Albatross Research

Antipodean wandering albatross satellite tracking and population study on Antipodes Island in 2021 and 2022

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ABSTRACT

The Antipodean wandering albatross *Diomedea antipodensis antipodensis* has been in decline since 2005. The decline appears to be driven in large part by high female mortality, though reduced breeding success and increased recruitment age have exacerbated the problem. Research into the causes of and solutions to the falling numbers of Antipodean wandering albatrosses includes an annual visit to the breeding grounds on Antipodes Island, and this report describes the results of the field programme in the 2020/2021 and 2021/2022 breeding seasons.

In total 93 pairs nested in the study area in 2021 and 90 pairs in 2022. The number nesting in 2022 across the whole island was estimated to be 2,927 pairs, the second lowest ever recorded. Measurement of female survivorship in 2020–2022 was detrimentally affected by the very late timing of fieldwork in March 2020, artificially exacerbating existing high interannual variation in female survivorship. While the population has been approximately stable for the last three years, there is no sign of recovery.

Most of the 40 courting and breeding albatrosses to which satellite transmitters were attached in March 2020 (Elliott & Walker 2020) survived the year, but one male breeder W-659 appeared to be killed on a Chinese long-line. Breeding birds and birds which had expected to breed but didn't were found to retain their transmitters significantly longer in 2020 than non-breeders, presumably because feather moult is postponed whilst birds breed. While most of these transmitters were eventually lost at sea, one solar powered and two battery-powered transmitters were recovered from birds when they returned to Antipodes Island in January 2021.

In January 2021 a further 66 satellite transmitters were deployed, 36 on adults and 30 on chicks about to fledge. While most adults survived the year, the transmitters of three juveniles stopped close to pelagic long line vessels and may have been caught. In June 2021 another tagged juvenile, W-20k, was confirmed caught by a Taiwanese long-liner when its bands, along with the metal band of an adult female Antipodean wandering albatross O-805, not wearing a satellite tag, were recovered from the vessel. Given only a small proportion of the Antipodean wandering albatross population are banded (2.7%), to have caught two banded birds suggests many more birds without bands will also have been caught. Given the number of satellite transmitters deployed in 2019–2022 (220) and the number of days from which locations were received from the birds (38,812) the estimated reported fisheries related mortality of satellite-tagged birds is about 2% per annum. However, capture of satellite-tagged birds is likely considerably higher than 2% as the two captures that were documented came not from fishing operators voluntarily reporting bycatch, but from detection of an interaction from the combination of

tracking data and Global Fishing Watch. It is likely that additional tagged birds whose transmitters stopped close to fishing vessels were also caught but their capture was not reported.

In January 2022, 50 satellite transmitters of two types were deployed on adult Antipodean wandering albatrosses. Soon after deployment data stopped being received from the 10 “Icarus” transmitters because of a failed data-agreement with Russia. The remaining 40 (30 on adults, 10 on juveniles) were of the second type of which 26 were still transmitting at the end of July 2022.

INTRODUCTION

Antipodean wandering albatross (*Diomedea antipodensis antipodensis*) is one of two subspecies of *D. antipodensis* and is endemic to the Antipodes Islands, with approximately 99% of the population breeding there. A few pairs also nest on both Campbell Island and at the Chatham Islands. They forage mainly in the Pacific Ocean east of New Zealand, and to a lesser extent in the Tasman Sea (Walker & Elliott 2006).

They are a known bycatch in New Zealand long-line fisheries, with small numbers annually observed caught on domestic vessels (Abraham & Thompson 2015). Total potential fatalities within New Zealand’s EEZ were estimated in 2018 at a mean 63 birds per annum (MPI 2019). In addition, there are substantial long-line fleets with poor observer coverage in international waters in the southern Pacific Ocean (Peatman *et al.* 2019) where the birds mostly forage (Walker & Elliott 2006).

Due to the vulnerability of this long-lived and slow breeding species to any additional mortality, their survival, productivity, recruitment and population trends have been monitored during almost annual visits to Antipodes Island since 1994. In the 1990’s the population increased following a major, apparently fisheries-induced, decline during the 1980’s (Walker & Elliott 2005, Elliott & Walker 2005 and Walker & Elliott 2006). However, around 2006 there was a sudden drop in the size of the breeding population, and it has continued to decline since then.

This report summarises the most recent findings on the survival, productivity, population trends and at-sea distribution of Antipodean wandering albatrosses, collected during a nine-week trip to the island in December 2020–February 2021 and an eight-week trip in December 2021–February 2022.

METHODS

Mark-recapture study

In summer 1994 and every year thereafter except 2006, a 29 ha study area on Antipodes Island (Figure 1) has been visited to band nesting birds and record the band numbers of already banded birds. All birds found nesting within the study area are double banded with individually numbered metal and large coloured plastic bands, and since 1995, most chicks in 60% of cohorts have also been banded. 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 18 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 2021 season was on 18 December 2020 so 100% of the chicks produced in 2020 were able to be banded, but arrival for the 2022 season was later (31 December 2021) by which time six (10%) of the 60 chicks produced in 2021 had already fledged.

Survival of birds in the study area is estimated using R 3.6.3 (R Core Team 2020) and the package RMark (v2.2.7, Laake 2013). For the models used in RMark, 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 potentially different survival rates, so the models estimate re-sighting probabilities and survivals separately for each class.

Population size is estimated by multiplying the actual counts of birds in each class by its estimated re-sighting probability. The survival estimates assume no emigration which is appropriate because wandering albatrosses have strong nest site fidelity, a pair's separate nesting attempts are rarely more than a few hundred metres apart, and birds nesting at new sites within a few hundred metres of the study area are detected during the census of surrounding country (Walker & Elliott 2005).

Counting nests in two representative blocks

Since 1994, all the nests in two areas (Figure 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 (Clarke *et al*. 1995, Walker

& Elliott 2002a). The "upper" portion of the largest block ("MCBA") was not counted in 2021 but both portions were in 2022 (Figure 1).

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

Counts are carried out between 5 and 10 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 and displayed on a GPS map, 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 with spray paint and counted. 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 for paint marks indicating the nest has been counted.

Total 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 done in 1994, 1995 and 1996 (Clarke et al. 1995, Walker & Elliott 2002a) and subsequent annual counts of parts of Antipodes Island. The proportion of the total population in 1994–1996 that was nesting in those parts of the island subsequently repeatedly counted is used to estimate the current total population using the following formula.

$$\hat{t}_i = \frac{t_{1994-1996}}{p_{1994-1996}} \times p_i$$

Where

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

$t_{1994-1996}$ is the mean total number of pairs counted nesting in 1994–96.

$p_{1994-1996}$ is the mean number of pairs counted nesting in 1994–96 in those parts of the island that were subsequently repeatedly counted.

p_i is the number of pairs counted nesting in year *i* in those parts of the island that are repeatedly counted.

This estimate assumes that the proportion $\frac{t_i}{p_i}$ is constant from year to year, which is true when the pattern of distribution of nests remains the same from year to year, as it has been found to do on Antipodes Island (Elliott & Walker 2018).

Total population size and trend

Measuring change over time in the total population of Antipodean wandering albatross is complicated by the difficulty of estimating the size of the pre-breeding population. After fledging, birds don't return to the breeding island for at least three years and often for much longer, making a reliable estimate of the size of that part of the population difficult.

However, change over time in the size of the adult breeding population can more easily be calculated. Mark-recapture estimates of the number of birds breeding in the study area are much less variable than counts of nests so were used here as the basis of some population change metrics. Each year's mark-recapture estimate of the number of breeding birds represents the number of birds recorded breeding that year, as well as the birds that have previously nested, and are still alive but are not nesting. During the 1994–1996 censuses 2.7332% of all the nests found during the censuses were in the study area, and this proportion was used here to estimate the total size of the breeding population in subsequent years. To determine whether this proportion varies over time, the number of nests in the study area was compared to the number of nests in the two other large and regularly counted blocks (MCBA and Block 32) using a generalised linear model with binomial errors.

Developing drone census techniques

In anticipation of a whole-island census of nesting albatrosses being undertaken in the next few years, the use of a drone to undertake nests censuses on difficult to access parts of the island was explored in February 2022. While it is cost-effective to census albatross nests on foot when nest densities are high and access is easy, where nests are sparse and walking difficult, censuses might be more effectively undertaken using a drone. For this a drone must not only be able to spot albatrosses on the ground from a distance, but also be able to fly within a few metres of these birds to determine whether they are nesting or just "loafing". The combinations of a Mavic II Pro drone, a digital tablet, DJI goggles and several flight-planning and automated drone flying programs were tested. For the trials the drone was flown over a difficult to walk in area with only a few nesting albatrosses, and over part of the study area where the number and location of nesting birds was known.

Collecting Antipodean wandering albatross blood

To aid exploration by PhD student Imogen Foote of the genetic differences between Antipodean and Gibson's wandering albatrosses and to improve their identification in fisheries bycatch, sampling blood from unrelated birds across Antipodes Island was undertaken. To try and avoid sampling related birds, a minimum distance of 300 m was walked between sampled males, and 100 m between females.

