Development of aerial monitoring techniques to estimate population size of great albatrosses (*Diomedea* spp.)

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ABSTRACT: Two approaches to estimating the population size of great albatrosses (*Diomedea* spp.) were tested in the Auckland Islands, New Zealand. The first approach used a series of aerial photographs taken on Adams Island to produce high-resolution photo-mosaics suitable for counting nesting Gibson's wandering albatross (*Diomedea antipodensis gibsoni*). The second involved a direct count from a helicopter of southern royal albatross (*D. epomophora*) breeding on Enderby Island. Both techniques produced results that closely matched counts of albatrosses attending nests derived from ground counts, although aerial counts could not determine whether birds were sitting on eggs or empty nests. If estimates of breeding pairs are required, aerial counts of nests require a correction factor to adjust for birds that are apparently nesting but have not laid. Such correction factors are best based on ground counts undertaken simultaneously with the aerial counts. Used in conjunction with correction factors, the two techniques provide a method of estimating the population size of great albatrosses breeding in remote areas where it may be logistically difficult to undertake ground counts of the whole population.

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FIGURE 1. A. Adult Gibson's wandering albatross, Adams Island, Auckland Islands. *Image: Barry Baker.*

FIGURE 1. B. Adult southern royal albatross, Enderby Island, Auckland Islands. *Image: Barry Baker.*

Introduction

Accurate estimation of numbers is critical for determining conservation status, and for identi-fying factors influencing changes in population size and demography of albatrosses. Recent technological advances in cameras, lenses, and image-processing software have led to aerial photography becoming increasingly used to census surface-nesting seabirds, especially in remote locations (Wolfaardt & Phillips 2013). The technique has been applied to a range of colonially nesting albatross and petrel species, including black-browed albatross (*Thalassarche melanophrys*) and grey-headed albatross (*T. chrysostoma*) in Chile (Arata *et al.* 2003; G. Robertson *et al.* 2008), black-browed albatross in the Falkland Islands (Strange 2008), white-capped albatross (*T. cauta steadi*) in New Zealand (Baker *et al.* 2015a), shy albatross (*T. c. cauta*) in Australia (Alderman *et al.* 2011), and southern giant petrel (*Macronectes giganteus*) in the Falkland Islands (Reid & Huin 2008).

Not all colonies lend themselves to being censused accurately by aerial photography, and those photographed successfully so far have been high-density colonies. Techniques used for colonial species have involved low-altitude flights over colonies and taking sequential overlapping photographs, which are later stitched together using software to form photo-montages. These are enlarged to allow counts of apparently-occupied nests (Wolfaardt & Phillips 2013). Most species of great albatross (*Diomedea* spp.) are not highly colonial, and typically nests are widely dispersed (Tickell 2000). As a result, aerial censusing has been rarely attempted so far for albatross populations that possess these characteristics (McClelland *et al.* 2016). Large distances between nests that are located in essentially featureless topography pose challenges that may not be easily addressed through existing techniques, and these methodologies need to be tested for relatively dispersed species.

This project was developed to test the suitability of aerial survey methods for counting breeding populations of great albatrosses. We report on two different approaches developed in the Auckland Islands, New Zealand. The first approach used a series of aerial photographs taken on Adams Island to produce high-resolution maps suitable for counting nesting Gibson's wandering albatrosses (*Diomedea antipodensis gibsoni*; Fig. 1A) in defined areas. The second approach involved a direct count of southern royal albatrosses (*Diomedea epomophora*; Fig. 1B) breeding on Enderby Island, which was conducted from a helicopter flying a series of transects to ensure complete coverage of the island.

