Gibson's wandering albatross: population study and assessment of potential for drone-based whole-island census

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Final report to Department of Conservation, Conservation Services Programme

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SUMMARY

Gibson's wandering albatross (*Diomedea antipodensis gibsoni*) has been in decline since 2005. Research into the causes of and solutions to the falling numbers of Gibson's wandering albatross includes an annual visit to the main breeding grounds on Adams Island, and this report describes the results of the field programme in the 2022/2023 breeding season.

The survival and productivity of Gibson's wandering albatross has recovered from the dramatically low rates recorded during 2006–08, but the average survival rate for both sexes remain lower than before the population crash in 2005, and nest success has only just recovered to pre-crash levels. Recent increases in the number of nesting birds are almost certainly attributable to a higher proportion of the population choosing to breed and mark-recapture models estimates of population size still show a decline. The data missed because of the late cancellation of the 2021 season field trip precludes better estimates of population size until next year.

Twenty-two juvenile Gibson's wandering albatrosses were fitted with satellite transmitters and dataloggers before they fledged in late December 2022. In the subsequent seven months juveniles spent more time foraging north-east of New Zealand than previously tracked adult birds. No information has previously been collected on the at-sea distribution of juvenile Gibson's wandering albatross, so this data filled a major data gap.

For investigation into diet and mercury pollution in Gibson's wandering albatross, work additional to the CSP annual plan, feather and blood samples were collected from 20 juvenile and 58 adult birds outside the main albatross study area.

Drone census techniques were refined, allowing a more reliable estimate of the effort required for a whole-island drone-assisted count of the number of Gibson's wandering albatross nesting on Adams Island. High variability in the number of birds sitting on nests but not incubating eggs (loafing birds) is a large source of error when trying to count breeding birds from the air, which would require substantial concurrent ground-truthing to ameliorate. The costs and benefits of undertaking whole-island nest counts using a variety of methods including drones are explored. The island's large size, height and persistent bad weather mean a large amount of time and resources are required to obtain a reliable whole-island count using any method. It would be a major undertaking, requiring its own dedicated effort, best done after the regular field programme to ensure the vital mark-recapture trend monitoring dataset is not compromised.

INTRODUCTION

Gibson's wandering albatross *Diomedea antipodensis gibsoni* is a long-lived, slow-breeding seabird, vulnerable to incidental capture in commercial fisheries. As such, it is a species of high conservation concern (Birdlife International 2018; Robertson et al. 2021). Assessments of the risk of commercial fisheries to seabird populations (e.g. Richard et al. 2020) can be affected profoundly by uncertainty in population size and uncertainty in demographic rate estimates, particularly adult survival (Walker et al. 2015). To reduce uncertainty or bias in estimates of risk from fishing, robust information is needed on key aspects of biology (survival, productivity, recruitment, trends), and is the focus of this report.

Gibson's wandering albatross is endemic to the Auckland Island group. Most (94%) of the population breed on Adams Island, about 5% on Disappointment Island and a few scattered pairs on main Auckland Island make up the remaining 1% (Elliott et al. 2020). They forage largely in the Tasman Sea, but also along the continental shelf off southern and south eastern Australia and off eastern New Zealand (Walker & Elliott 2006).

Gibson's albatross survival, productivity, recruitment, and population trends have been monitored during annual visits to Adams Island since 1991. In the 1990s the population slowly increased following a major, presumably fisheries-induced, decline during the 1980s (Walker & Elliott 1999; Elliott et al. 2020). However, between 2004 and 2006 there was a sudden 68% drop in the size of the breeding population, from which recovery has been very slow (Elliott et al. 2020). The Gibson's wandering albatross population is still less than half of its estimated size in 2004, having lost the gains slowly made through the 1990s (Rexer-Huber et al. 2020).

This report summarises work undertaken as part of the Department of Conservation's (DOC) Conservation Services Annual Plan 2022-23 (DOC 2022) which has objectives:

1. To monitor the key demographic parameters of Gibson's albatross to reduce uncertainty or bias in estimates of risk from commercial fishing.
2. To estimate the population size of Gibson's albatross.
3. To describe at-sea distribution of Gibson's albatross

The most recent findings on the survival, productivity, population trends and at-sea distribution of Gibson's wandering albatross collected during a nine-week trip to the island from 9 December 2022—11 February 2023 are presented.

METHODS

Mark-recapture study

Since 1991, a 61ha study area on Adams Island (Fig. 1) is visited repeatedly each season to leg-band nesting birds and collect re-sightings of previously banded birds. The wider areas around the study area (within a kilometre) are visited less frequently and any banded birds are recorded. All birds found nesting within the study area have been double banded with individually numbered metal bands and large coloured plastic bands, and since 1995 most of each year's chicks have also been banded. The proportion of chicks that are banded each year depends on the timing of the research field trips which in turn is dependent on the availability of transport. In 24 of the last 32 years researchers have arrived at, or soon after, the time at which the first chicks fledge and more than 90% of the chicks were still present and were banded. In the other eight years researchers either did not arrive (2021; research cancelled too late to organize an independent trip) or arrived late when most chicks had already fledged and were therefore not banded.

Survival is estimated from the banded birds with maximum likelihood mark-recapture statistical methods using the software package MARK via the R package RMark (White & Burnham 1999; Laake 2013; R Core Team 2023). For the models, 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 quite different probabilities of being seen on the island but similar survival rates, so the models estimate resighting probabilities separately for each class, but survival is estimated separately only for males and females, and for breeding and non-breeding birds.

Population size is estimated by dividing the actual counts of birds in each class (except sabbatical birds) by the resighting probability produced when estimating survival. Counts of sabbatical birds are always very low, so the number of sabbatical birds are estimated by multiplying the number of successful breeders in the previous season by their estimated survival. The survival estimates assume no emigration and thus underestimate survival as birds that emigrate are treated as if they died. However, wandering albatrosses have strong nest site fidelity, and 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 usually detected during the census of surrounding country (Walker & Elliott 2005). The under-estimate is small, unquantified but consistent from year to year.

Nest counts in representative blocks

Since 1998, all the nests in three census areas (Fig. 1) have been counted each year, apart from 2021 when the island was not visited. Counts are carried out between 23–31 January just after the completion of laying, and as close as possible to the same date 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 25m wide programmed on a GPS, searching for 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 a dot of spray paint, recorded on the GPS, and counted. All non-breeding birds on the ground are also counted, and they and most breeding birds on eggs are checked for leg bands, the number and location of which are recorded.