To help understand the diet of Antipodean wandering albatrosses through genetic identification of prey species detected within their faeces, fresh faecal material was collected opportunistically throughout the 2021 and 2022 Antipodes Island expeditions.

At-sea distribution

To better describe in real time the foraging range across life history stages and identify ocean areas where albatrosses might be interacting with fishing vessels, a large programme of satellite tracking begun in 2019 (described in Elliott & Walker 2019) was continued in 2020, 2021 and 2022.

Tracking in 2020

Forty birds to whom a small Migrate Technology geolocator datalogger (GLS) as well as a satellite transmitter had been attached in March 2020 (Elliott & Walker 2020) were searched for on Antipodes Island in summer 2021 and 2022. The GLS found on surviving birds was recovered, downloaded, and the locations used by the birds which had carried these loggers calculated from the logger's light data (see Elliott & Walker 2019 for details). Twenty-six (35%) of the 40 satellite transmitters deployed in March 2020 stopped transmitting "prematurely" (before 1 November 2020) so the endurance of the different satellite tags and the status of birds to which they were attached was examined for possible explanations for failure. Generalised linear models with normal errors and model selection (Burnham & Anderson 2002) were used to examine the data. Transmitters were classified by their manufacturer and were divided into two weight classes: light for the two types of solar powered tags (Microwave Telemetry and GeoTrak) which weighed 22 g and heavy for the battery powered tags (Telonics, TAV2630) which weighed 35 g. To explore differences in the endurance of transmitters attached to birds of different statuses, birds were classified in four ways:

1. Expecting breeders and non-breeders. "Expecting" breeders were birds that arrived on the island "expecting" to breed in 2020. Some expecting breeders did not breed because their partners failed to arrive. Non-breeders had no expectation of breeding that year as they were single at the end of the previous courting season.
2. Expecting breeders and old non-breeders and young non-breeders. Old non-breeders were birds that had previously been recorded on the island either as a breeder or non-breeder, whereas young non-breeders were young known-age birds that had never bred before.
3. Breeders (birds that nested in 2020) and non-breeders (including old and young non-breeders).
4. Breeders and old non-breeders and young non-breeders.

Tracking in 2021

Three types of tracking devices (Table 1) were attached to 66 albatrosses between 28 December 2020 and 12 February 2021. Breeding birds (19), non-breeding birds (17) which had arrived in the study area anticipating breeding in 2021 but did not, and chicks (30) about to fledge (Table 2) were selected preferentially for tracking, as birds in these life stages have undertaken a complete body moult the previous year so have strong new plumage in less danger of losing the transmitter through moult. A nearly even number of males : females (34 : 32) were selected, with the gender of chicks, which cannot be distinguished readily by plumage (unlike adult males and females) determined on bill-tip and bill-length measures and relative estimated weight of fully feathered birds on 1-2 January 2022.

One adult non-breeding male was tagged with a solar powered satellite transmitter while the other 65 birds had battery-powered satellite transmitters, and all transmitters were taped onto the bird's back feathers. Many of the chicks in the study area nearly ready to fledge were tagged with both a satellite transmitter and a geolocator datalogger (the latter cable-tied to its metal leg band). All the satellite transmitters were attached with 12.5 mm wide fabric Tesa® tape to the feathers above the spine of the bird in line with the front of the wings. For the 65 TAV transmitters strips of tape were used to fix three or four clusters of 4–10 feathers to the underside of the transmitter. On 11 fledglings an additional feather "outrigger" was attached about 25 cm directly above the transmitter. It comprised a "sandwich" of 4–8 feathers held between two strips of tape, tied with string to the top of the transmitter and aimed to increase the number of feathers which had to be moulted out before the transmitter fell off the bird. Two adult males were fitted with two feather outriggers, one on each side of their transmitter. One was fitted with the single solar transmitter successfully retrieved from a female who had worn it throughout 2020. To prevent tape covering the solar panel, this transmitter was mounted on a plastic base, as described elsewhere (Elliott & Walker 2020).

Table 1: Satellite transmitters and GLS dataloggers attached to Antipodean wandering albatross in December 2020—February 2021. Duty cycle refers to the potential number of locations obtained or estimated.

Model (No. of tags)	Location system	Power	Data retrieval	Duty cycle	Weight (g)
Telonics, TAV2630 (65)	Argos satellite	Battery	Satellite	3hrs/day	35.0
Microwave Telemetry (1)	GPS + Argos	Battery + solar	Satellite	5/day	22.0
Migrate Technology c330	GLS	Battery	At recapture	2/day	3.3

Table 2: The number, sex and status of Antipodean wandering albatross to which satellite transmitters were attached. Non-breeders were all expecting to breed but failed early or their mate didn't arrive. All chicks also had a Migrate Technology GLS attached and their gender (determined on size) assignment may not be correct

Albatross life stage	Female	Male	**Total**
Chick	16	14	**30**
Non-breeder	7	10	**17**
Breeder	9	10	**19**
Total	**32**	**34**	**66**

Tracking in 2022

Two types of satellite transmitter tracking devices (Table 3) were attached to 50 albatrosses between 4 January and 18 February 2022. Ten new prototype, solar-powered Icarus GPS transmitters and 10 battery powered Telonics TAV2630 Argos transmitters were attached to near-fledging chicks in the study area, while the remaining 30 TAV2630 transmitters were attached to adults (Table 4).

All the satellite transmitters were taped to the birds back, with the battery powered TAV2630 transmitters attached as described above. The solar powered Icarus transmitters were attached using spectra cord to plastic base plates which were taped to feathers in the same way as the TAV2630 transmitters. This prevented tape covering the solar panels.

Table 3: Satellite transmitters attached to Antipodean wandering albatross in January–February 2022. Duty cycle refers to the potential number of locations obtained or estimated.

Model (No. of tags)	Location system	Power	Data retrieval	Duty cycle	Weight (g)
Icarus (10)	GPS	Battery + solar	Satellite	1/day	5
Telonics TAV2630 (40)	Argos	Battery	Satellite	3hrs/day	35

Table 4: The number, sex and status of Antipodean wandering albatross to which satellite transmitters were attached in 2022. Non-breeders were all expecting to breed but failed early or their mate didn't arrive. The gender of chicks was estimated from their size and assignment may not be correct

Albatross life stage	Transmitter	Female	Male	**Total**
Chick	Icarus	5	5	**10**
	TAV2630	5	5	**10**
Non-breeder	TAV2630	5		**5**
Breeder	TAV2630	9	9	**18**
Failed breeder	TAV2630	3	4	**7**
Total		**27**	**23**	**50**

The TAV transmitters can run for up to a year, while the solar-powered transmitters can keep transmitting until the feathers they are attached to moult. The dataloggers deployed on chicks in 2020 and 2021 will continue to store location information for at least 5 years by which time the young birds they are attached to will have started returning to Antipodes Island, allowing the GLS to be retrieved and the data downloaded. Overlap of tracked birds and fishing fleets was analysed by comparing the birds' tracks with the locations of fishing boats available from the Global Fishing Watch website https://globalfishingwatch.org/map/.

RESULTS

Population size estimate from mark-recapture

The size of the breeding population in the study area estimated by mark-recapture was increasing up until 2005 at an average rate of about 8% per annum for both sexes— slowly initially, then rapidly in 2002–2005 (Figure 2). After 2007 the population of breeding pairs declined, initially at about 9% per annum but in recent years the rate has abated, and the population of breeding females has been roughly stable for the last 4 years (Figure 2). The sex ratio prior to 2005 was about 1:1 but now there are about 1.5 times as many males as females.