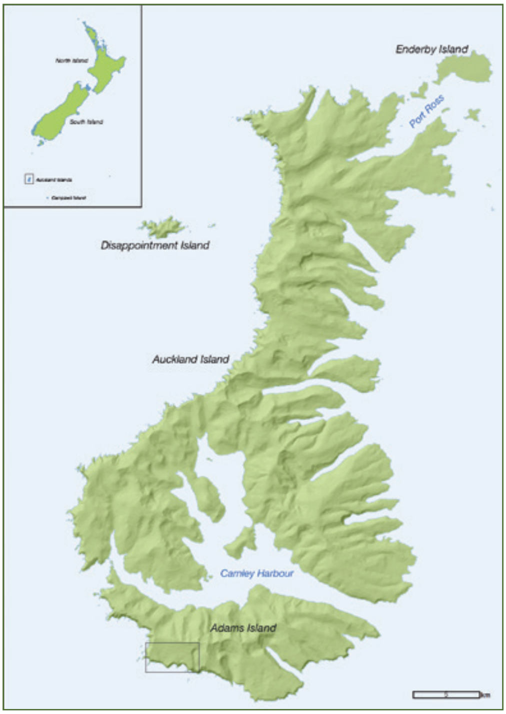

FIGURE 2. The Auckland Islands, showing the study sites referred to in the text. The box on the south-west coast of Adams Island is the location of Fig. 3.

Methods

Study species and breeding locations

The Auckland Islands (50°44'S, 166°05'E; Fig 2) lie 460 km south of New Zealand's South Island and comprise the largest island group in the New Zealand subantarctic. The archipelago consists of four relatively large islands (Auckland, Enderby, Adams, and Disappointment Islands), together with many smaller islands. Four species of albatross breed within the archipelago, including two great albatrosses.

The biennially breeding Gibson's wandering albatross is a large seabird endemic to the Auckland Islands group. It is listed as Threatened – Nationally Critical in the New Zealand Threat Classification System (H.A. Robertson *et al.* 2017) and (when combined with the conspecific Antipodean albatross *D. a. antipodensis*) as Endangered on the IUCN Red List (BirdLife International 2018). Approximately 95% of the global breeding population of Gibson's wandering albatross breed on Adams Island (50°53'S, 166°03'E) (Elliott *et al.* 2016), the southernmost island in the Auckland Islands group. The remaining birds occur on Disappointment Island and the southern parts of main Auckland Island.

Adams Island (9,693 ha) is the second-largest island in the Auckland Islands archipelago (Walker & Elliott 1999). It is mountainous with a 600 m high range running west–east along its length (Walker & Elliott 1999) and features high coastal cliffs in places (Elliott *et al.* 2020 – Chapter 3 in this book). The northern slopes of the island have a narrow band of coastal forest dominated by southern rātā (*Metrosideros umbellata*) and scrub, with tussock and then bare fellfield above (Walker & Elliott 1999; Elliott *et al.* 2020 – Chapter 3). Gibson's wandering albatrosses nest on most ridges off the main range, with two large concentrations of nesting birds on the southern slopes of the island (Walker & Elliott 1999).

Since 1991, an annual long-term research programme on Gibson's wandering albatross on Adams Island has shown declines in adult survival, productivity, and recruitment, although there has recently been a small increase in recruitment, nesting success, and survival from low points recorded in 2006 (Elliott & Walker 2014). Annual counts of the number of active albatross nests in three areas (representative of low-, medium-, and high-density nesting habitat) provide data to estimate annual population size and trends (Walker & Elliott 1999; Elliott & Walker 2005). These three areas comprise approximately 10% of all the nests on Adams Island (Elliott & Walker 2005).

The southern royal albatross is an endemic New Zealand species that breeds primarily on Campbell Island (52°33'S, 169°09'E) (99% of breeding birds), with a small number of birds breeding in the Auckland Islands archipelago, mainly on Enderby Island but with a few birds nesting on the high slopes of Adams Island