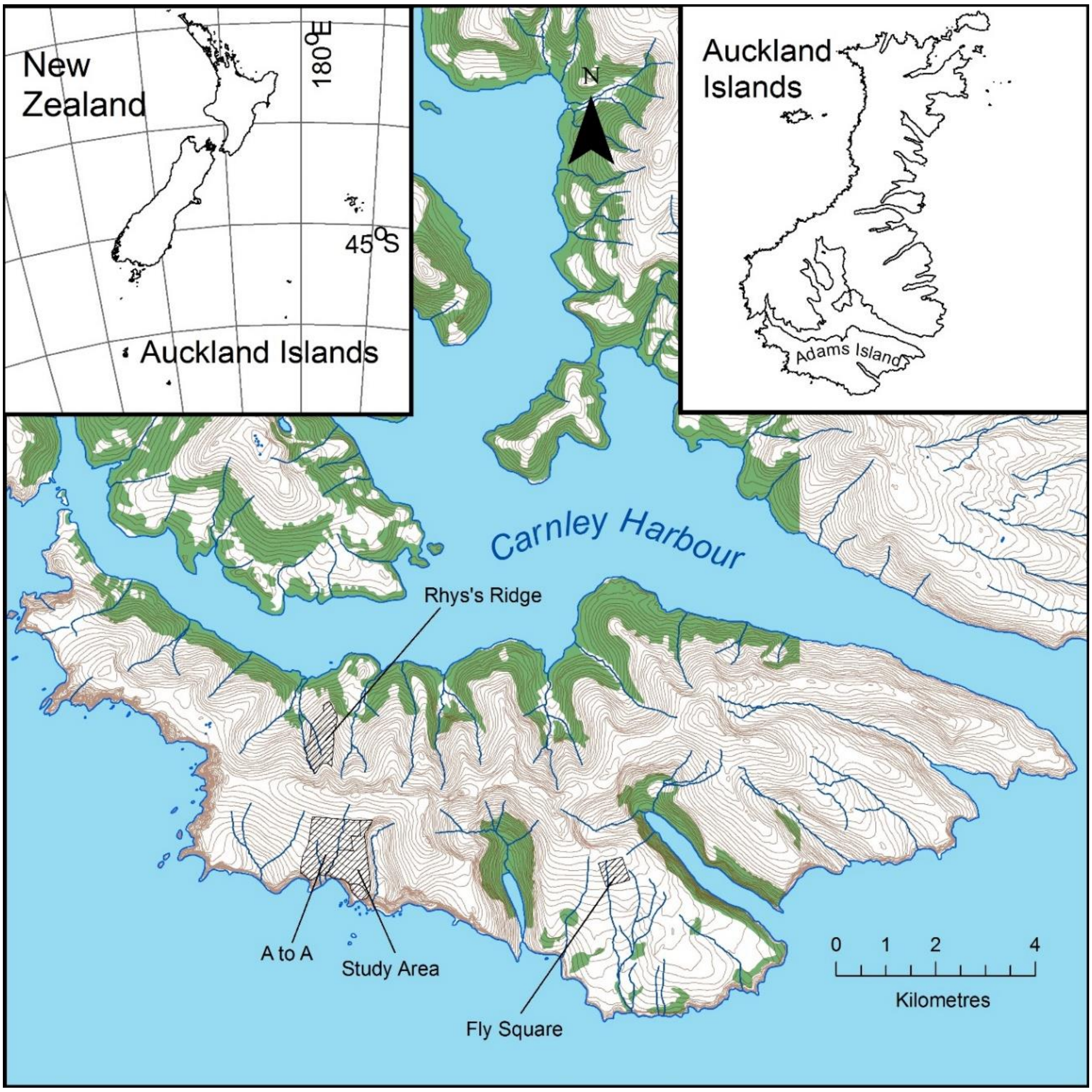


Figure 1: Adams Island, showing the Study Area (61ha) and three other areas in which counts of breeders are made (shaded): Amherst to Astrolabe (A to A; 101ha) Rhys's Ridge (67ha), and Fly Square (25ha).

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 10–15m of the transect for paint marks indicating the nest has been counted. Counts are corrected to take account of any eggs not laid or any failed nests at the time of counting. The corrections involve estimating the number of eggs yet to be laid and nests that are likely to have failed in each count block by interpolating the proportion eggs laid and nests failed in the repeatedly monitored study area on the day of the count.

Total number of nests on the island

The number of pairs of Gibson's wandering albatross nesting on the whole of the Auckland Islands each year is estimated from the corrected number of nests counted in the three blocks divided by 9.87%, the percentage of birds nesting in the 3 census blocks in 1997 when nests on the whole island were counted (Walker & Elliott 1999).

This estimate assumes that the proportion of the population in the three counted blocks is constant from year to year, which is supported by the fact that the relative abundance of nests in the three blocks is similar from year to year (Elliott et al. 2016).

Developing drone census techniques

Trials were undertaken with a DJI Mavic II pro drone to assess its usefulness for undertaking censuses of nesting albatrosses over all or part of Adams Island. Trials were undertaken to:

1. Determine the height above ground and flying speed that the drone could be flown that was the best compromise between high resolution for identify nesting birds (flying low and slow) and maximum area censused per drone battery (flying high and fast).
2. Develop flight planning, flying and counting workflow.
3. Estimate the ratio of breeding birds to the total number of birds on the ground by simultaneously counting birds on the ground and from the air and explore the variability in this ratio.
4. Estimate the time, person-power and resources required to census the whole island.

Collecting samples from Gibson's wandering albatross

Samples were collected to help understand the diet of Gibson's wandering albatross. Feather samples were taken from 20 fledglings, 20 adult females and 19 adult males for a corticosterone and stable isotope study (Brendon Dunphy, University of Auckland) of change over time in the diet of Gibson's wandering albatross. Adults were only sampled west of the A–A census block (Fig. 2). which is not regularly visited, to reduce impact on the albatross study population. For further insight into diet, fresh faecal material for genetic identification of prey species was collected opportunistically from 6 near-fledging chicks in the study area, just after they had been banded.

To aid exploration of Pacific-wide mercury contamination (Akiko Shoji, University of Tsukuba, Japan), blood and feather samples were collected from 19 adult Gibson's wandering albatrosses (9 males and 10 female). Mostly birds west of the A–A census block (Fig. 2) where birds are not regularly visited were sampled, to avoid as much as possible for a short-term study, intrusive disturbance to the valuable long-term albatross study population.

All samples and data derived from it will be stored and managed according to protocols agreed between the Department of Conservation and Te Rūnanga o Ngāi Tahu.

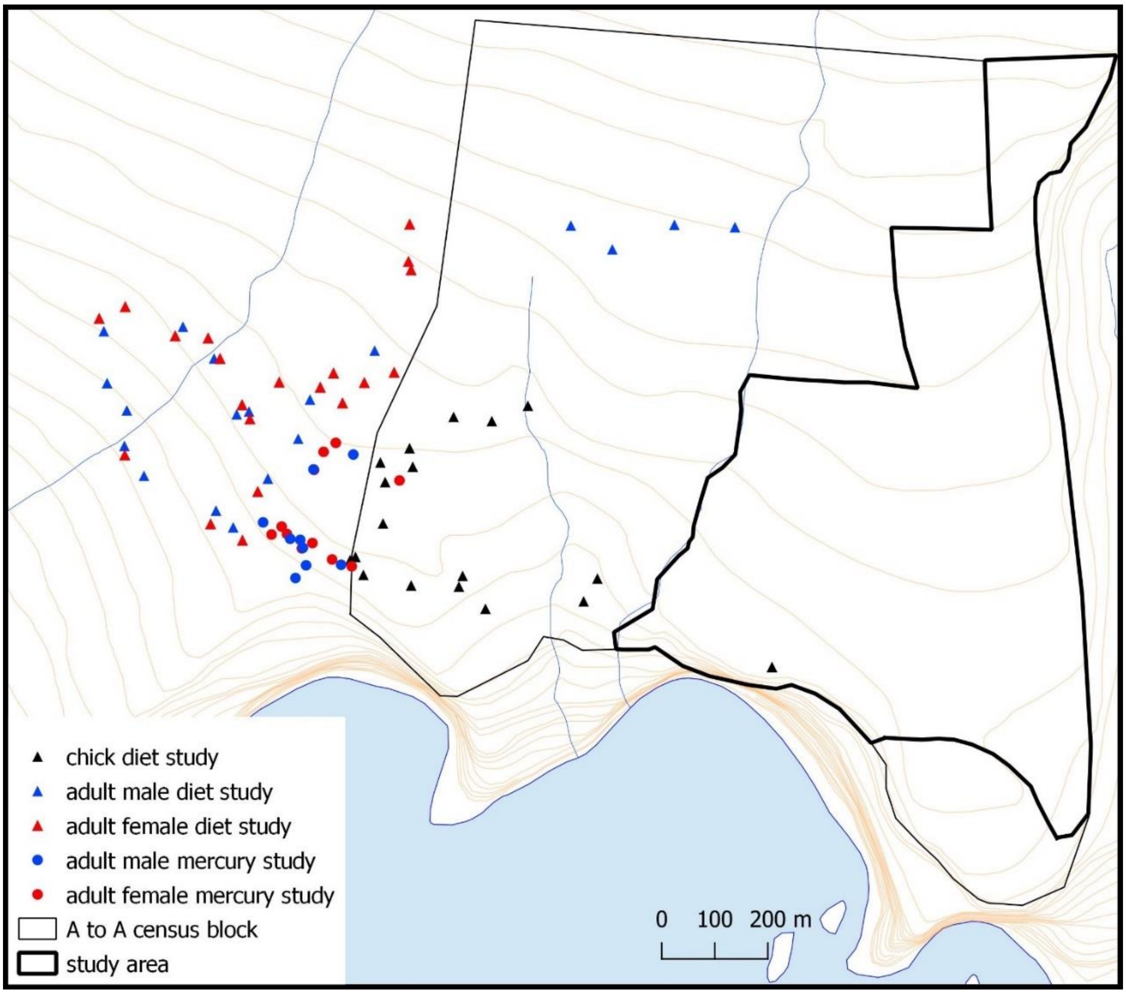


Figure 2. Sites just west of the albatross study area and the A–A census block on Adams Island where feather and blood samples were collected from Gibson's wandering albatrosses in December 2022 – February 2023.

At-sea distribution

To identify where juvenile Gibson's wandering albatrosses forage, and might be interacting with fishing vessels, 22 satellite transmitters (Telonics TAV2630) were deployed in December 2022. These satellite tags will transmit for maximum of 15 months. The tags were taped onto the back feathers (Taylor 2013) of 12 chicks which were probably female and 10 chicks which were probably males, just before they fledged from the study area. Sex was judged from relative bill depth at the nail of birds measured at the same stage of development (i.e., fully feathered and ready to fledge), with birds considered to be female when bill depth was 37mm or less and male when bill tip was 39mm or more, cut-off points found to reliably discriminate sex in adults whose sex was known (unpub data).