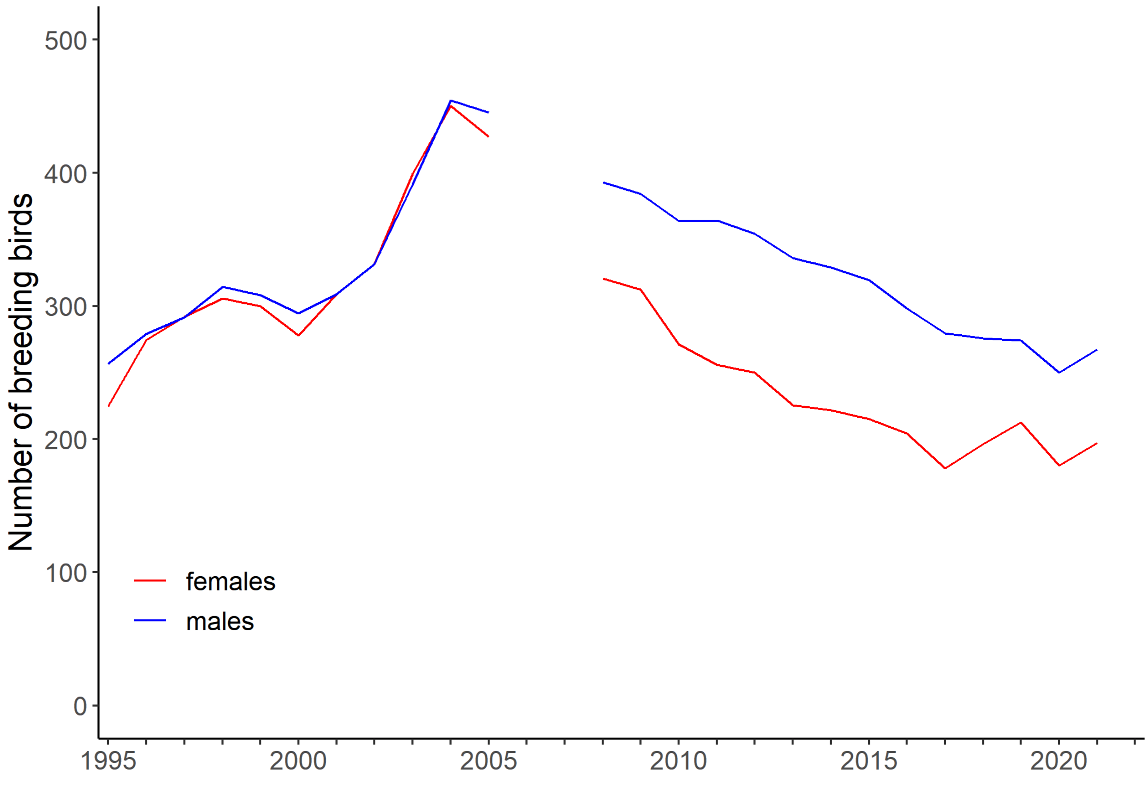

Figure 2. The number of breeding birds in the study area on Antipodes Island estimated by mark-recapture. Note: population estimates produced by mark-recapture are not reliable in the last year of data collection, so results are only up to 2020

Survivorship

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 both male and female survival has declined, with female survival significantly lower and more variable than that of males (Figure 3). Since 2014 female 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 5 year rolling averages, average female survival appears to have increased since 2010 (Figure 3). The breeder survival data has been particularly unreliable over the last 3 years as boat breakdown then Covid-19 lockdown led to a very short and late visit to Antipodes in mid-March 2020, when many breeding birds were no longer on the island.

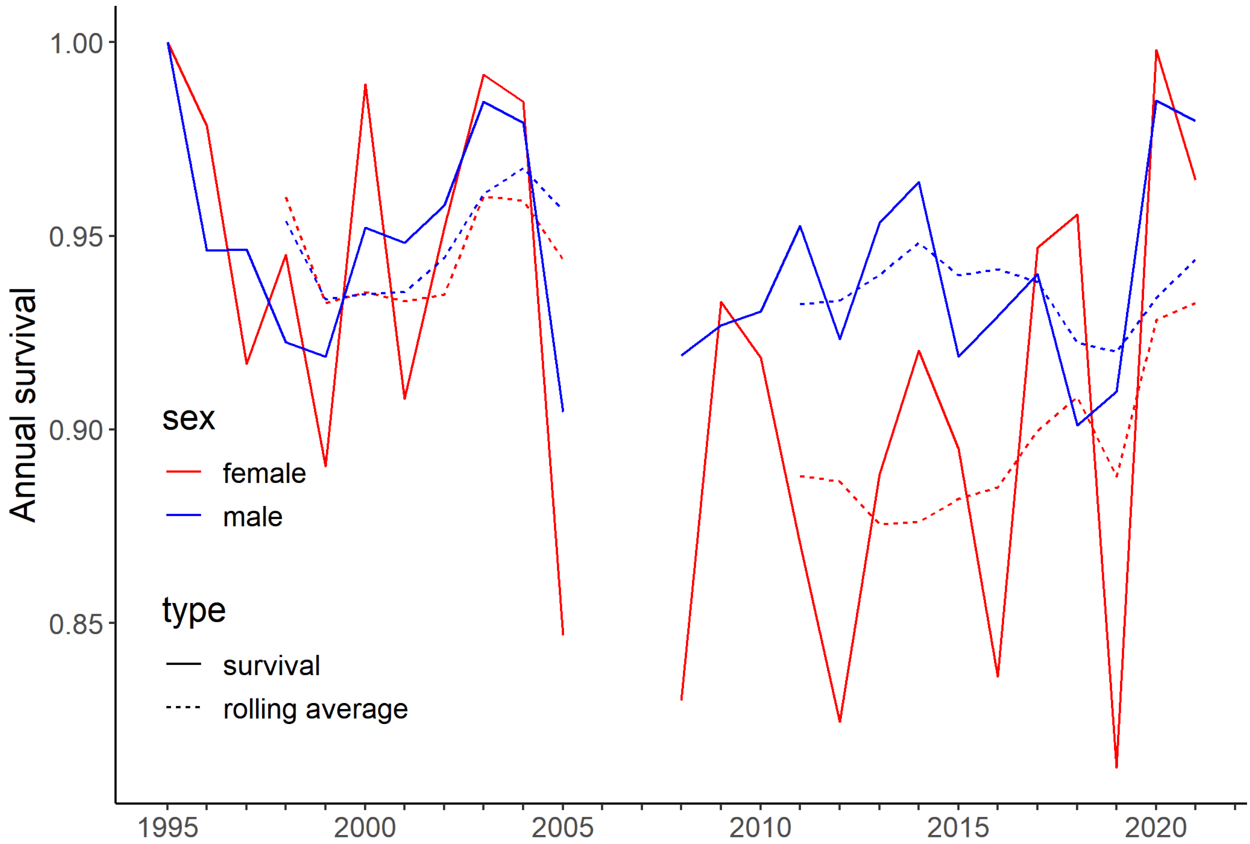

Figure 3. Estimated annual survival of male and female Antipodean wandering albatross on Antipodes Island since 1996. Dashed lines represent 4 year rolling means. Mark-recapture estimates of survival for 2022 are unreliable and are not presented

Not only has male and female survivorship differed substantially since 2005, but the survivorship of breeding and non-breeding birds (Figure 4), and the confidence in those estimates (Figure 4) has also differed. Male breeding birds have fared worse than non-breeding males since 2005, while breeding and non-breeding female survivorship has see-sawed since 2005 (Figure 4).

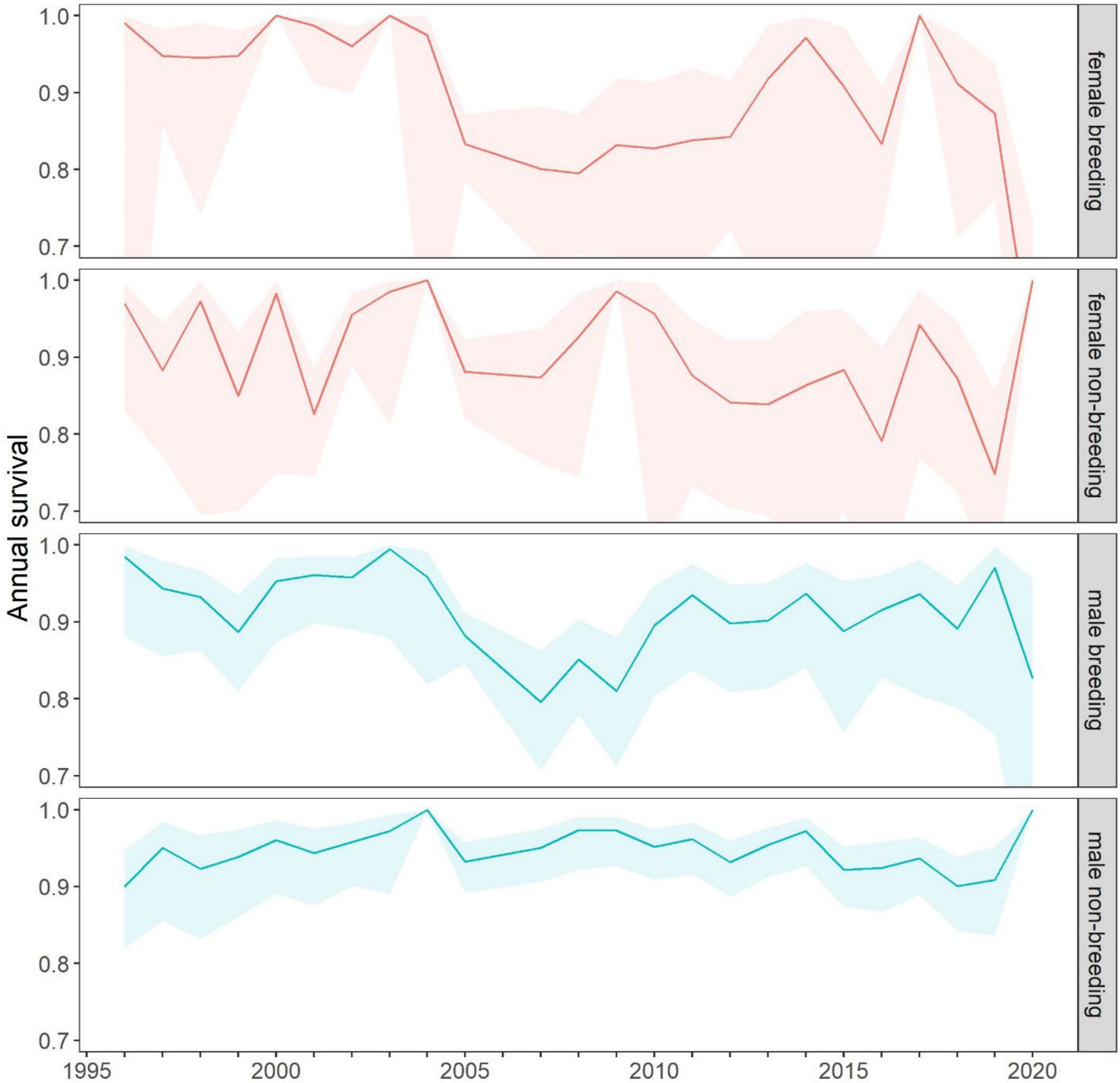

Figure 4. Estimated annual survival of male and female breeder and non-breeder Antipodean wandering albatross since 1996 with 95% confidence limits (shaded). Confidence intervals were not estimated when survival estimates were 1. Mark-recapture estimates of survival for 2022 are unreliable and are not presented

