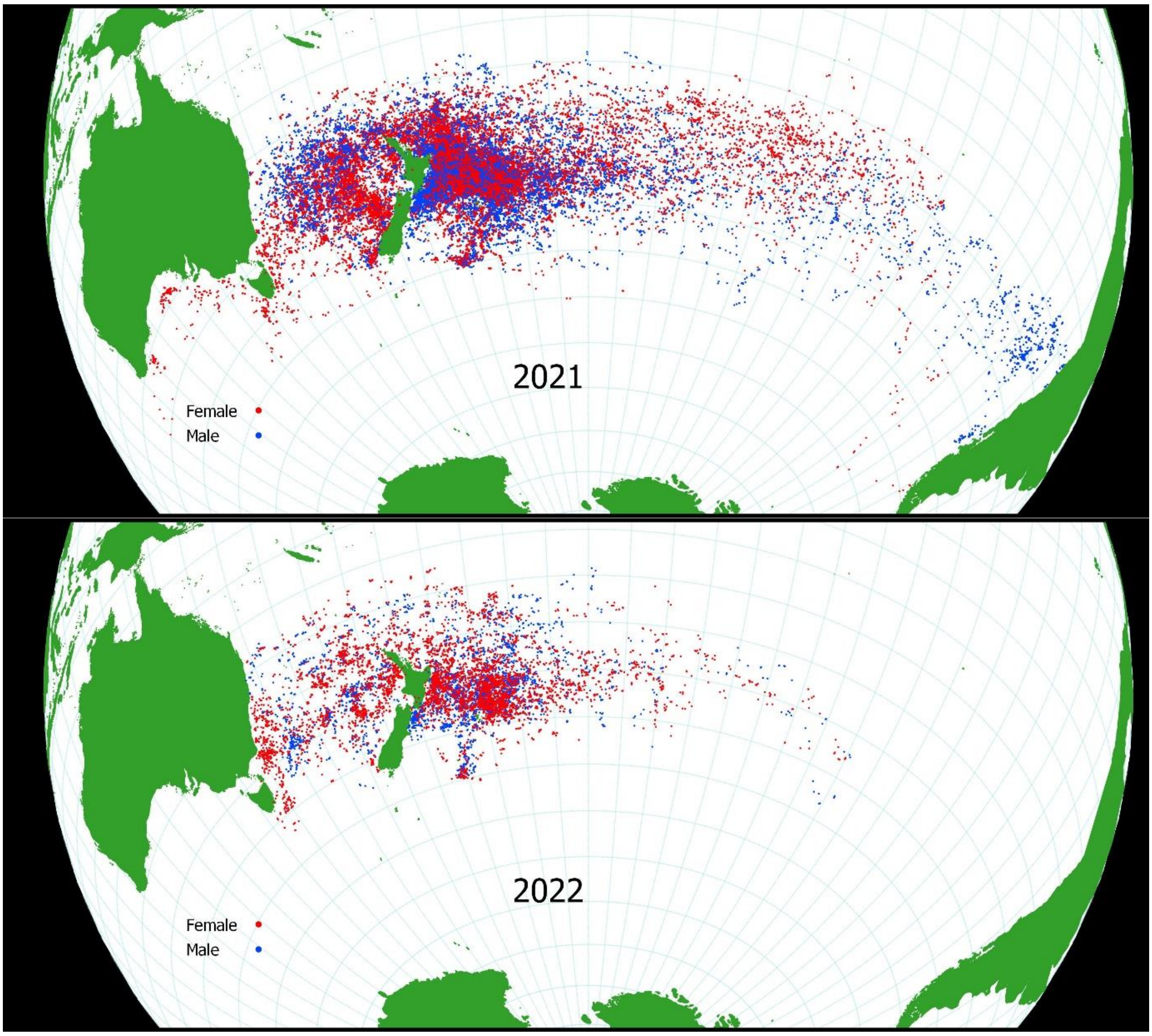

Figure 8. Satellite fixes from 30 fledgling Antipodean wandering albatross in 2021 and 10 fledglings in 2022.

In 2022 the ranges of breeding and non-breeding adult males and females all overlapped to some extent, but breeding birds of both sexes did not travel as far as the coast of Chile. Both breeding and non-breeding males foraged further south than did females, and breeding males foraged much further to the east than did breeding females. Some breeding and non-breeding females ventured into the Tasman Sea, but males never did (Fig. 9).