In addition, a geolocator datalogger (GLS: Migrate Technology C330) was cable-tied to the metal leg bands of 16 of the 22 satellite-tagged juveniles (Table 1, 2). The GLS deployed on chicks in 2023 will continue to store location information for at least 3–5 years by which time the young birds they are attached to will have started returning to Adams Island, allowing the GLS to be retrieved and the data downloaded.

Table 1: Satellite transmitters and GLS dataloggers attached to Gibson's wandering albatross chicks in December 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)
Telonics, TAV2630 (22)	Argos satellite	Battery	Satellite	3hrs/day	35.0
Migrate Technology c330	GLS	Battery	At recapture	2/day	3.3

Table 2: The number, inferred sex and status of Gibson's wandering albatross chicks to which satellite transmitters and GLS were attached in December 2022. The sex of chicks was estimated from their bill tip and length measures at fledging and some assignments may not be correct.

Albatross life stage	Transmitter	Female	Male	**Total**
Chick	TAV2630	5	1	**6**
Chick	TAV2630 plus GLS	7	9	**16**
Total		**12**	**10**	**22**

Here positions to date are simply mapped. After a full annual cycle overlap of tracked birds and fishing fleets will be analysed by comparing the birds' tracks with the locations of fishing boats available from https://globalfishingwatch.org/map/, the Global Fishing Watch website.

RESULTS

Population size estimate from mark-recapture

The data gap in 2021 prevents reliable estimation of the size of the population in 2021, 2022 and 2023. Figure 3 (reproduced from Rexer-Huber et al. 2020) shows population estimates up until 2020. The size of the breeding population in the study area estimated by mark-recapture was increasing up until 2005, but between 2005 and 2012 the population declined rapidly ($\lambda_{\text{both sexes combined}}=0.955$). Between 2012 and 2020 the decline slowed ($\lambda_{\text{both sexes combined}}=0.991$), but both female and male populations showed continued gradual decreases.

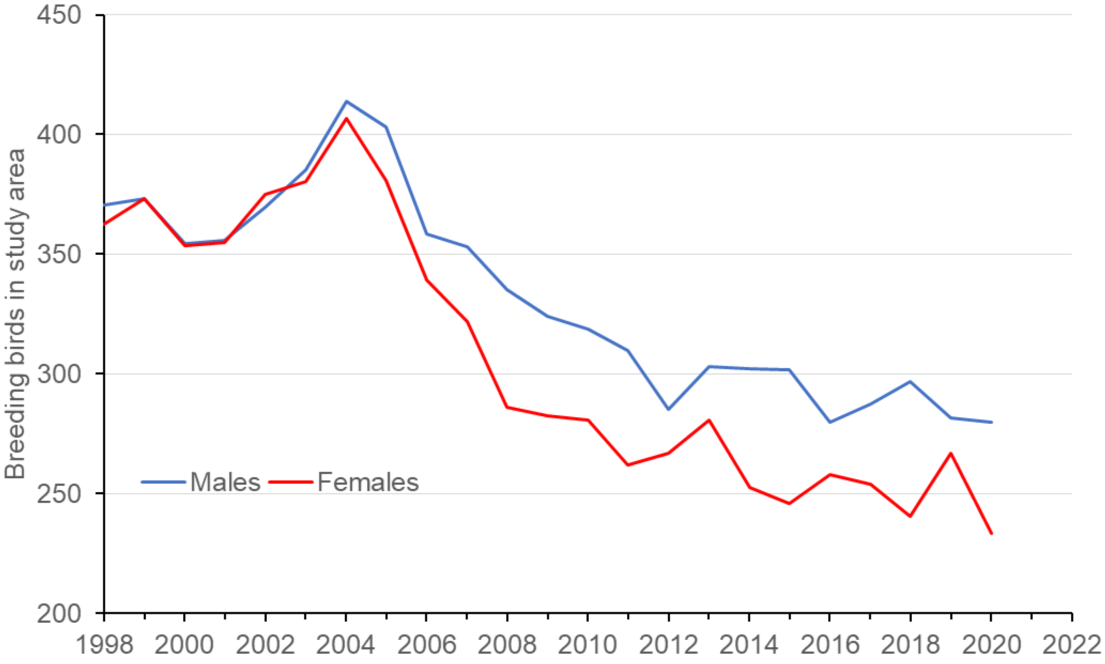


Figure 3. The number of breeding Gibson's albatrosses in the Adams Island study area between 1998 and 2020 estimated by mark-recapture (reproduced from Rexer-Huber et al. 2020). Mark recapture techniques cannot accurately be used to estimate the size of the population in 2021–2023 due to a cancelled field trip in 2021, so no estimates for those years are presented.

Survivorship

The data gap in 2021 prevents reliable estimation of survival in 2021, 2022 and 2023. Figures 4 and 5 (reproduced from Rexer-Huber et al. 2020) show survival estimates up until 2020. Adult survival varied around a mean of about 96% up until 2004 and during this period male and female survival were not notably different. Survival dropped substantially after 2005, with female survival reaching catastrophic low levels in 2006–08 (81 & 83%, Fig. 4). Between 2008 and 2020 survival improved (mean = 91%)

though female survival was very low in 2018. Within sexes, survival differs between breeders and non-breeders (Fig. 5). Non-breeding females generally have had lower annual survival rates than breeding females, particularly since 2013. In contrast, non-breeding males have generally had similar or slightly better survival than breeding males (Fig. 5**Error! Reference source not found.**).

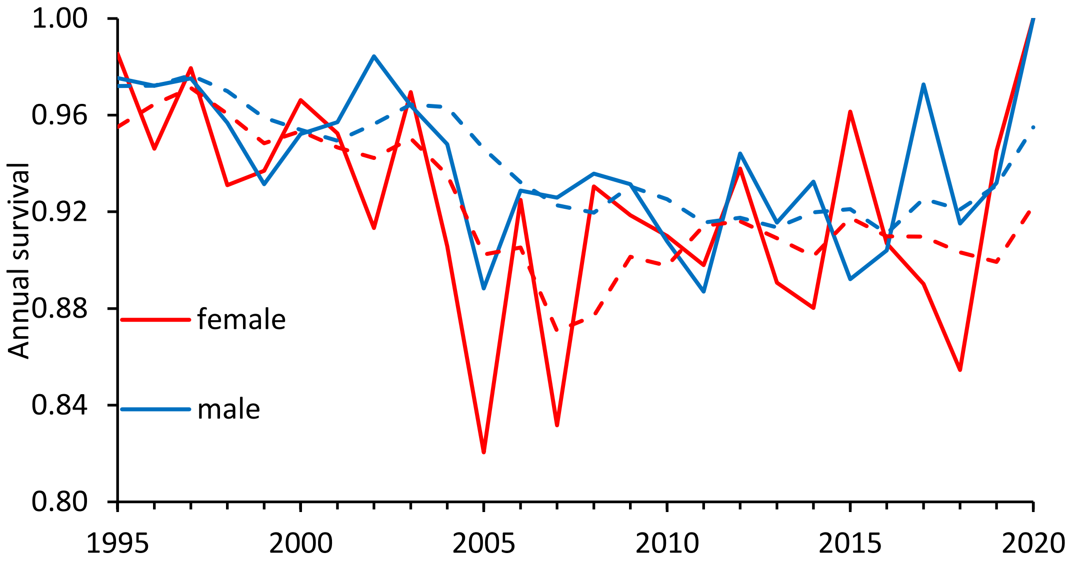


Figure 4. Annual survival of Gibson's wandering albatross in the Adams Island study area since 1995, estimated by mark-recapture (reproduced from Rexer-Huber et al. 2020). 4 year rolling averages are also shown. Estimates of survival since 2020 are not reliable due to a cancelled trip in 2021 and are not presented.