Productivity

Nesting success in 2020 was 61.5% and in 2021 62.5% roughly equal to the average since the 2006 crash, and lower than the 74% average pre-crash (Figure 5). The number of chicks produced in the study area continues to be much lower than that before the crash (Figure 5) mostly because of the much smaller size of the breeding population.

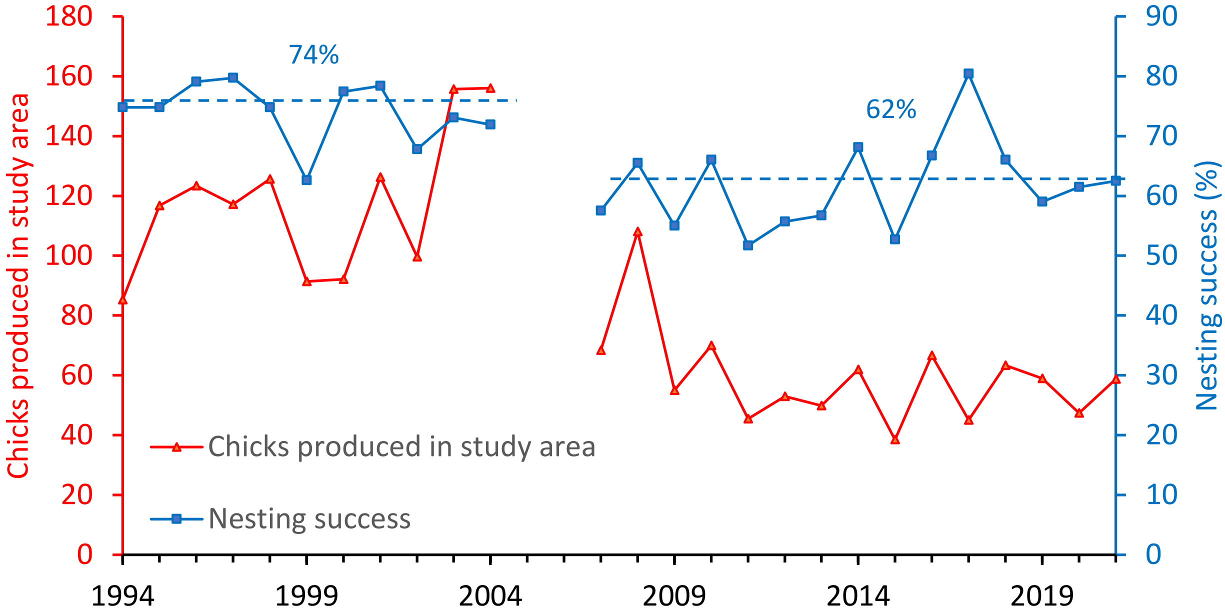

Figure 5. Nesting success and the number of chicks fledged from the study area on Antipodes Island since 1994. The dashed lines indicate average nesting success in two periods, 1994-2004 and 2007-2020.

Recruitment

The number of birds breeding in the study area for the first time has remained (on average) steady despite the declining number of breeding pairs (Figure 6). The average age of known-age birds 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.

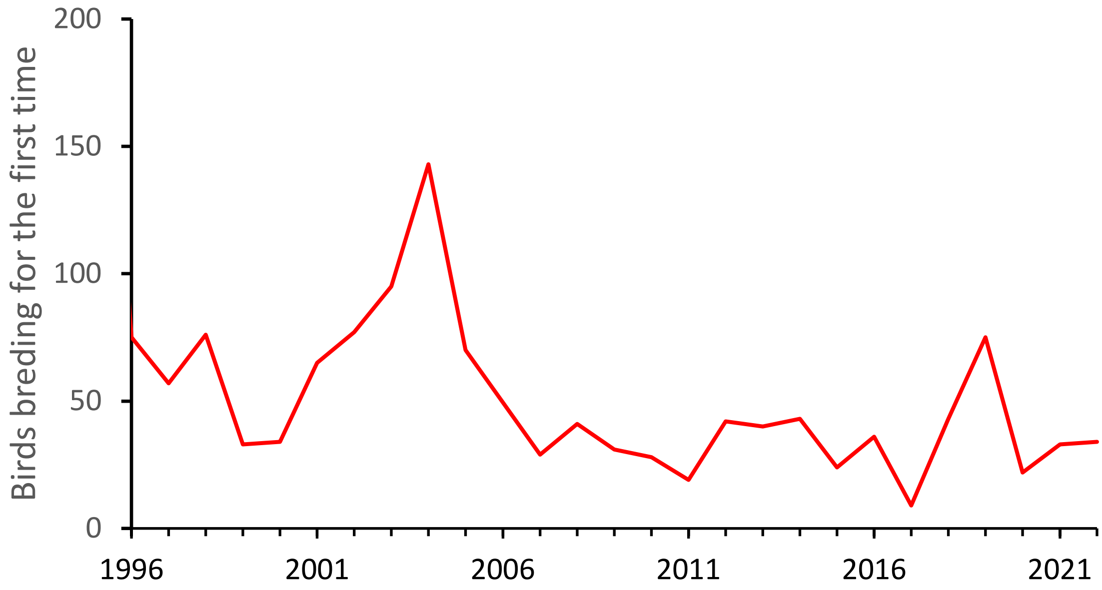

Figure 6. Recruits. The number of Antipodean wandering albatrosses breeding for the first time in the study area on Antipodes Island.

Nest counts

Nests were counted in the study area, Block 32 and lower MCBA in 2021. In 2022 nests were counted in the study area, Block 32, and both the lower and upper portions of the MCBA for the first time since 2019. From these counts the total number of breeding pairs on the island were estimated (Table 5). After an increase between 2000 and 2005, the number of nests dropped sharply between 2005 and 2007 by about 38% (Figure 7). In the following decade this reduction slowed, and since 2017 the numbers of pairs nesting has remained fairly similar from year to year (Figure 7).

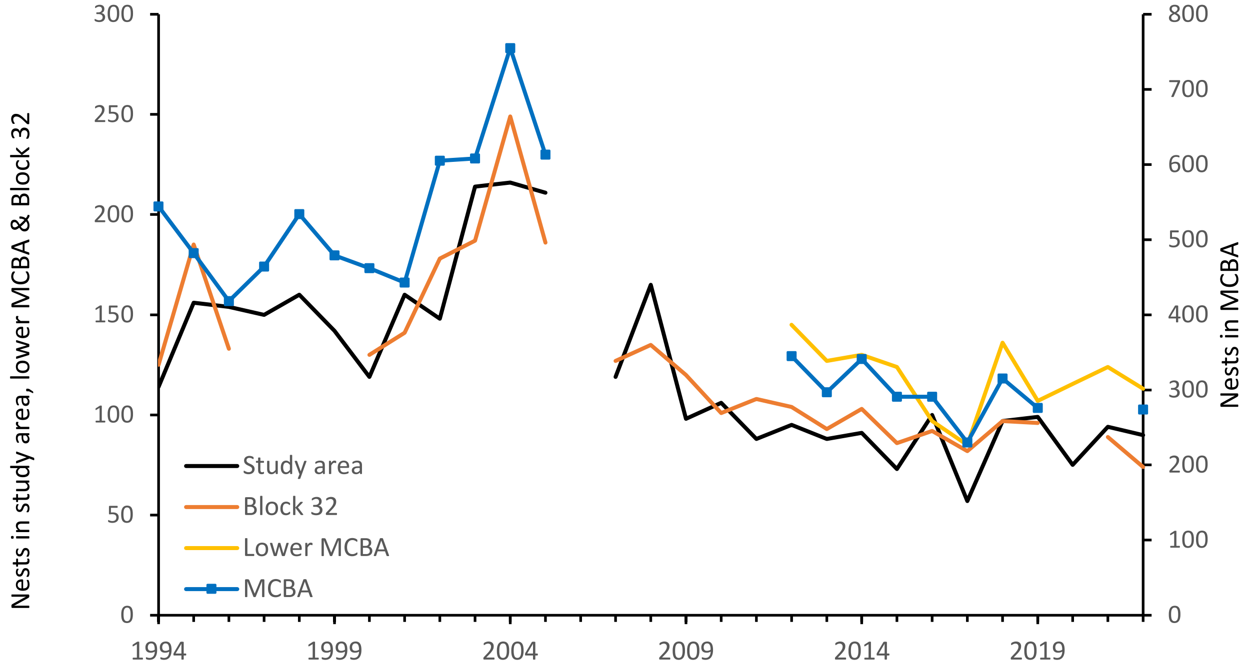

Figure 7. The number of Antipodean wandering albatross nests in three blocks on Antipodes Island since 1994

The proportion of nests in the study area relative to the larger regularly counted blocks has not changed in any systematic way since 1994–96 (Table 5), and it is therefore reasonable to assume that estimates from intensively studied parts of the island are representative of the whole population.