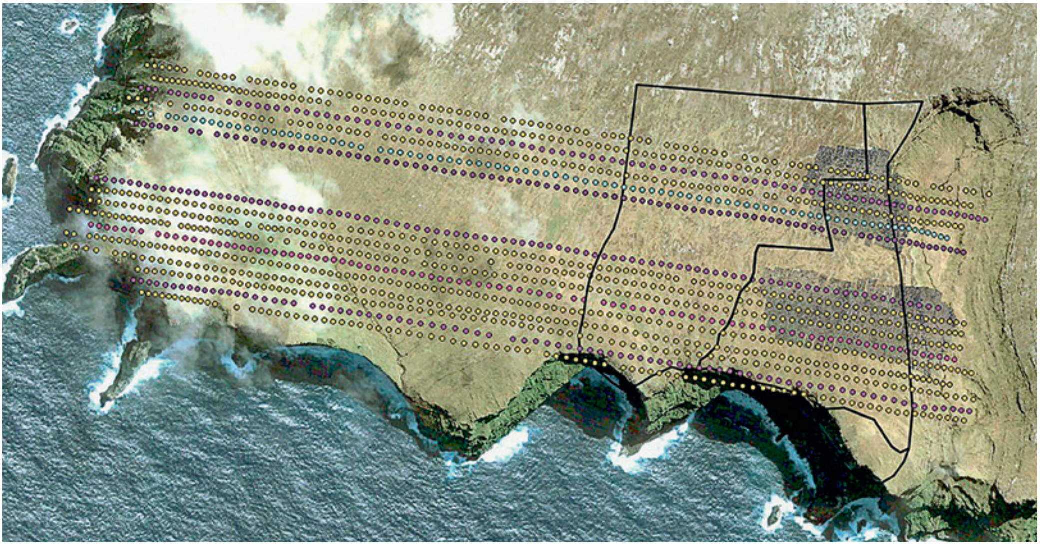

FIGURE 3. The area on Adams Island that was overflown and photographed in Jan 2016, which incorporates two study blocks used for fine-scale demographic studies undertaken by Walker & Elliott (1999) – outlined by the solid lines. The coloured circles indicate the transects flown. Only a subset of photos was subsequently analysed as part of this study, and this formed three maps taken from the two shaded areas located within the demographic study sites.

TABLE 1. Aerial counts of Gibson's wandering albatross ashore on Adams Island on 17 Jan 2016, taken from three maps developed from aerial photos using the internet-based online geo-referencing interface Maps Made Easy, together with the results of ground-truthing.

Category	Aerial assessment	Ground-truthing		
	Bird on nest	Correct	No nest	Not a bird
Bird on nest	129	95	34	–
Possible bird	3	0	–	3
Totals	**132**	**95**	**34**	**3**

(Miskelly *et al.* 2020 – Chapter 2 in this book; Elliott *et al.* 2020 – Chapter 3; French *et al.* 2020 – Chapter 4 in this book). The species is a biennial breeder and is currently assessed as Vulnerable on the IUCN Red List (BirdLife International 2018), and At Risk – Naturally Uncommon under the New Zealand Threat Classification System (H.A. Robertson *et al.* 2017). The global population is estimated to number 8,300–8,700 annual breeding pairs on Campbell Island (Moore *et al.* 2012), with a further 60 pairs breeding each year on Enderby Island (ACAP 2009). Counts on Enderby Island during 1992–2015 fluctuated from 32 to 69 nests annually (L. Chilvers *unpubl. data in* ACAP 2009; Childerhouse *et al.* 2003, 2016; French *et al.* 2020 – Chapter 4). There are no recent comprehensive data on the number of pairs breeding on Adams and Auckland Islands, but in 1991 there were six pairs on Adams Island, and a single chick was found being brooded on Auckland Island in Feb 2019 (Miskelly *et al.* 2020 – Chapter 2).

Enderby Island (50°30'S, 166°17'E) is a small (695 ha), low-lying island (maximum elevation 43 m) located at the northern end of the Auckland Islands archipelago. Southern rātā forms thick forest and scrub along the south and east sides of the island, but elsewhere the vegetation comprises moorland in the centre of the island and tussock grassland on the lower-lying, more exposed areas (Russ & Terauds 2009; French *et al.* 2020 – Chapter 4). Most of the *c.* 60 pairs of southern royal albatross breeding each year on Enderby Island nest within the moorland and grassland vegetation (ACAP 2009; French *et al.* 2020 – Chapter 4).