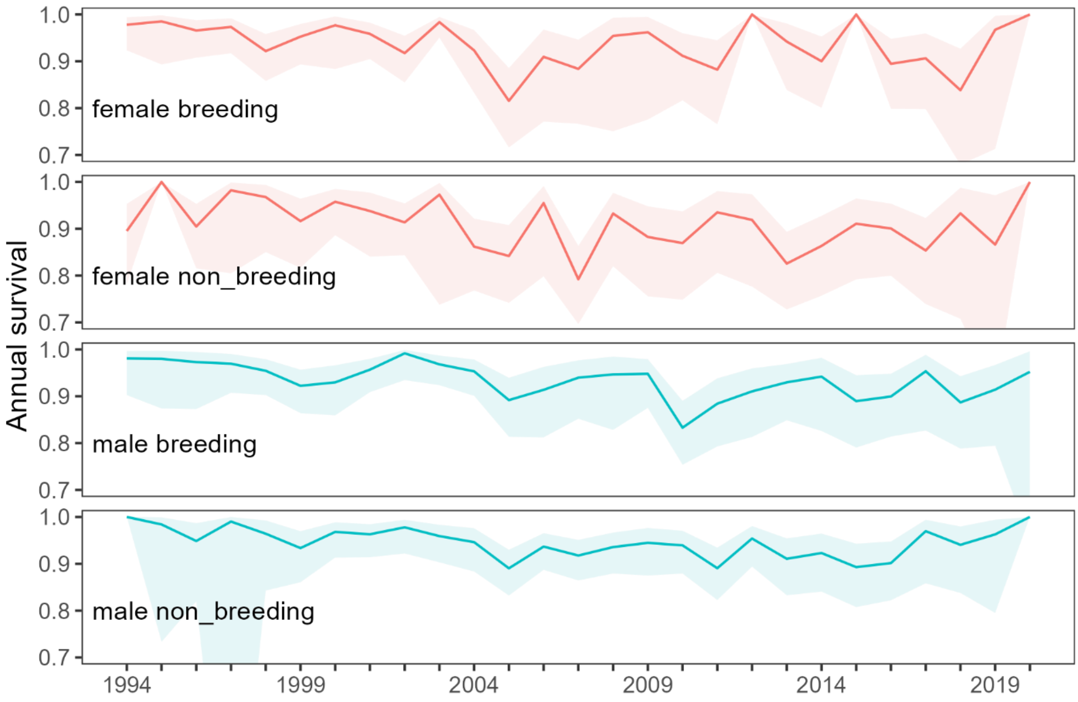


Figure 5. Survival estimated separately for breeding and non-breeding female and male Gibson's wandering albatrosses, estimated by mark-recapture (reproduced from Rexer-Huber et al. 2020).

Productivity

Breeding success was estimated as 75% in 2022: the highest breeding success recorded since 1993 (Fig. 6, blue line). Nesting success has been gradually rising since 2011. Nesting success in 2022 is now comparable to levels before 2005 ((63% pre-crash), but the number of chicks produced remains lower than pre-2005 since fewer birds are breeding (Fig. 6, red line).

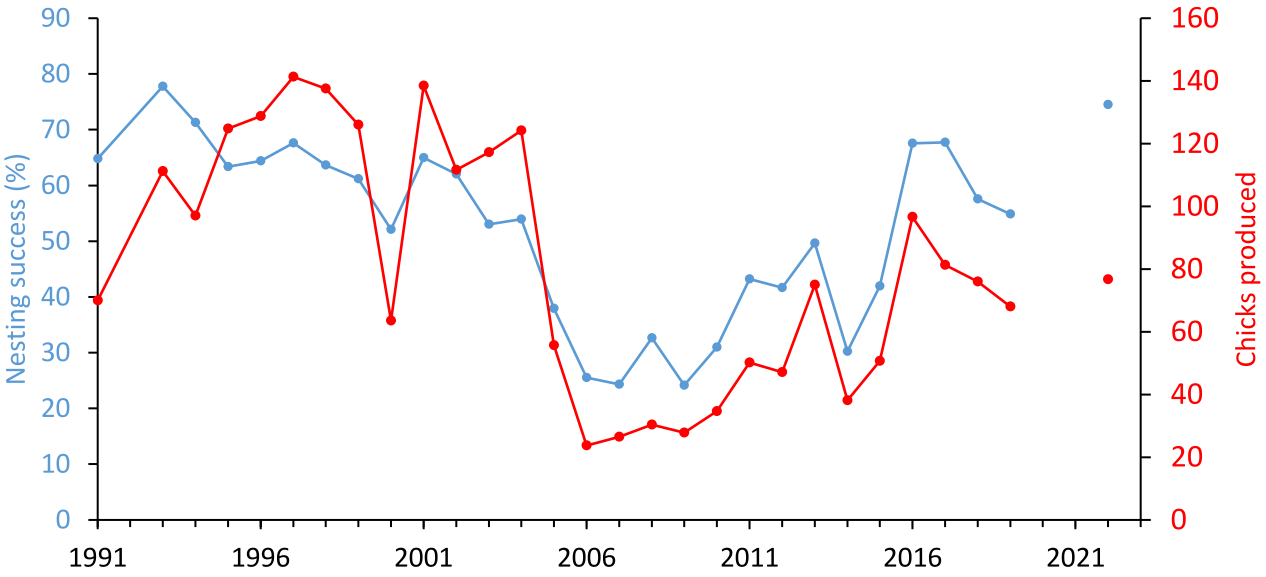


Figure 6. Gibson's wandering albatross nesting success and the number of chicks fledged from the study area on Adams Island since 1991.

Nest counts and whole-island estimate of nest numbers

The three blocks in which nests have been counted since 1998 were counted again in late January 2023, from which the total number of breeding pairs on the island were estimated (Table 3). Counts were corrected to take account of as-yet unlaid eggs and nest failures at the time of census (Elliott et al. 2016). Trends in the three Adams Island census blocks have been similar over the last 25 years (Table 3, Fig. 7) and a detailed analysis (see Appendix 2) suggests there is no justification for regarding the 3 blocks as having different trajectories.

The number of nests across the island dropped sharply 2004–06 by about 46%. Numbers nesting grew only slowly in the period 2007–16 with annual growth rate of 1.027 but since then has been approximately stable (Fig. 8). There are now an estimated 4,947 nests on Adams Island (Fig. 8; Table 3).

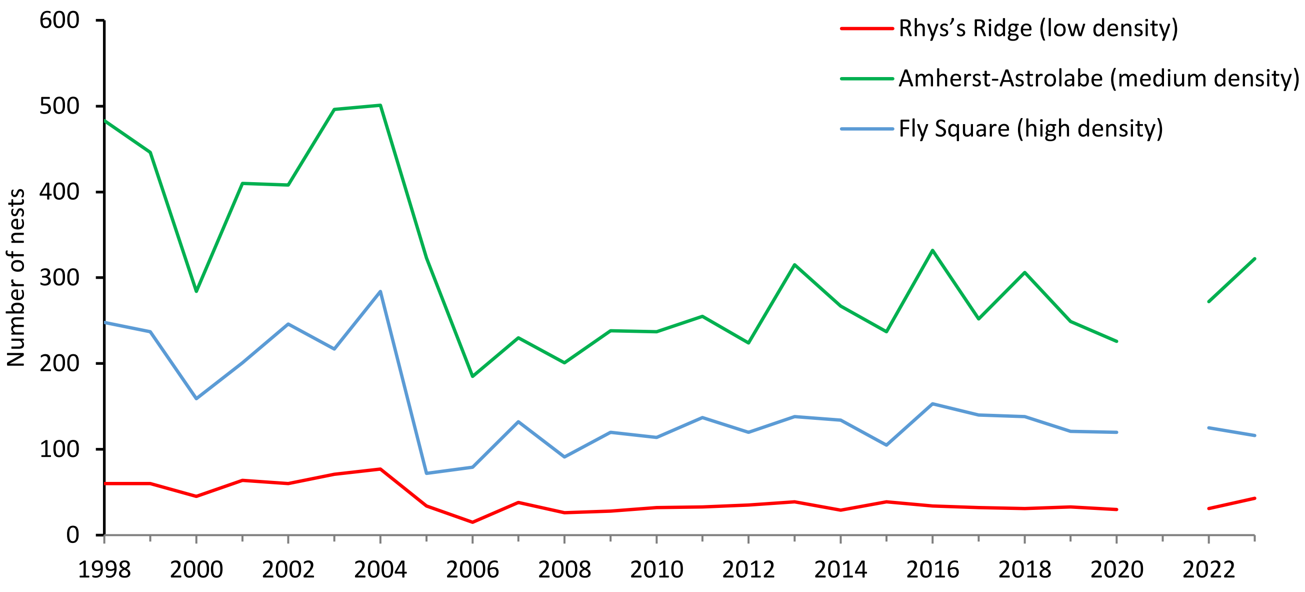


Figure 7. The number of Gibson's wandering albatross nests in three census blocks on Adams Island 1998–2023.