The population of breeding birds has been approximately stable for the last three years but is showing no sign of recovery.

Table 5: Antipodean wandering albatross nests with eggs in February in three areas on Antipodes Island in 1994–2022, and from the proportion nesting in those areas relative to island-wide totals in 1994–97, an estimate of the number nesting on the island in 1998–2022

Year	Study area	Block 32	Total MCBA	Lower MBCA	Study area as % of areas counted	Total counted	Estimated nests on island
1994	114	125	544*			783	5233
1995	156	185	482*			823	5500
1996	154	133	418*		28	705	4712
1997	150		464*				5463
1998	160		534				5827
1999	142		479				5172
2000	119	130	462		20	711	4752
2001	160	141	443		27	744	4972
2002	148	178	605		19	931	6222
2003	214	187	608		27	1009	6743
2004	216	249	755		22	1220	8153
2005	211	186	613		26	1010	6750
2006							
2007	119	127					4368
2008	165	135					5327
2009	98	120					3871
2010	106	101					3676
2011	88	108					3480
2012	95	104	345	145	21	543	3629
2013	88	93	297	127	23	478	3195
2014	91	103	341	130	20	535	3576
2015	73	86	291	124	19	450	3007
2016	100	92	291	97	26	483	3228
2017	57	82	230	85	18	369	2466
2018	97	97	315	136	24	509	3402
2019	99	96	276	107	27	471	3148
2020	75						2714
2021	93	89		124			3196
2022	90	74	274	113	26	438	2927

* estimated (see Walker and Elliott 2002b).

Developing drone census techniques

Initial attempts to count nesting albatrosses using the drone involved flying the drone at a height of about 30 m above ground level (AGL) and using goggles or a tablet, to search for birds while flying in roughly straight lines. The goggles proved superior to a tablet as ambient light made the tablet almost unusable. A brighter tablet might solve that problem.

Manual control of the drone meant that it was not possible to keep track of where the drone had flown in real time and there was a risk of counting birds more than once and of missing birds because the drone did not fly over them. Furthermore, when flying close to birds to determine whether they were nesting, the pilot became disorientated and thus could not systematically fly the target area.

This was overcome using flight planning and automatic drone flying software. A variety of applications for flight-planning and automatic drone flying were tested, but not all allowed automatic flights to be interrupted and resumed. It proved important to be able to interrupt planned and automated flights when birds were seen, fly the drone close to the birds to determine whether they were breeding, then resume the planned flight. A free program Litchi (https://flylitchi.com/) was found to provide this function, though other applications might be equally suitable.

To develop automatic flight plans a computer is required to which the drone operator has administrator privileges, and a tablet or cell phone. Both need to be connected to the internet to plan the flights, but the actual flying does not require an internet connection. The work-flow developed on Antipodes Island for flight planning and operation of the drone is as follows:

1. Using QGIS with Google Earth satellite imagery as a base map, draw a polygon around the area to be censused.
2. Create a 22.5 x 100 m grid over the area to be censused to guide the drawing of flight lines.
3. Rotate the grid lines to match the area to be censused.
4. Draw a flight path with flight lines 22.5 m apart and waypoints at 100 m intervals along the flight lines using the grid lines for guidance. A flight can have no more than 99 waypoints.
5. Save the waypoints as a kml file.
6. Import the kml file into Litchi's (https://flylitchi.com/) mission hub and save as a new mission with a suitable name.
7. Using the Litchi app on a tablet or cell phone connected to the internet, load the mission just created.
8. Select all the waypoints in the mission and adjust altitude to 20 m above ground, and flight speed to 20 km/hr. Save the mission.
9. Out in the field, launch the drone and automatically fly along the pre-determined flight path using the Litchi app. While the drone is flying automatically, use goggles to look for albatrosses on the ground. When an albatross is spotted take control of the drone, fly to within a few metres of the bird, and if it is nesting take a photo which automatically records the bird's latitude and longitude. Resume automatic flying from the last waypoint.

A preliminary trial using the drone to count nesting birds in the study area (where the number and location of all nests was known) identified only 20% of nests present (Figure 8). This seemed to be because the strips flown were too wide and the drone was too high.

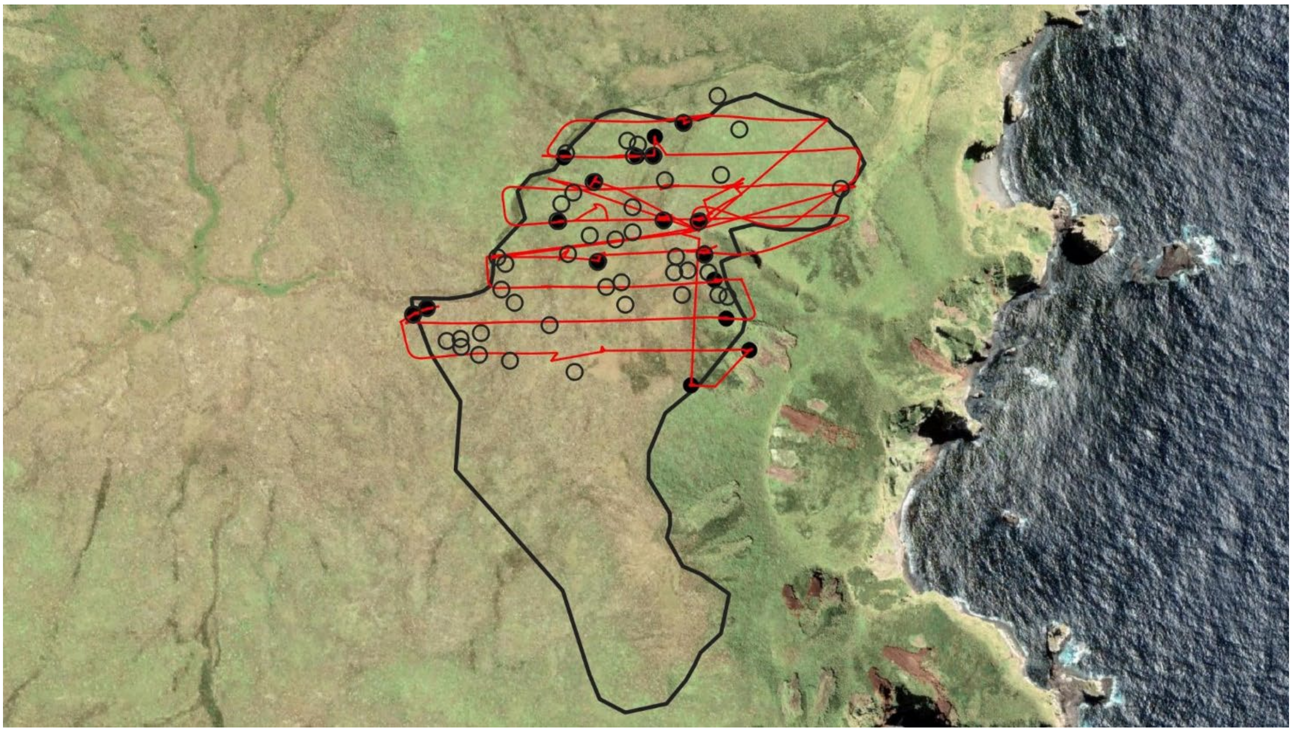

Figure 8. Drone path (red line) flown across the northern portion of the albatross study area on Antipodes Island in February 2022. Solid black dots show nests located by drone and empty black circles the location of additional nests present but undetected by drone.

At-sea distribution

Tracking in 2020

Three of the 40 birds who had tracking devices attached in January-February 2020, two adult breeding males and a young courting female, have not been seen since and are presumed to have died. White-659, an 18-year-old male, was likely caught in the mid-Pacific on 4 September 2020 as it was only 4 km from a Chinese flagged long-line vessel and within 15 km of seven other long-liners when its transmitter suddenly stopped.