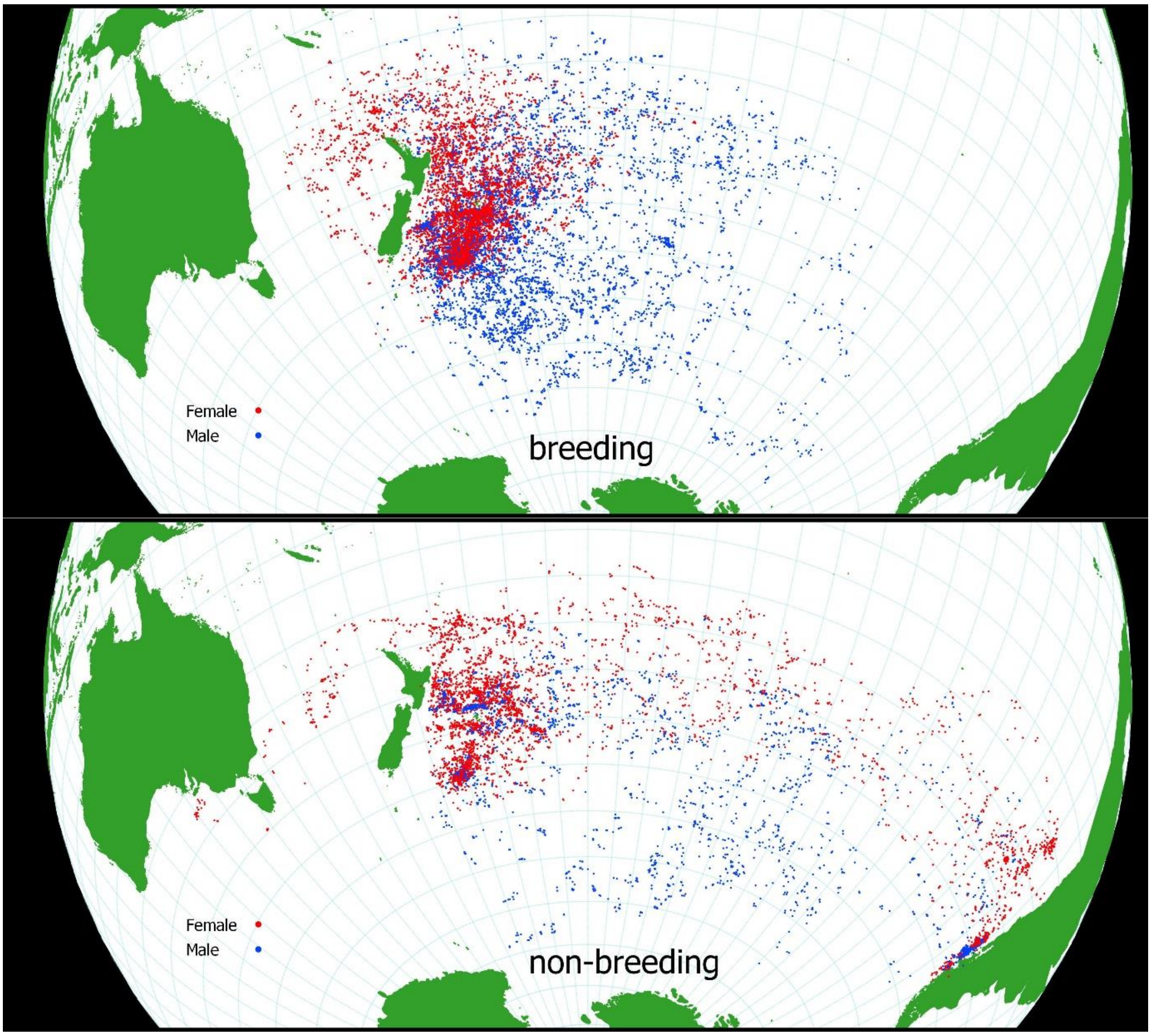

Figure 9. Satellite fixes from 9 male and 9 female breeding Antipodean wandering albatross and 8 female and 4 male non-breeding adult Antipodean wandering albatross tracked in 2022.

Discussion

Population size

After an extended period of decline starting in 2005, the number of male and female Antipodean wandering albatrosses breeding has been roughly stable for the past four seasons. This is seen in nest counts and confirmed in estimates from mark-recapture, a method that is more sensitive to changes in the population than are simple counts of nests.