Aerial photography – Adams Island

Between 1100 h and 1700 h on 17 Jan 2016 we took a series of photographs of Gibson's wandering albatross colonies on Adams Island. The photos were taken along 35 transects designed to provide full coverage of an area adjacent to and including a long-term mark-recapture study site on the south of the island (Walker & Elliott 1999) (Fig. 3). The area surveyed overlapped an area that was later ground-counted, which allowed ground-truthing and comparison with ground survey methods.

The aircraft used for the survey was a single-engined Squirrel AS350B3 helicopter. We flew a series of west–east transects (Fig. 3) at 70 m intervals using the aerial guidance system TracMap Flight Pro (http://www.tracmap.com/aviation/products). The transects were set up to ensure that there was at least a 20 m side overlap with photographs taken in parallel transects, and a 20 m frontal overlap with consecutive photographs. Transects were flown at 150 m above ground level (determined by radar altimeter) at 75 km/h, and photographs were taken at 2-second intervals using a full-frame digital single-lens reflex camera (Nikon D800) with a 50 mm lens (Nikon 50 mm f1.8).

The camera was vertically mounted in a purpose-built camera mount fitted in a weather-proof pod suspended underneath the aircraft, and manually controlled from inside the helicopter. Shutter speeds were 1/1,000 s or faster to minimise the effect of vibration on image quality. To assist with spatial resolution of each photo, a Garmin GPSmap 60CSx GPS was connected to the camera, and latitude and longitude were recorded with the metadata for each photograph. All photographs were saved as raw files and subsequently converted to fine-scale JPG format files. The combination of flight height, ground speed, photo-frame rate, and focal length was derived from an earlier trial of lens/flight height combinations designed to ensure complete ground coverage (adequate overlap between transects).

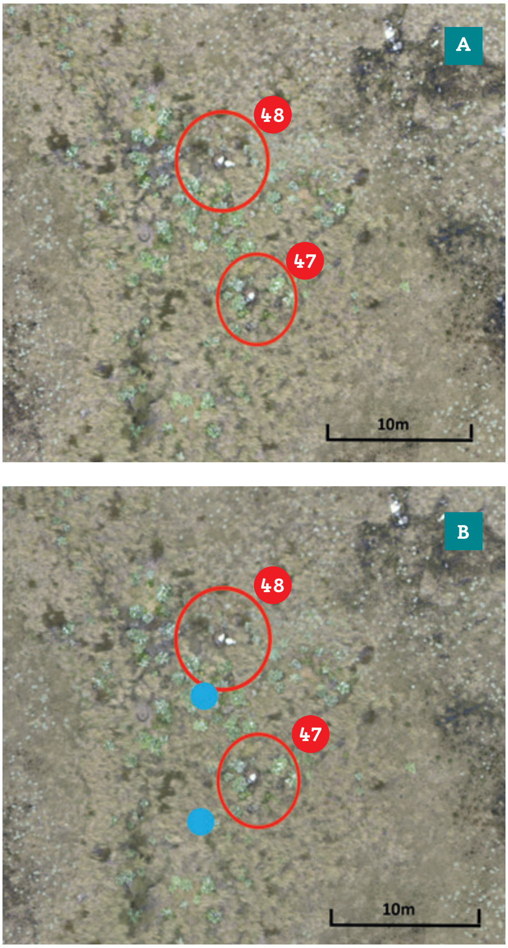

FIGURE 4. A. Section of a high-resolution map generated from the aerial photographs showing the convention used to identify Gibson's wandering albatross nesting birds in the initial analysis – a red circle and unique site number. **B.** Nests identified in ground counts were subsequently marked on the map by a solid blue circle to assess the efficiency of the aerial count. Generally there was close alignment between aerial and ground counts, and the slight differences evident here are due to datum and projection differences.