The remaining 37 tagged birds survived and the dataloggers (which have various activity sensors) they were wearing were recovered and downloaded either in early 2021 or early 2022. The satellite transmitters on three of the 37 birds were still attached when the birds were re-sighted on Antipodes Island and were also recovered, allowing the condition of the attachments of the tags after a year of wear at sea to be examined. Two were Telonics TAV2630, retrieved on 18 and 25 December 2020 just before their batteries went flat. One was a Microwave Telemetry transmitter, retrieved on 20 January 2021 and because it was solar-powered, was able to be re-deployed in February 2021. Approximately ¾ of all the feathers used to attach these transmitters had been moulted such that those feathers were attached to the transmitters, but not to the birds: with only ¼ of the original feathers still holding the transmitters onto the bird's back, none looked like they would stay on the bird much longer.

There was no support for the type or weight of transmitter having any effect on transmitter endurance and the best model had only bird status as an explanatory covariate (Table 6). In the best model, status was classified as "expecting" breeder and old and young non-breeders, though the support for separating old and young non-breeders was not strong. It was concluded that transmitter model and weight had no effect on transmitter endurance, but transmitters on breeding birds or birds expecting to breed had a longer endurance (mean=209 days, se=14) than other birds, and transmitters on young non-breeders probably had a longer endurance (mean=166 days, se=22) than transmitters on non-breeding birds that had bred before (mean =108 days se=22).

Table 6. Model selection for the relationship between transmitter endurance, status of the bird and the make and weight of transmitter.

Model	df	AICc	ΔAICc
"Expecting" breeders, old and young non-breeders	4	454.9	0.00
"Expecting" breeders, non-breeders	3	456.0	1.04
"Expecting" breeders, old and young non-breeders + transmitter weight	5	458.3	2.62
"Expecting" breeders, old and young non-breeders + transmitter type	6	459.7	4.79
Breeders, non-breeders	3	461.8	6.90
Breeders, old and young non-breeders	4	464.0	9.06

Tracking in 2021

Given the finding in 2020 that satellite transmitters on average remained attached much longer on birds with freshly moulted plumage, such birds were preferentially targeted for carrying transmitters in 2021. In light of the wear pattern seen on the three transmitters retrieved in late 2020, one (or on two adult males, two) additional feather/tape "sandwiches" were made and tied to the front end of the transmitter package on 13 (11 chicks and two adult males) of the 67 birds tracked in 2021. The aim was to see if spreading the load onto more distant feathers increased the longevity of transmitter attachment. Of the 67 satellite tags deployed in the summer of 2020-21, seven stopped transmitting before June 2021, 36 stopped between June and October, and 24 (36%) lasted until at least November. One transmitted for the last time on 19 May 2022 after having transmitted (and remained attached) for a record 506 days (Figure 9).

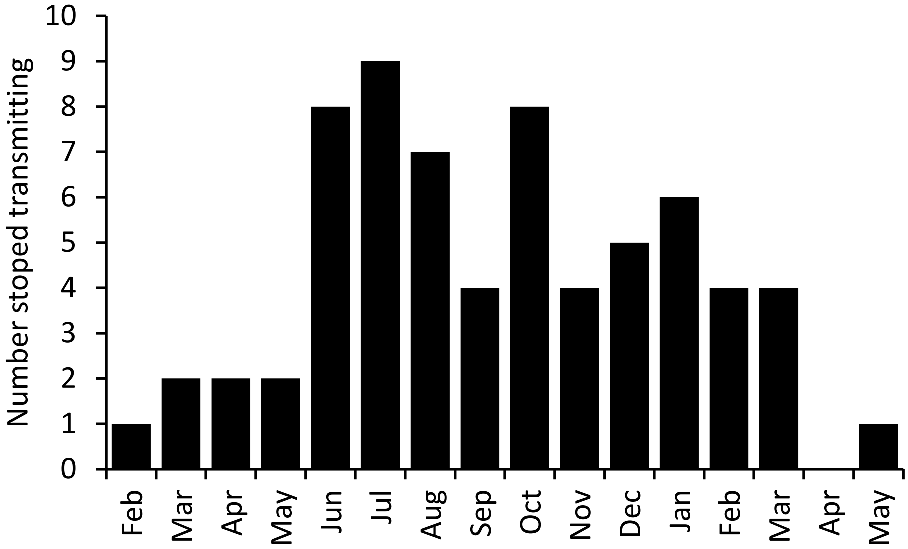

Figure 9. Histogram of the endurance of satellite transmitters attached to Antipodean wandering albatrosses between December 2020 and February 2021.

The addition of feather sandwich “outriggers” did not increase the duration of transmitter attachment. As the construction of such “outriggers” meant the bird had to be held longer, which was trying for both the researchers and the albatrosses, further use of it is not recommended. Despite a greater proportion of the birds chosen for tracking having new plumage in 2021 than in 2020, a similar proportion of transmitters had failed by 1 November in both years (64% and 65% respectively), presumably because moulting has a biologically fixed timetable. However, in 2020 the transmitters were attached to birds between 18–26 March, while in 2021 they were attached between 28 December 2020–13 February 2021, so were on for a longer period overall in 2021. The mean time satellite transmitters were attached in 2020 was 190 days, and in 2021 it was 249 days, and this difference was significant (p=0.043).

There were obvious differences in the foraging ranges of birds of different sex and age in 2021 (Figure 10). Adult females commonly foraged in the Tasman Sea, while adult males rarely did so. In contrast adult males often foraged in the Southern Ocean south of 45°S, while adult females rarely did. The distribution of juveniles was most similar to that of adult females with both male and female juveniles foraging in the Tasman Sea, and neither foraging in the Southern Ocean south of 45°S.

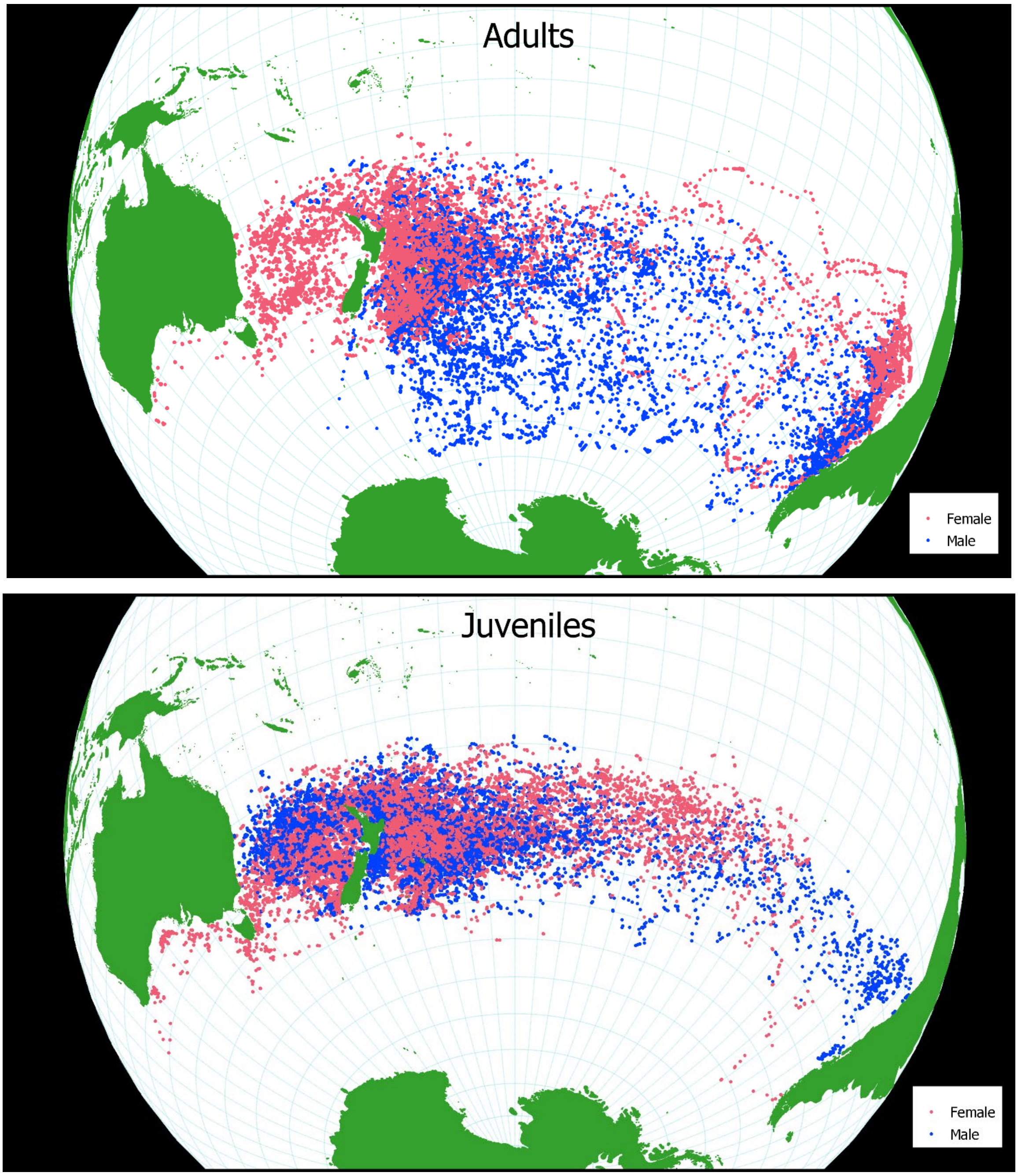

Figure 10. Satellite fixes from Antipodean wandering albatrosses wearing satellite transmitters throughout most of 2021