Although a stable breeding population is preferable to one that is declining, stable is not enough for Antipodean wandering albatrosses. Simulations predict that without intervention to the current situation, the breeding population will decrease from the current ~3,300 pairs to 400 breeding pairs after 30 years (Richard 2021). Even incorporating recent improvements in female survival (most recent five-year average), the simulation models indicated that without other intervention, improvements are not great enough to cause population increase (Walker & Elliott 2022). Without recovery of key demographic vital rates to pre-crash levels, population projections show that numbers will continue to decline (Edwards *et al.*

2017; Richard 2021). This is seen in wandering albatrosses elsewhere: the population could only grow when survival, breeding or success probabilities were higher than the long-term means (Pardo *et al.* 2017). A scenario where numbers do not decline further but remain stable at the current low does not provide resilience against future rapid significant change of the type already seen in both Antipodean and Gibson's wandering albatrosses (Elliott & Walker 2014; Elliott & Walker 2020; Richard 2021). Without a subsequent increase in the size of the breeding population after a population decline, each sharp drop is a step to a smaller population. Small populations are vulnerable to stochastic events, for example landslips, (~12% of Antipodes Island slipped in 2014) or disease such as avian influenza.

Securing the population and halting the projected decline logically requires an increase in the size of the Antipodean wandering albatross breeding population, but there is no indication of such an increase in nest counts. Even taking into account birds absent because on breeding sabbatical, and different detection rates for breeding and non-breeding birds, and different survival rates (using data from the mark-recapture study), no growth in the breeding population is detectable. Indeed, it is now nearing 20 years since the breeding population was last increasing.

Contributing factors

Several factors together explain the state of the Antipodean wandering albatross population: low survival rates, differing between males and females; a skewed sex ratio with attendant behavioural change; recruitment, and productivity.

Of these, productivity and recruitment have improved or are stable. In 2022 productivity approached the average pre-crash nesting success of 74%. It is encouraging that the 2022 rate was the second-highest nesting success recorded for 17 years, although the average rate remains 62%. However, more-normal looking productivity rates cannot change that the actual number of chicks produced each year is still much lower than before the 2005 crash, because the breeding population is now the lowest that it has been since 1995 when this fine-scale population study began.

Recruitment—the number of birds breeding in the study area for the first time—has remained (on average) steady since 2007, despite the declining number of breeding pairs over that period. In other words, the rate of recruitment has been higher, which has been an important factor in slowing the population decline (Elliott & Walker 2020). The recruitment age is getting younger, with females recruiting at an average age of 18 years in 2019 and 2020 and 15 years in 2022 (Elliott & Walker 2020; Walker & Elliott 2022). Most of these birds hatched around or just before the 2005–07 population crash. This is worrying because after 2005 far fewer chicks were produced, so the supply of birds available to recruit into the breeding population—buttressing breeding numbers—is now expected to shrink.

Sex ratio

The Antipodean wandering albatross population now features an unusually skewed sex ratio. The sex ratio before 2005 was about 1:1, as typical for the great albatrosses, but now there are about 1.5 times as many males as females in the Antipodean wandering albatross population. It is important to consider some of the behavioural consequences of this imbalanced sex-ratio that are becoming apparent, as some could impact on population recovery.

The male excess in the breeding population has contributed to the well-documented male-male courtship and pairing behaviour on the island. Other behavioural changes are concerning as they at times disrupt male-female courtship, with unknown consequences. For example, there is more aggression between (the many) males competing for a female's attention than we have observed over decades of working on other albatross species, including the closely related Gibson's wandering albatrosses and other wanderers (Tristan and Snowy wandering albatrosses). During the early breeding season, particularly aggressive and persistent males appear to disrupt the normal progress of courtship between males and females, as well as aggressively pursuing females that have landed but are not yet courting (typically resulting in the female taking flight again). Forced copulation also appears notably more common than we have observed in other albatross species. If the courtship required to produce a stable pair bond is indeed disrupted or pre-empted by these interactions, we expect that pair formation—and therefore productivity—would be affected.

Survival

A skewed sex ratio is the logical result when survival rates for males and females become different. Before 2004 survival rates were similar for male and female Antipodean wandering albatrosses, varying around a mean of 96%, but since then female survival has been much lower and more variable than male survival. Survival rates for females varied before the 2005 crash, but since have roughly doubled in variability. This likely simply reflects the spatial and temporal variability of fishing effort, such that bycatch some years occurs at higher rates.