Ground-counting – Adams Island

Ground-counting of all albatrosses nesting in the Adams Island mark-recapture study blocks was undertaken on 24 Jan–5 Feb 2016 (Elliott *et al.* 2016). Counts were carried out just after the completion of egg-laying, using a strip search method where two observers walked back and forth across the area to be counted, each within a strip about 25 m wide and displayed on a GPS map. Every bird on a nest was checked for the presence of an egg, and the location of each nest found with an egg was recorded using a hand-held GPS. All non-breeding birds on the ground were also counted but their locations were not recorded.

Analysis of photographs and mapping – Adams Island

Three areas within the demographic study sites were randomly chosen for analysis, and 80–100 photos covering each area were selected for analysis. Photos from only 16 of the 35 transects flown were necessary for this purpose. These were uploaded to an internet-based online geo-referencing interface Maps Made Easy (https://www.mapsmadeeasy.com/) for stitching and geo-referencing. The uncompressed TIFF files produced by Maps Made Easy were imported into image-editing software. Counts of all Gibson's wandering albatrosses on each map were then made by first quickly assessing each image to identify likely birds, and then magnifying the image to closely inspect potential birds. Each identified bird was marked with a small red circle (Fig. 4A) and given a unique number, which was also marked on the map. Maps were then imported into GIS software so that the locations of nests detected in the ground counts could be plotted on the same maps (Fig. 4B).

Each single bird was assumed to represent a breeding pair, as were two birds that were sitting close together.

Aerial counts – Enderby Island

On 21 Jan 2017 we used a helicopter and three on-board observers to count nesting southern royal albatrosses on Enderby Island. We flew a series of eight west–east transects (Fig. 5) spaced at 200 m intervals, and counted every albatross seen on the port side of the aircraft within 200 m of the aircraft. Transect start and end points were programmed into the on-board GPS system and the helicopter was flown along each transect at 90 m above ground level at 75 km/h.

For each bird sighting we recorded the number of birds, the apparent breeding status of each bird (nesting – bird sitting on a nest; loafing – bird standing, not associated with a nest), the distance of each bird from the helicopter measured using a Leupold RX-600i laser range-finder, the angle of the bird from the line, and the angle of inclination using a Suunto tandem compass clinometer (to permit calculation of horizontal distance). Photographs of each bird were taken using a Nikon D800 digital camera, fitted with a Garmin GPSmap 60CSx GPS, and an image-stabilised Nikkor 300 mm f2.8 telephoto lens. These photographs were used to identify the location of each nesting bird and to assist in determining the breeding status. All visible nests were recorded as unoccupied (empty) or occupied. A bird standing on an empty nest was classified as a loafer, and the nest classified as 'empty'. All birds recorded as 'on nest' were assumed to be breeding birds, and all others were assumed to be loafers. At the time of the flight the weather was calm but overcast with high cloud cover, and we were able to see and obtain clear photographs of birds.

Ground-counting – Enderby Island

On 26 Jan 2017 a complete search of Enderby Island was made for royal albatross nests using techniques described by Childerhouse *et al.* (2003). Briefly, searching was undertaken on foot by two people, walking 20–40 m apart, keeping in visual and voice contact. The entire area of open ground on the island was searched. Areas that were not searched included underneath dense scrub and in the rātā forest, which has an average canopy height of 4–5 m. Birds on nests were not lifted to check for the presence of eggs; however, if a bird stood up when approached to within a few metres, the presence or absence of an egg was noted. Approaches were close enough that loafing birds would stand up and/or begin to move away, whereupon the observer would withdraw to minimise disturbance.

Searches were conducted with the naked eye, with binoculars used to scan areas from high vantage points prior to ground searches. If a bird or suspected nest was seen from a distance, it was visited to confirm the presence of a nest. The locations of all nests were determined using a handheld GPS.