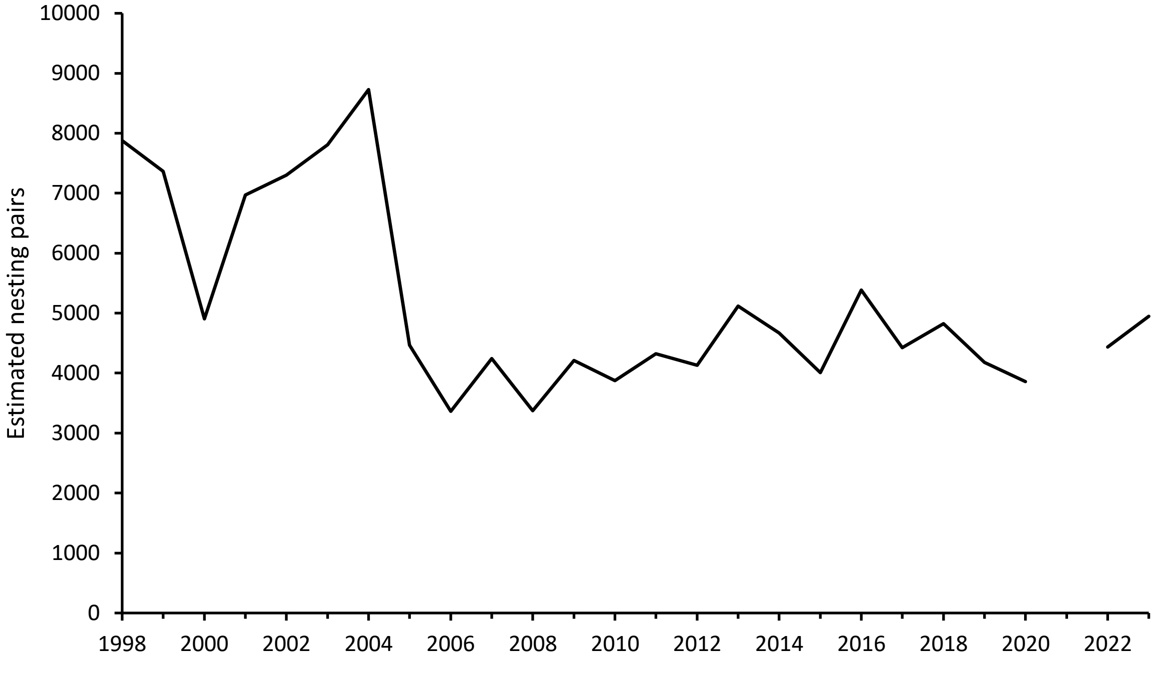


Figure 8. Total Gibson's wandering albatross nests across Adams Island 1997–2023. The estimated number of nesting pairs on the island is based on annual counts in the three census blocks, taking account of the number of failed nests and unlaid eggs at the time of counting.

Table 3. Gibson's wandering albatross nests with eggs in late January in three census blocks on Adams Island, 1998–2023. Corrected total is the estimated number of nests in the three blocks taking account of the number of failed nests and unlaid eggs at the time of counting (the correction factor applied each year is the ratio between the 5th and 6th columns). Estimated total is the estimated number of nests on the island, based on the proportion (9.87%) nesting in the three counted blocks relative to island-wide totals in 1997 when the last whole island count was undertaken.

Year	Rhys's Ridge (low density)	Amherst-Astrolabe (medium density)	Fly Square (high density)	Total no. of nests counted	Total corrected for unlaid eggs and failed nests	Estimated total
1997					796	7857
1998	60	483	248	791	798	7875
1999	60	446	237	743	746	7367
2000	45	284	159	488	497	4904
2001	64	410	201	675	706	6969
2002	60	408	246	714	740	7303
2003	71	496	217	784	791	7809
2004	77	501	284	862	884	8728
2005	34	323	72	429	452	4467
2006	15	185	79	279	341	3363
2007	38	230	132	400	430	4245
2008	26	201	91	318	341	3371
2009	28	238	120	386	426	4211
2010	32	237	114	383	392	3872
2011	33	255	137	425	438	4323
2012	35	224	120	379	418	4131
2013	39	315	138	492	519	5120
2014	29	267	134	430	473	4669
2015	39	237	105	381	406	4010
2016	34	332	153	519	545	5385
2017	32	252	140	424	448	4424
2018	31	306	138	475	489	4827
2019	33	249	121	403	423	4180
2020	30	226	120	376	391	3861
2021	No count					
2022	31	272	125	428	449	4434
2023	43	322	116	481	501	4947

Developing drone census techniques

A workable compromise was found between photo resolution and area coverage when the drone flew at 60 m above ground at 12m/s. At this height a resolution of 1.5cm per pixel was achieved with no obvious blurring caused by speed. 1.5cm per pixel resolution was sufficient to confidently distinguish albatrosses from rocks and sometimes sufficient to distinguish sitting from standing albatrosses. To produce orthomosaic images without gaps, photos needed to be taken with 65% forward and side overlaps. Larger overlaps were unnecessary, but smaller overlaps sometimes failed to produce a complete orthomosaic. With these specifications it was possible to census between 15 and 20ha of ground per battery depending on how far the drone had to fly from the take off point to the census block. A workflow was developed for undertaking drone census using QGIS (https://qgis.org/en/site/), UGCS flight planning software (https://www.ugcs.com) and WebODM (https://www.opendronemap.org/webodm/) drone mapping software and is described in detail in Appendix 1.

Reliability of aerial counts of nesting albatross

Using the workflow described in Appendix 1, six blocks, divided for ease of droning into 18 approximately 16ha "chunks", were censused in 2023. The six blocks together comprised about 300ha or about 9% of the albatross nesting grounds on Adams Island (Fig. 9). Unlike most other albatross nesting grounds on Adam's Island, all these blocks were comparatively accessible, being relatively close to the hut, and no special visits were necessary (i.e., blocks were visited as part of other regular work). Three of the blocks were chosen simply as those places with albatrosses closest to the hut, where it was most economical to experiment with drone speeds and heights, as each variation required a stiff climb up to albatross habitat, then a return to the hut to check its outcome on computer. The other three blocks droned comprised the normal census blocks Rhys's Ridge and Fly Square, plus the study area, as each of these blocks had a ground count against which the accuracy of aerial photos taken by drone in distinguishing nesting birds could be tested.

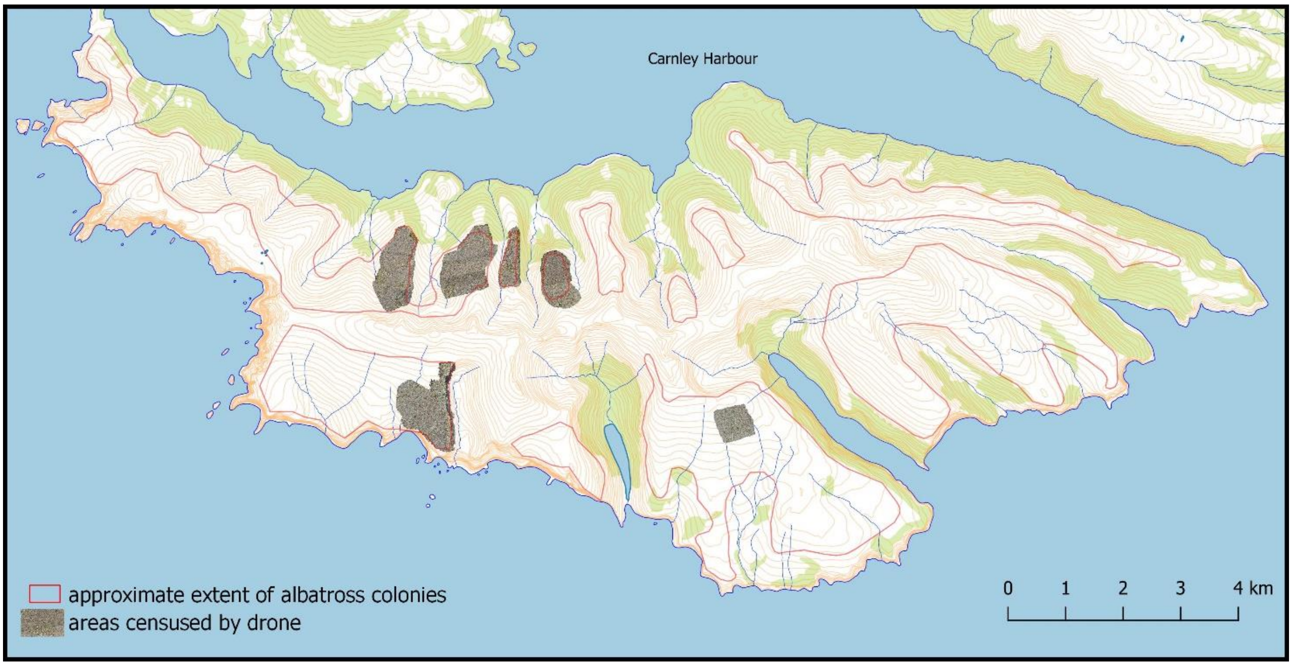


Figure 9. Drone albatross censuses undertaken on Adams Island and the approximate extent of albatross nesting colonies.