One adult female, Blue-05F, made two very long foraging trips in 2021 although she was trying to breed that year. She left for Chile on 5 February as soon as her partner relieved her at the nest after she'd laid an egg and headed directly to the coast off South America (Figure 11). Although she stayed there only briefly before making an equally direct flight back to Antipodes, she didn't get back until 23 March after 46 days away. Her mate was also wearing a satellite transmitter, so it was possible to see that he continued incubating their egg (and fasting) all that time, then made only the usual 10-15 day long trips himself to regain condition when she finally returned to take over incubation. Blue-05F spent the next few months undertaking normal length foraging trips to provision their growing chick, often circumnavigating New Zealand. Then she undertook a 65-day foraging trip, from 7 August until 11 October 2021, this time to the far south-west tip of Australia before returning to feed her chick. Somewhat surprisingly B-05F's chick successfully fledged, thanks to the strength of the male parent who managed to stay and protect the egg for so long, and to do a large proportion of the chick provisioning.

This is the first time a female has been recorded visiting the Chilean coast whilst undertaking an eventually successful breeding attempt. It is also the first year a male, B-90B, did the same although, unlike B-05F, his long trip was in mid-June once chicks can be left on their own. It's clearly a risky strategy to stay away so long during incubation, especially as it gives the partner no time to recover condition before the chick hatches & needs guarding, when many short 1-3 day trips into probably less productive waters close by are needed to feed the young chick. That B-05F did so indicates that she was struggling, and presumably her condition was marginal for breeding.

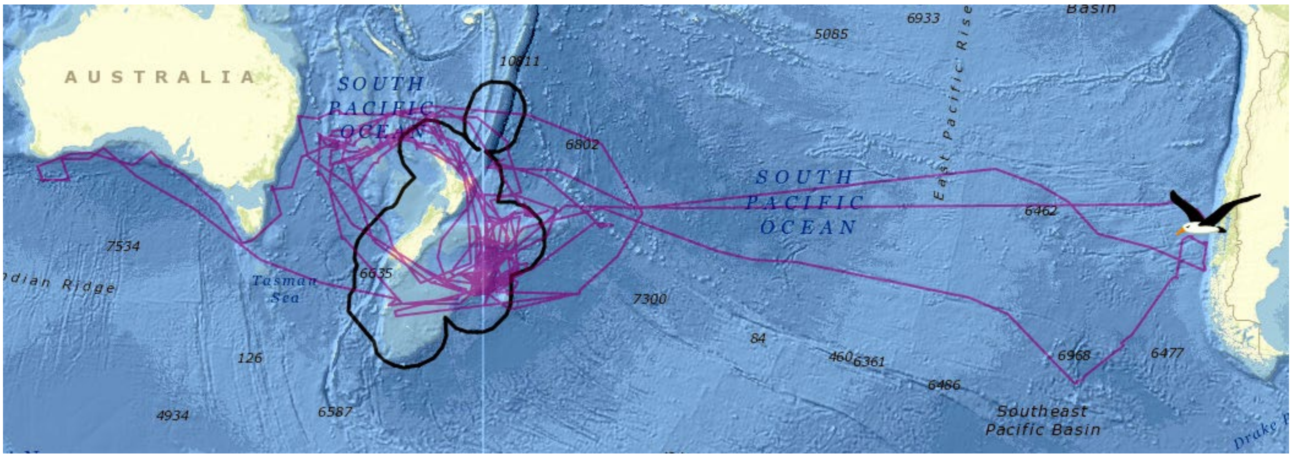

Figure 11. The 118,619 km flown by female Antipodean wandering albatross Blue-05F between 10 February and 31 December 2021 whilst successfully rearing a chick on Antipodes Island.

The transmitter attached on 28 December 2020 to a juvenile (White-20k) started transmitting intermittently on 22 June 2021 when it encountered a Taiwanese long-line fishing boat at 36.49°S, 143.39°W. The transmitter was subsequently recorded seven times at the same location as the boat. The fishing company was approached, and they returned the bands of White-20k along with the bands of another Antipodean wandering albatross 25-year old female R51296 which they had killed in the same fortnight (Figure 12).

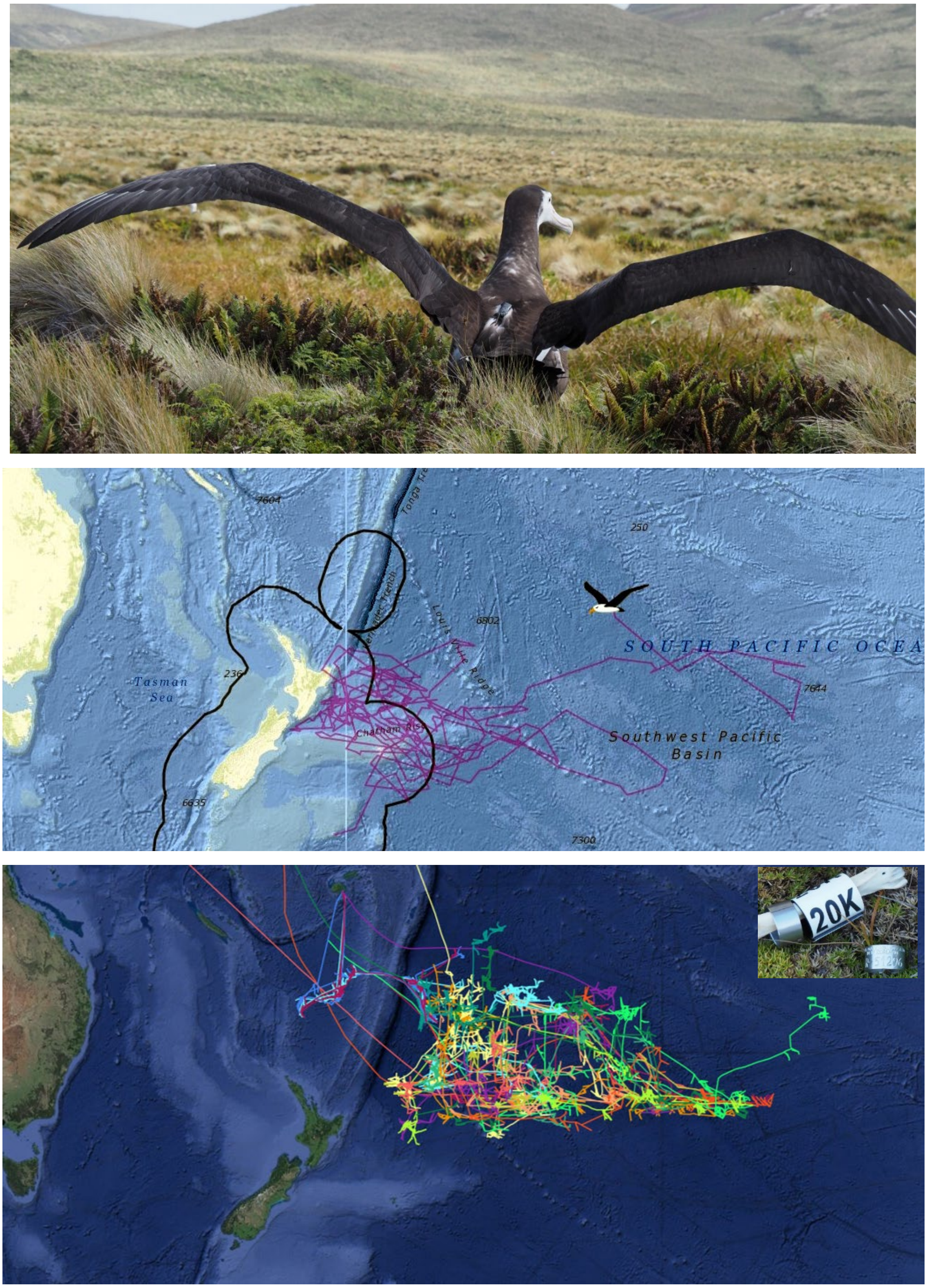

Figure 12. Top Juvenile Antipodean wandering albatross White-20k after a satellite transmitter was taped to its back **Middle** The flight of W-20K after it fledged from Antipodes I on 7 January 2021 until it was killed on 22 June 2021 **Bottom** The locations of 36 long-liners fishing NE of New Zealand in June & July 2021 (downloaded from Global Fishing Watch), including the Taiwanese long-liner which caught W-20K and female R51206 (inset: their bands, returned by the fishers)

The satellite transmitters on a further three of the 30 juveniles wearing satellite tags in 2021 suddenly stopped transmitting close to long-liners (W-19K, 12 km from boat in north Tasman Sea on 19 May 2021; W-22K 48 km from boat on 9 June 2021, and W-08K, 62 km from boat on 19 August 2021- both northeast of New Zealand) and may also have been caught. Most of the 37 adult Antipodean wandering albatrosses carrying transmitters in 2021 lost their transmitters further away from fishing vessels.