Analysis of photographs and mapping – Enderby Island

GPS positions of the helicopter location when each nest photo was taken were recorded, along with the distance, compass bearing, and inclination angle to the nest. Distances were converted to the

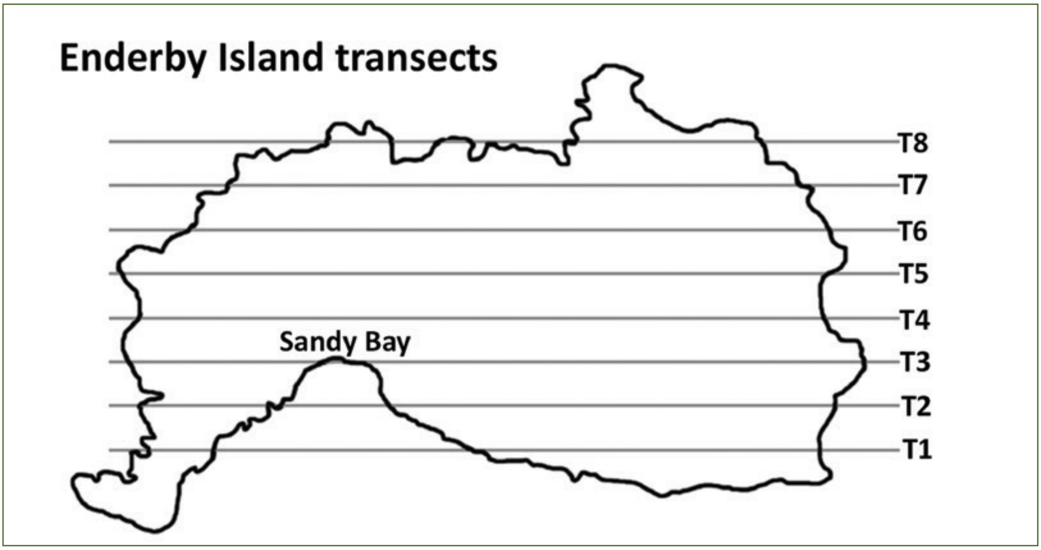

FIGURE 5. Location of transects spaced at 200 m intervals, Enderby Island.

TABLE 2. Aerial and ground counts of southern royal albatross ashore on Enderby Island in January 2016.

Aerial assessment			Ground-truthing		
Apparent nest	Uncertain	Loafers	On egg	Empty nest	No nest
57	2	10	47	5	10

horizontal distance from the flight line using trigonometry, and nest positions plotted using GIS.

Results

Analysis of photographs and mapping – Adams Island

Unfortunately, data from four of the 35 transects flown at Adams Island were lost because of a corrupt memory card, leaving a gap in the planned coverage of the area. An attempt to re-fly these four transects was unsuccessful because of inclement weather.

We counted 129 birds from the aerial photographs in the three randomly chosen areas (Table 1). Subsequent ground counts showed that only 95 (74%) of these birds were on nests with eggs. The other 34 birds (26%) were therefore loafing at the time of the aerial count (Table 1).

The resolution of the images was substantially improved over that obtained in aerial photography in 2015 (Baker *et al.* 2015b), leading to very little uncertainty distinguishing albatrosses from the large number of white rocks that are present at this site. There were only three white objects located on the maps for which identification was uncertain – the assessment of three observers was that these objects were most likely not birds, which was subsequently confirmed by ground-truthing.

Analysis of aerial and ground counts – Enderby Island

Aerial surveys counted 69 southern royal albatrosses on Enderby Island, of which 57 appeared to be on nests (Table 2), ten were obviously loafers, and two were only partially visible and their status could not be assessed. Ground surveys counted 52 southern royal albatrosses apparently nesting (Table 2), of which two were on nests with broken eggs, and five were empty nests occupied by loafers. Of the remaining 45 nests, 12 were confirmed to be on an egg, while the rest were assumed to be on an egg because they did not stand up when approached. We estimate that there were 47 breeding pairs, and that 26% of the birds that appeared to be nesting were in fact loafers.