From a comparison of the nests and birds identified from the air with those identified on the ground it became clear that while it was sometimes possible to distinguish nesting and loafing birds from the air, many birds that appeared from the air to be nesting were not incubating (Fig. 10). Furthermore, the ratio of known nesting birds to apparently-nesting birds counted from drone photos varied considerably, with drone counts "overcounting" birds on eggs by an average of 37% (Fig. 10, Table 4).

This is consistent with observations made in regular study area checks that the number of non-breeding birds present varies considerably with wind direction and strength, the passage of fronts and the time of day, and that many non-breeding birds sitting on empty nests are nearly indistinguishable on the ground from nesting birds unless they stand, allowing an egg to become visible.

Table 4. Drone counts of apparently nesting albatrosses compared with ground counts of nesting birds.

Date	Where	Apparently-nesting birds counted from drone	Nests from ground counts	Ratio drone counts:nests
17/01/2023	Upper Study Area	26	17	1.53
18/01/2023	Lower Study Area	170	127	1.34
24/01/2023	Rhys's Ridge	12	10	1.20
28/01/2023	Fly Square	169	116	1.46
30/01/2023	West of Study Area	51	42	1.21
Total		**428**	**312**	**1.37**

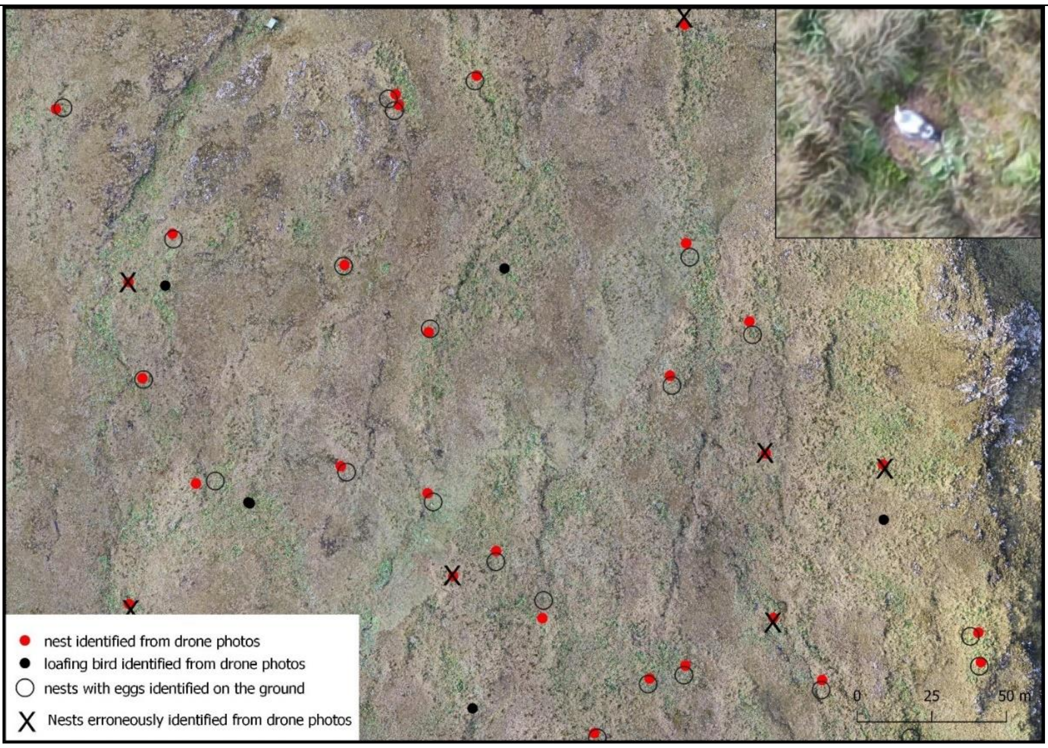


Figure 10. An example of birds and nests identified from drone photos and ground searches of Hinemoa's Gully in the upper albatross study area. Note the number of apparent nests identified from drone photos (X) which in fact had a non-breeding male sitting on a nest mound without an egg. The inset shows what a nesting albatross looks like from a drone photo.

To census the whole island using drones would require concurrent measurement of the ratio between birds on the ground and breeding birds (a "correction factor"), and this measurement would have to be undertaken either in the same area as the drone was flying, or in an area with similar exposure to wind. A two-person team could have one person flying the drone while the other person walked transects recording the number of birds on the ground and the number of nesting birds and calculating a concurrent correction factor. Obtaining a correction factor would be relatively straightforward in the denser colonies on the island's southern slopes, but it would be difficult to make a reliable correction factor on the northern slopes where nests are much sparser, as the ground walker would need to cover so much ground to find a large enough sample.

Effort required for aerial count of nesting albatross.

There are about 3500ha of albatross nesting grounds on Adams Island (Fig. 9) which could be divided into roughly 240 15ha blocks. If an average of 5 blocks were counted each day by a two-person team it would take 48 good days to census the whole island. At best only half the days are suitable for drone flying so it would take 96 days, or with 2 x 2 person teams about 48 days. At worst, it could take twice as long.

Because some of the albatross colonies are 5 or 6 hours walk from the hut where batteries can be charged, parties would have to camp to undertake the census, yet they would still have to return to the hut to charge batteries. For example, to census the albatross colonies at the eastern end of Adams Island it would take 85 batteries and the census team would have to carry batteries and camping gear. Eighty-five batteries weigh about 28kg, so even a team of 4 people would probably have to make two visits, and with two teams using 10 batteries a day each it would take 4 days of good weather and 4 days of travel to count the eastern colonies.

Good weather spells are often short-lived on Adams Island, with the weather usually a changeable mixture of strong winds, mist, and periods of rain and sometimes a few hours of sun. To successfully use a drone for photographs of the albatross breeding grounds, the weather needs to be relatively calm with no mist or rain. In February on Adams Island approximately 1 day in 3 typically have at least part of the day suitable for droning. Allowing for weather contingency—adding it to flight time needed during planning—is vital for a fieldwork plan to be feasible. For example, census at the eastern end discussed above could involve as much as ~16 days (4 days of travel, allowing 12 days for census work to ensure the 4 days of good flying conditions required are likely to occur). More optimistic weather contingency (1 in 2 flyable) would still require ~12 days be allowed for census of the eastern end of Adams Island.

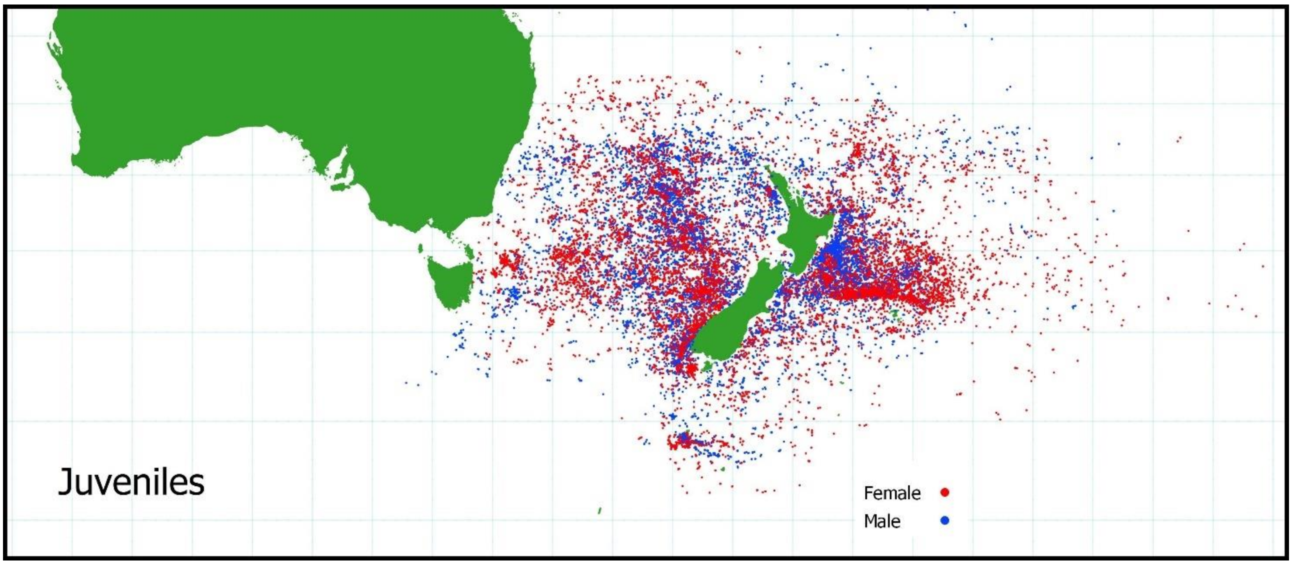
During a census, one day in every 5–7 would need to be set aside for checking the study area for nest failures, against which to calibrate drone block counts made around that time. Time would also need to be set aside at the hut to calculate and program the drone flights for each of the 240 blocks, to download the data after each block is flown, to stitch the images together to make orthomosaics (to check the flight has adequately captured the area); and to label and safely store it along with the correction factor data for that flight. The substantial time required to count nests on each of the orthomosaics (~6 weeks work) could be done after leaving the island.