2022 satellite transmitter deployments

Of 20 Icarus satellite transmitters taken to Antipodes Island in January 2022, no data was received from 10 during pre-deployment testing so only 10 were deployed. Three of the 10 deployed failed to transmit any data after deployment. The remaining seven Icarus satellite transmitters gave useful information during February 2022 but no data was received after 4 March 2022 as the data from Icarus transmitters is sent via the international space station through a joint Russian-German programme which was cancelled due to sanctions imposed by Germany on Russia after its invasion of Ukraine.

Of the 40 TAV2630 satellite transmitters deployed in January and February 2022, 17 had stopped transmitting by the end of July 2022.

Collecting blood samples

Samples of blood (1-3 ml) were taken from 50 un-banded Antipodean wandering albatrosses (23 male and 27 female) who were each incubating an egg along transects across Antipodes Island. The legs of incubating birds were found to be cold with restricted blood flow and yielded only small blood samples, so a blood sample was also collected from four banded females in the albatross study area who were courtship dancing so able to provide much bigger samples which will be used for whole genome sequencing.

DISCUSSION

Biological value of satellite tracking programme

The four-year intensive programme of Antipodean wandering albatross satellite tracking 2019–2022 has not only provided up to date knowledge of their at-sea distribution but also provided information on Antipodean albatross biology. The satellite tracking showed that males tend to undertake a greater share of the chick provisioning in the last few months before chicks fledge, as wandering albatross elsewhere do (Weimerskirsch *et al*. 2000); that courting birds continue to attend the island for up to five months from January through to May, with foraging during this courting period mostly relatively close to Antipodes Island; and that some breeding females can make extraordinarily long foraging flights without their nest failing as long as their partner is in good enough condition.

Satellite tracking also showed that juveniles always migrate north-eastward when they fledge from Antipodes Island and stay relatively close to New Zealand for several months, with many foraging between the Chatham Rise and East Cape. Only one of the 70 chicks fitted with a satellite transmitter in January 2019 (20 chicks), 2021 (30 chicks) and 2022 (20 chicks) appeared to be unsuccessful in its fledging attempt, with its transmitter stopping only a few days after the bird left the island. This high initial survival is perhaps not surprising as only healthy well-developed chicks were selected to carry transmitters, but it was previously thought that fledging could be a particularly risky time for juveniles so that any satellite transmitter put on them had quite a high chance of almost immediately being lost, but this does not seem to be the case.

Population trends

The number of breeding Antipodean wandering albatrosses, estimated by both nest counts and mark-recapture, has been declining since 2005, though the rate of decline has slowed in recent years and the number of nests and the mark-recapture estimates of the number of breeding females has been approximately stable for the last four years.

High female mortality has driven the population decline, and although female survival has improved in the last two years, it was the lowest ever recorded in 2019. Female survival has on average improved since 2012, but it is highly variable, and further episodes of high female mortality would drive further decline and prevent recovery.

To assess the impact of the recently improved female survivorship on likely future population performance, the most recent five year average of female mortality (c93%) was used in the simulation model developed for just this purpose (https://dragonfly-science.shinyapps.io/antipodean-albatross-simulations/). This simulation model suggests that everything else being equal, the improved female survivorship is not great enough to cause population increase (Figure 13).

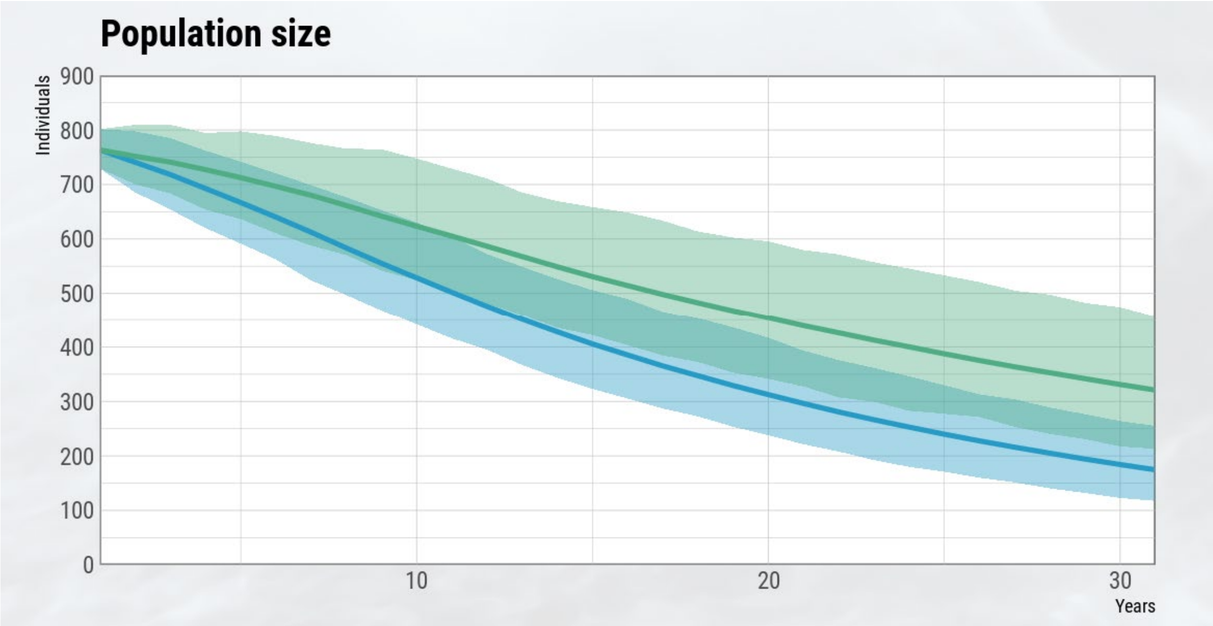

Figure 13. The likely impact of recently improved female survivorship on the population size of Antipodean wandering albatrosses – a screenshot from https://dragonfly-science.shinyapps.io/antipodean-albatross-simulations/. The blue line is the simulated population size based on data from the last x years, while the green line is the same data, but with annual female survival increased from 88 to 93%.

Estimation of bycatch rate

In the last three years two satellite-tagged birds have been killed by and recovered from longline fishing boats. Given the number of transmitters deployed (220) and the number of days from which locations were received from the birds (38,812) the estimated reported fisheries related mortality of satellite-tagged birds is about 2% per annum. However, capture of satellite-tagged birds is likely considerably higher than 2% as the two captures that were documented came not from fishing operators voluntarily reporting bycatch, but from the researchers approaching the fishing companies when albatross satellite tracking, in combination with Global Fishing Watch (GFW) (https://globalfishingwatch.org/map) data, detected an interaction.

Observer coverage is low (<5%) in boats fishing in the Western and Central Pacific Fisheries Commission region (Panizza *et al*. 2021) and fishers may be disinclined to report albatross kills. Substantial cryptic mortality also occurs, with up to half of bycaught birds lost from hooks before the line is hauled (Brothers 2010). There are clearly many fisheries-related mortalities from which the non-tracked birds, as well as the tracked birds, are neither recovered nor reported. The return of two bird's bands from a fishing vessel when it was contacted regarding the single satellite-tagged bird it appeared to have caught, is informative in other ways. Given the small proportion of the albatross population which is banded (2.7%), another 74 birds without bands could be expected to have also been caught (95% binomial confidence intervals 10–204 birds).

Long-lived unproductive species such as wandering albatrosses are sensitive to small changes in adult survivorship (Weimerskirch *et al*. 1997). A 2% reduction in survivorship caused by fisheries mortality is conceivably enough to cause a population to decline, and a fisheries related mortality much greater than 2% might account for much of the recent decline in Antipodean wandering albatrosses.

The most hazardous time for all tracked Antipodean wandering albatrosses, both juvenile and adult, has proved to be the winter months from late May till early September when birds were spending more time than usual in more northerly waters, particularly north-east of New Zealand near the Kermadec Trench, in the north Tasman Sea and the mid Pacific Ocean. Over the four years of intensive satellite tracking of Antipodean wandering albatrosses, all eight of the satellite tracked birds definitely or highly likely caught by pelagic long-line vessels fishing for tuna were caught during these winter months at between 36 and 27 degrees north, six were juveniles, and six of the eight were females.

While such an extensive programme of satellite tracking has been very costly, it has provided evidence that a significant number of Antipodean wandering albatrosses, particularly young females, are being killed in pelagic surface long-line fisheries, frequently in international waters. The magnitude of fisheries mortality is such that its elimination would result in a substantial improvement in the Antipodean albatross population trajectory. Other factors which may be contributing to reduced Antipodean wandering albatross survival, such as changing oceanic conditions, are difficult to mitigate, but the tools for albatross-safe fishing are available now.

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