At 89% average female survival (since 2010) remains 6% lower than the average before the population crash, and further spikes in female mortality would drive further decline and prevent recovery. However, since 2014, the occasional year with relatively high female survival appears to be slowly pushing upward the average (4-year rolling averages, to smooth the spikes and detect change), closing the gap between male and female survival rates. However, as discussed above, the improved female survivorship seen to date is not great enough to cause population increase in the Antipodean wandering albatross without other intervention, when the most-recent five-year average of female mortality was used in the simulation model (Richard 2021; Walker & Elliott 2022). We suggest the sophisticated modelling approach developed by Richard (2021) should be applied annually—that is, re-rerun with the latest up-to-date data—to properly benefit from the power of those models, rather than merely plugging new values into the forecasting tool or sticking with the approach used to date (simpler models run annually with new up-to-date data).

Overall Antipodean wandering albatross survival rates are 92%, considering females and males together, which are low for such a K-selected species (Weimerskirch & Jouventin 1987; Véran *et al.* 2007). Wandering albatross populations from four island groups in the South Atlantic and Indian oceans had survival rates of 96% and 97% recorded when population numbers were stable, and survival rates between 84% and 92% when numbers were declining (Weimerskirch & Jouventin 1987; Cuthbert *et al.* 2004; Pardo *et al.* 2017).

Ground-truthing for drone counts

To contribute to the bigger picture for Antipodean wandering albatrosses, a whole-island census is planned for 2023/24 and 2024/25, and the use of a drone to supplement ground-counts of nests is being explored. Research on Antipodes and Adams islands showed that where nests are sparse and walking difficult, censuses might be more effectively undertaken using a drone (Rexer-Huber *et al.* 2020; Walker & Elliott 2022; Walker *et al.* 2023). Method testing and workflow development was thoroughly conducted on Adams Island in January 2023 (Walker *et al.* 2023), and tests on Antipodes confirmed that that the methods developed on Adams can indeed be reasonably applied to Antipodes.

We focused on the potential influence of nest contents on aerial photo-counts, since the proportion of apparently nesting birds that are in fact not breeding (pretend-nesters) is a substantial source of error in aerial counts of breeding albatrosses (Parker *et al.* 2017; Thompson *et al.* 2020). A quarter of apparently-nesting Antipodean wandering albatrosses were actually pretend-nesters with no egg, ranging by site from 16% to 29%. Antipodean pretend-nester rates were higher than for Gibson's wandering albatross at the same nesting stage (13–18% in annually-repeated surveys in Astrolabe, Amherst and Fly basins 2016–20;

authors' unpubl. data), and closer to rates during late incubation for white-capped and Salvin's albatrosses (19–29%) (Thompson *et al.* 2015; Parker *et al.* 2017; Thompson *et al.* 2020). A correction of aerial photo counts for the proportion of apparently nesting birds that do not have an egg is therefore vital to ensure numbers of breeding pairs are not overestimated. The variability in pretend-nester rates between sites (Antipodes) and among years at the same sites (Gibson's) shows that applying a single nest-contents correction factor would be inappropriate. Instead, to reduce the error introduced to aerial photo-counts as much as possible, ground-truthing for nest contents should be concurrent with drone flights, so that the correction factor is as accurate as possible.

Recommendations

Overall, some gradual improvements in Antipodean wandering albatross demography appear to have slowed the rate of decline over the past four years. However, this slowing is fragile, being underpinned by tentative improvements in female survival—which is vulnerable to large fluctuations year to year—and driven by high recruitment rates from before the crash that cannot be sustained since recruitment is starting to draw from the (much smaller) cohorts produced since the crash. While the improvements detected are welcome, on their own they are insufficient to halt the population decline and secure the species, merely slowing the continued decline of Antipodean wandering albatrosses.

With nest numbers in stasis, more than a decade of low chick production, annual mortality remaining high for such a K-selected species, and impending shortage of recruiting birds, the situation for Antipodean wandering albatross is concerning. Monitoring the population size and trend and research into causes of declines remain a high priority. To do so, we recommend:

- ongoing intensive effort to monitor the marked population to ensure consistency and continuity in the dataset with most power to detect trend;
- applying the analytical approach developed by Richard (2021) for annual analyses of the mark-recapture data, building on the simpler models used for annual analyses to date;
- island-wide census combining drone-photo counts with substantial concurrent ground counting. Ground counts allow the detectability of nests in aerial photographs to be quantified, and allows nest-contents correction of the apparent-nest estimate from photographs, so that the number of breeding pairs are not overestimated;
- comprehensive analysis of tracking data in (Walker & Elliott 2022) be updated with full dataset from juveniles to identify which fishing fleets, in which jurisdictions, have overlap with juvenile and adult Antipodean wandering albatross, enabling more-targeted engagement efforts around seabird mitigation; and
- other potential issues (pollution, diet changes) be explored further.

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