Adams Island is long and steep with a large zone between the coast and the fellfield of impenetrable scrub, so travel time adds substantially to time needed for census efforts. Censusing the far eastern and western parts of the island would be easier and safer with a small boat, to cut some of the travel/walking time from base up to count areas, or with larger boat support for a temporary camp (with generators for charging batteries and computers) at both the eastern and western extremities of Adams Island. Even with a boat it remains a lengthy and expensive undertaking to accurately count all the nests on the island, with or without using a drone.

Overall, a reliable, accurate whole-island estimate of the number of breeding pairs–one with extensive ground truthing–will be a major undertaking, incompatible with simultaneous completion of the regular mark-recapture programme. Putting less effort into the mark recapture work to make space for a whole island count wouldn't be wise, as mark recapture is the only reliable way to obtain information on population trend.

At-sea distribution

Of the 22 satellite tags attached to juveniles in December 2022, 14 of them were still transmitting at the end of July 2023 and the young birds had dispersed widely in the Tasman Sea and to the east of New Zealand (Fig. 11). There was no obvious difference in the distribution of male and female juveniles (Fig.11) but the juveniles in the first few months after fledging in 2023 spent more time east and north of New Zealand than did adults tracked since 1994 (Fig. 11).



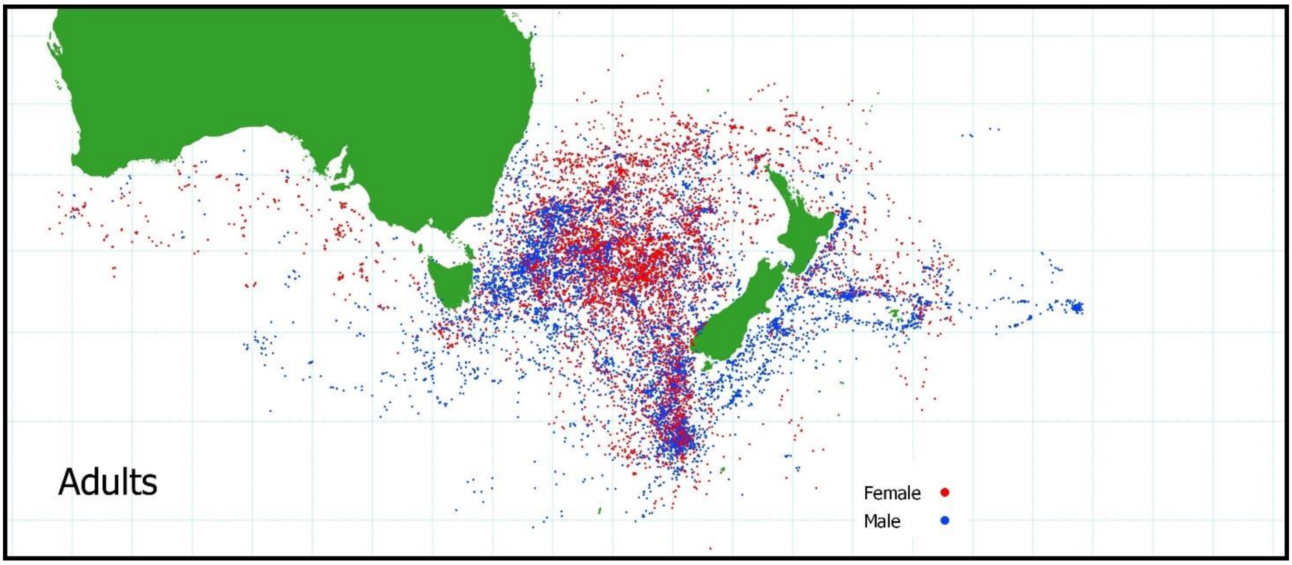


Figure 11. (Top) Satellite fixes from 22 juvenile Gibson's albatross tracked between December 2022 and July 2023 and (Bottom) 87 adults tracked since 1994.

DISCUSSION

Population trajectory

The demography of Gibson's albatross has shown gradual improvement following the population crash in 2006, but it is difficult to assess whether this improvement has continued because of the data gap in 2021. It is possible to estimate survivorship and population size since the data gap, but the estimates will be made without knowing the breeding status of the birds and will consequently be biased and not be comparable with earlier data. The consequences of a missed season highlight the importance of continuity: a year's missing data has meant that for 2 years no comparable estimate of survivorship or population size using mark recapture techniques has been possible. Another year's data (without missing any further years) will substantially improve the ability to estimate population trajectory.

Integrated population models, like that developed for Gibson's albatross by Francis et al. (2015) can provide estimates of survival and breeding population size, as well as estimating the survival rates and size of the pre-breeding population and the size of the whole population. The model of Francis et al. (2015) required considerable expertise to use, but recently Richard (2021) developed a similar model for Antipodean albatrosses which could be run in the freely available R environment. A similar model should be developed for Gibson's albatross.

Much of the increase in the number of nesting birds since 2006 can be attributed to a recovery in the proportion of females breeding. Prior to 2006 about half the adults bred, but this dropped to less than 30% and then between 2006 and 2012 recovered to close to pre-2006 levels (Elliott et al. 2018). Since the proportion of the population breeding is now close to its pre-2006 level, further increase in the number of nests can only arise from increased recruitment and survival.

Although survival has improved since 2006, the most recent estimate of adult survival (92% in 2019) remains substantially below the average pre-crash survival rate and is low for such a K-selected species (Weimerskirch & Jouventin 1987; Véran et al. 2007). The most recent mark-recapture estimates of population size indicate that the population is declining, not stable as the nest counts suggest.

Together, survival, recruitment and productivity shed some light on the slow increase in the number of breeding birds on the island. Although nesting success had shown recovery, the number of chicks produced remains lower than it used to be, since the breeding population is still substantially smaller than before 2005 and annual adult mortality remains higher. Wandering albatrosses start breeding at about 12 years old, so most birds joining the breeding population now were produced during a period when chick production was very low. Further, the trend to recruiting at a younger age may have already depleted the pool of birds available to recruit. Along with adult mortality remaining high, this is likely to continue to limit population recovery. For as long as the conservation status of Gibson's wandering albatross remains of concern, monitoring the size of the population and its structure and trend on Adams Island remains a priority.

Size of the breeding population

The Conservation Services Programme Annual plan for 2022-23 (DOC 2022) identifies estimating the size of the Gibson's albatross population as a priority. This requires counts of breeding birds which can be combined with demographic data to estimate population size. Counts of breeding birds alone do not provide estimates of the population size as only a proportion of the population is available to be counted and this proportion is estimated from demographic data derived from the study area. To this end, considerable effort was devoted to refining methods of counting nests across very large areas, particularly using drones, with the aim of developing more accurate methods of counting than were possible the last time the whole island was counted in 1997 (Walker & Elliott 1999).

The drone counting methodology developed this year can provide an alternative but probably equally unreliable estimate of the number of pairs nesting on Adams Island to that based on the ground counts of 1991-1997 (Walker & Elliott 1999). It would be exchanging one source of error (uncounted nests hidden in deep tussock, or distant nests counted with binoculars and not checked for eggs in 1991-1997) with another (substantial and variable numbers of non-breeders which appear in aerial photos to be breeders).

An alternative approach to a whole island count might involve a combination of drone counts on lower albatross density and difficult country, and ground counts in the two main concentrations of albatross (Amherst to Astrolabe block, and the accessible parts of Fly Basin). The advantage would be accurate counting of the biggest portion of the breeding population, and less accurate but faster counting of the smaller (but much more geographically spread) portion.