Discussion

Aerial photography and mapping – Adams Island

Vertical mounting of the camera, in combination with a flight height of 150 m and use of a GPS guidance system, greatly improved the resolution and utility of the photographic images over that obtained in an earlier trial (Baker *et al.* 2015b).

The aerial photographs were taken at a time when only about 89% of eggs had been laid (Walker & Elliott 1999), and therefore photos taken in mid-January do not provide a complete assessment of the number of breeding pairs. Future aerial counts should be taken after laying is completed, if possible. Alternatively, it would also be feasible to adjust aerial counts by using a correction factor that takes into consideration the stage of breeding at the time of aerial survey.

Direct aerial and ground counts – Enderby Island

For southern royal albatross, the use of aerial counts of 200 m wide transects was effective in rapidly assessing the population size on Enderby Island. Ground counts of apparent nests were 8.8% lower than aerial counts, but ground counts may have under-estimated birds present, as only open areas of the island were counted and birds have been recorded nesting among heavy cover in previous years (Simon Childerhouse & Louise Chilvers, *unpubl. data*). The aerial counts may also have over-estimated the number of apparent nests because there was some degree of drift associated with reliance on standard onboard navigational equipment when flying transects. Use of a GPS guidance system similar to TracMap Flight Pro, as used in the Adams Island aerial photography, would greatly improve transect precision and is recommended with this technique.

Our trial method of offsetting GPS locations using a laser range-finder allowed nest locations of dispersed-nesting southern royal albatross to be more accurately mapped from an aerial survey and directly compared with locations obtained from ground counts. This allowed for comparison of nests found using each method, as well as an analysis of their relative efficiency for finding nests and determining numbers of nesting and loafing birds. Offsetting of GPS positions can be calculated automatically by some laser range-finders, which makes this task even easier.

Estimating the number of breeding pairs

Counts of great albatrosses on Enderby and Adams Islands indicated that 24% and 26% of apparently nesting birds were loafers, respectively. It is tempting to suggest that about 25% of apparent nests are loafers and to use this figure to correct future aerial counts. However, Walker & Elliott (2015) showed that the proportion of non-breeding Gibson's wandering albatross on Adams Island varied considerably with weather and time of day. This means that aerial counts can only reasonably be used to estimate breeding population size if a correction factor derived from a simultaneous ground count of part of the aerially counted block is applied. Alternatively, the distinction between nesting and loafing birds could be ignored and the counts regarded as an index of albatross abundance rather than an estimate of the number of breeding pairs. This approach would, however, necessitate a much longer series of counts to reliably detect population change, as the abundance indices would have greater variance than the estimated number of breeding pairs.

Which method to use?

Where archival records are necessary, high-resolution mapping of colonies based on aerial photography would be most appropriate as they provide a reference that can be subsequently reviewed by others, if necessary. For both methods, helicopters appear superior to fixed-wing aircraft, as they can operate at slower speeds and fly closer to the ground. Slower flight speeds and getting closer to albatrosses aids higher-resolution photography and improved visibility for direct aerial counts.

Acquisition of photographs for mapping purposes is best achieved by flying parallel transects, using a camera vertically mounted underneath the aircraft, geo-referencing photographs using suitable GPS equipment and software, and generating high-resolution maps to permit counting of all visible birds. Such an approach requires significantly more flying time and post-flight data analysis than direct counts. For example, 4 hours of flying time was necessary to produce photographs suitable for mapping the 4 km^2 Gibson's wandering albatross study site on Adams Island, while counts of Enderby Island (8 km^2) were complete after 1 hour of flying time. Where counts of large areas are needed, direct counting of birds from an aerial platform offers a practical, cost-effective solution.

Summary

The use of both aerial photography to produce high-resolution maps suitable for counting, and direct aerial-counting of great albatross colonies, can provide useful estimates of breeding colonies for sites where access is difficult. Application of appropriate correction factors to account for the presence of non-breeding birds in colonies can improve the utility of aerial counts in estimating the number of annual breeding pairs nesting at a site.

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Gibson's wandering albatrosses. *Image: Kath Walker.*