Astrolabe Basin was counted on foot in 2016 as a trial in a large area of using modern GPS based methods which are more accurate but take longer (9 days for 2 people; Elliott et al. 2016) than the ground count method used in 1997 (2 days for 4 people; Jacinda Amey pers. comm.). The aim was to determine the feasibility of counting such large blocks with the modern intensive GPS method used until then only in relatively small census blocks, and to determine the reliability of the current method of assessing the total breeding population size (described earlier). The intensive ground counts were found to be feasible but very time consuming, even though it was done near the bivy which reduced travel time greatly. The accurate ground count was 8% higher than estimated by extrapolation (Elliott et al. 2016), but this difference could be caused by a more accurate counting method or by interannual variation in the number of birds nesting. It is unlikely to be caused by population change in the Astrolabe Basin differing from population change over the rest of the island, because the three annually-monitored blocks have the same trajectory (see Appendix 2).

Whichever way it is done, another whole island census will provide a new estimate of the total breeding population size, but not one that can be compared with previous estimates and if drones are used, will only be more accurate if enough time and money are spent on ground truthing. Undertaking a credible drone-based whole island nest count with extensive concurrent ground-truthing, or a combination approach using both large areas of intensive ground counts plus drone counts in difficult country, would be a major undertaking requiring its own dedicated effort.

Possible methodologies for a whole island count and their costs and benefits are summarised in Table 5. None of the methods is 100% accurate as ground counts invariably miss some nests and aerial counts must be corrected for the proportion of birds that appear from above to be on eggs but are not. All methods require concurrent monitoring of the study area so that an estimate of the number of failed nests and nests not yet laid in can be made, and this estimate involves some error. All methods require very fit and strong workers, or the census will take longer, and risks of injury will increase. Having a small boat based at Maclaren Bay would substantially speed the counts, remove the necessity of camping, and enable drone batteries to be charged each night. All methods require considerable pre-trip office time, constructing drone flight plans, and designing 25m walking swathes that minimize walking effort.

Given the annual budget for Gibson's albatross monitoring it is unlikely a whole island count can be completed in a single summer. This means that population size estimates will need to comprise results from several partial island counts, corrected for inter-annual variation using the blocks which are censused every year. The final choice of methodology involves trade-offs between accuracy, cost and the availability of transport and a small boat (Table 5).

Table 5. Possible methods of a whole island nest count on Adams Island and their pros and cons.

Method	Person weeks on island	Pros	Extra requirements
Ground count at 25m spacings	40	Most accurate	Small boat
Ground count at 25m spacings (60%) Drone with ground truthing (40%) with a boat	30	2nd equal most accurate.	Small boat. Off island time processing drone images. Drones, drone pilots and 20 batteries.
Ground count at 25m spacings (60%). Drone with ground truthing (40%) without a boat	40	2nd equal most accurate.	Off island time processing drone images. Drones, drone pilots and 40 batteries.
Drone count and ground truthing with a boat	20	4th equal most accurate	Small boat. Off island time processing drone images. Drones, drone pilots and 20 batteries.
Drone counting and ground truthing without a boat	30	4th equal most accurate	Off island time processing drone images. Drones, drone pilots and 40 batteries.
Ground counting using 1997 techniques with a boat	20	Least accurate	Small boat.
Ground counting using 1997 techniques without a boat	30	Least accurate	

Conclusion

Although the demography of Gibson's albatross has improved since the crash in 2005–06 the population is at best stable rather than increasing. Monitoring the size of the population and its structure and trend on Adams Island remains a priority, as does more tracking to better understand the overlap and interaction of Gibson's albatross with long line fishing fleets.

Future estimates of demographic parameters would best be made using an integrated population model such as that developed for the Antipodean albatross.

A census of the nesting population on Adams Island is possible but will take considerable extra resources over and above that required for the demographic study and at-sea foraging work. The extra time and cost involved is dependent on the method chosen. The best choice is probably a whole island nest count using a combination of ground counts at 25 m spacings in easy country with dense albatross nests and drone counts of difficult country with sparse albatross nests. A whole island drone count with concurrent ground truthing would be a quicker, cheaper but less accurate option. Both would still need to be spread over several years at current funding levels.

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Appendix 1: Workflow when using a drone to count Gibson's wandering albatross.

1. Divide the areas to be censused in 15ha blocks using QGIS.
    a. Draw polygons around all the areas to be censused. Draw polygons with a projected coordinate reference system e.g. EPSG: 3788 NZGD2000 / Auckland Islands TM 2000
    b. Divide all likely albatross nesting areas into 15ha blocks by
        i. Measuring the area of the polygon and dividing it by 15 to determine how many blocks are required in each polygon.
        ii. Generating 10,000 random points inside each polygon.
        iii. K-means clustering the random points into as many clusters as you require blocks.
        iv. Aggregating the clustered points
        v. Calculating the centroids of the aggregated clusters of points.
        vi. Generating Voronoi polygons from the centroids of the clusters of aggregated points.
        vii. Repeating for every polygon
    c. Export the Voronoi polygons as a rendered geotiff with a coordinate reference system of WGS84.
2. Import the geotiff raster into UGCS as an overlay.
3. Make a flight plan for each block using the photogrammetry tool in UGCS by drawing a polygon around the outside of each polygon in the imported overlay, and set the specifications as follows:
    a. Resolution = 1.5cm per pixel. With a Mavic II pro this will give a flying height of 58.9m.
    b. Flight speed = 12m/s. This is the fastest the drone can fly and still take pictures at the appropriate intervals of 25.54m once every 2 seconds.
    c. Forward and side overlaps of 65%. This will result in 19m flight spacings.
    d. Altitude mode = AGL (above ground level).
    e. Set camera by distance and auto – it will take photos at regular distances (25.54m) regardless of flying speed.
    f. Establish take-off and landing waypoints (usually at the same place).
    g. Check that the flight plan does not exceed about 18 minutes and has less than 100 waypoints.
4. Using UGCS for DJI software on a mobile phone or tablet.
    a. Upload flight plans for multiple 15ha blocks to a phone or tablet.
    b. For each flight plan
        i. Go to the take-off and landing waypoint – i.e., walk there.

   ii. Upload a flight plan from the phone or tablet to the drone and fly it.

5. Back at the hut download the photos and generate an orthomosaic for every block censused using WebODM software.
6. Count the albatrosses that seemed to be on nests (keeping a separate tally of those that appeared to be loafinga) in the orthomsaics using QGIS by overlaying a 15m grid over the orthomosaics to ensure that birds are neither missed nor counted twice.

This workflow for points 1-3 is described in a video available here which has to be downloaded to be viewed and listened to.

This workflow cannot sensibly be undertaken on a computer without administrator rights as it must be possible to download, install/re-install and update software whilst on Adams Island. An internet connection is required for flight planning, but not for flying. A spare computer and drone would be sensible.

While most of the flying is undertaken automatically the drone pilot needs:

1. To be able to launch and land the drone by hand as there is invariably no clear ground to land a drone on.
2. To be able to confidently fly the drone home should anything go wrong.
3. To be able to take control of the drone and fly away from skuas or falcons should they attack the drone.
4. To be familiar with the drone and mobile phone/tablet software. There are a large number of options and it is easy to choose the wrong ones.

Appendix 2: Are the trajectories of the nest counts in the three census blocks different?

A cursory examination of Figure 8 suggests the three census blocks have similar trajectories, but they are not identical.

Generalised linear models were used to explore whether the best explanation for the differences between the blocks is that each block has its own different trajectory, or that they share a common trajectory, and the differences are statistical noise.

Generalised linear models with negative binomial errors and exponential growth between years were constructed for the period of decline between 2004 and 2006 and the period of increase between 2006 and 2023. Generalised additive models (gams) with negative binomial errors and smoothed trajectories were constructed for the period between 1998 and 2023 during which time there were both increases and decreases in nest counts. For each time period two models were constructed, one with separate growth rates or smoothed curves (for the gam models) for each block and one with a common growth rate or smoothed curve for all three blocks. We compared the models using AICc or AIC (Tables 5, 6 and 7). In all three periods the best models were those with a single trajectory.

Table 6. Generalised linear models of nest count data between 2006 and 2018.

Model	Number of parameters	ΔAICc
One growth rate	5	0.00
One growth rate for each block	7	4.46

Table 7. Generalised linear model of data between 2004 and 2006.

Model	Number of parameters	ΔAICc
One decline rate	5	0.00
One decline rate for each block	7	92.30

Table 8. Generalised additive model for nest count data between 1998 and 2018.

Model	df	ΔAIC
One trajectory	12.77	0.00
One trajectory for each block	13.92	49.45