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Assessment of aerial census techniques to robustly estimate the total population size of Gibson's albatross on Adams Island

Report prepared for
New Zealand Department of Conservation

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August 2015

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1. Introduction

The biennially breeding Gibson's albatross (*Diomedea gibsoni*), listed as Vulnerable on the IUCN Red List (Birdlife International 2012) and Nationally Critical on the New Zealand Threat Classification system (Robertson et al. 2012), is endemic to the sub Antarctic Auckland Islands group. Approximately 95% of the global breeding population of Gibson's wandering albatross breed on Adams Island (50°53'S, 166°10'E), the southern-most island in the Auckland Islands group (Elliott and Walker 2014). The remaining birds occur on Disappointment Island and the southern parts of the main Auckland Island.

The remote and rugged Adams Island is roughly 20 km long and seven kilometres wide with a total area of approximately 101 km² (Walker and Elliott 1999). It is mountainous with a 600 m high range running east-west along its length (Walker and Elliott 1999) and high coastal cliffs in places (Cooper 2013). The island has a narrow band of coastal forest (including Southern Rātā *Metrosideros umbellate*) and scrub, with tussock then bare fellfield above (Walker and Elliott 1999; Cooper 2013). Gibson's albatross nest on most ridges off the main range although there are two large concentrations of nesting birds on the southern slopes of the island i.e. "Amherst–Astrolabe colony" and "Fly Basin colony" (Walker and Elliott 1999).

Since 1991, an annual long-term research program on Gibson's 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 and Walker 2014). The 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 and Elliott 1999; Elliott and Walker 2005). These three areas comprise approximately 10% of all the nests on Adams Island (Elliott and Walker 2005). Counts are undertaken as soon after completion of egg-laying as possible (most eggs are laid between 26 December and 25 January, ACAP 2012) and usually in late January to early February (Walker and Elliott 1999; Elliott and Walker 2014). The total number of pairs has been estimated by multiplying the proportional change in the number of nests in the three regularly counted blocks by the average number of nests counted in a comprehensive on-ground island-wide census undertaken in 1997 (Walker and Elliott 1999). The long-term monitoring on Adams Island recorded a rapid population decline between 2005 and 2008 when the size of the breeding population dropped more than 40%. Since then, the population recovery has been slow from the 2006 low of 2,816 annual breeding pairs to the most recent reported estimate of 4,340 breeding pairs on the Auckland Islands in 2014 (Elliott and Walker 2014).

However, the remoteness of the Gibson's albatross breeding population on Adams Island means that it is expensive to undertake regular on-ground site visits to census the albatross population. In addition, the albatross are widespread across the rugged, topographically challenging island and so obtaining whole island population size estimates using on-ground census methods is logistically extremely difficult and requires a substantial effort and significant time period. Aerial surveys are used for counts of a range of species and can allow rapid coverage of large areas of land and/or water as well as areas that are difficult to access on the ground (Magrath et al. 2010). Using helicopters, fixed-wing or ultra-light aircraft, aerial surveys usually involve flying along systematically or randomly-placed, straight-line routes, or along shorelines, rivers, cliffs or other natural features where birds may occur. In large study areas, a sampling procedure may be more applicable whereas in smaller areas systematic coverage of the entire area may be possible (Magrath et al. 2010). In recent years technological advances in cameras, lenses and image processing software have led to aerial photography becoming increasingly preferred as the census method for surface nesting seabirds, especially in remote locations (Arata et al. 2003; Wolfaardt and Phillips 2011). Although aerial photography has been successfully utilised to census a range of colonially nesting albatross and petrel species (Arata et al. 2003; Robertson et al. 2008; Reid and Huin 2008; Strange 2008; Alderman et al. 2011; Baker and Jensz 2012; Baker et al. 2014a; Cooper 2014), undertaking aerial censusing for the great albatrosses (*Diomedea* spp.) has been rare as most of these species are not highly colonial and nests are typically widely dispersed (Baker and Jensz 2013; Baker et al. 2014b).

The objective of this report is to provide recommendations for robustly estimating the total population size of Gibson's albatross at Adams Island and, in particular, to identify the range of feasible options for conducting an aerial survey of Gibson's albatross on Adams Island. This report reviews a range of aerial survey methods and provides recommendations for future survey work. For each survey option, we have, where data are available, identified and considered:

- the operational factors relevant to conducting research at Adams Island that may limit the cost-effective use of the option;
- the analytical requirements to estimate population size; and,
- the likely accuracy of resulting population estimates.

This assessment is based on a literature review and on the analysis of exploratory aerial census work conducted at the Auckland Islands with a particular focus on preliminary aerial surveys of Adams Island in January 2015. The recommendations include the suggested methodologies for future survey work taking into consideration operational feasibility, cost and accuracy.

2. Literature Review

2.1 Methods

We reviewed available published literature on aerial census techniques for surveying birds (although mammal studies were reviewed if relevant), in particular albatrosses, with a focus on studies that assessed the accuracy of different aerial census methods. The literature review assessed the following different aerial census techniques for surveying of bird breeding populations:

- Aerial census using static cameras, kite-borne cameras and remote-controlled unmanned aircraft systems;
- Aerial census (fixed-winged aircraft or helicopter based) using whole colony photo-montages of colonially-nesting albatrosses and petrels;
- Fixed-wing aircraft-based aerial census of seabirds using line and strip transect surveys; and
- Aerial photographic census (fixed-winged aircraft or helicopter based) of 'great albatross' populations.

2.2 Results

2.2.1 Aerial census using static cameras, kite-borne cameras and remote-controlled unmanned aircraft systems

a) Static cameras to monitor Adélie penguin (*Pygoscelis adeliae*) in Antarctica

Adélie penguin populations in the Antarctic marine ecosystem are closely monitored as an indicator of climate change and the harvesting of ocean resources. Therefore, it is crucial to accurately estimate and monitor penguin abundances at regional scales in order to detect any large-scale environmental perturbations (Low et al. 2008). Population estimates of penguins have commonly used total population counts where all individuals were counted by an observer on the ground or from aerial photographs. However, aerial photography can also utilise methods that do not require all individuals to be counted (e.g. transect lines) although there are two potential problems with this approach: (1) the assumption of constant density within and between penguin sub-colonies is often not tested and, therefore, may be violated under certain circumstances, and (2) aircraft may not be available in the short time-window when it is optimal for surveys of breeding Adélie penguins to be undertaken. Therefore, to estimate the density of nesting Adélie penguins, a ground-based technique has been developed where, using a camera mounted on a 3 m pole, an operator takes photos in four directions at numerous pre-defined survey points within an area of nesting penguins (Low et al. 2008; AAD 2015). The boundaries of the area are added post-survey (Low et al. 2008). Each photo is overlaid with a different counting template, depending on the slope of the ground at each point. All penguins in each grid of the template are counted and Distance Sampling Analysis is then used to provide estimates of colony density and population size with calculable levels of precision (Low et al. 2008; AAD 2015). Low et al. (2008) tested the techniques experimentally using models of penguins and reported that experimental assessment of biases in density estimates because of misclassification error was <2% when compared to true density. This indicated that this survey method is effective at accurately estimating penguin density and, therefore, abundance (Low et al. 2008).

b) Kite-born cameras to monitor New Zealand sea lions (*Phocarctos hookeri*) at the Auckland Islands

Photography of sea lion rookeries in the Auckland Islands using fixed-wing aircraft was considered to be complicated by the distance of colonies from base, rapidly changing weather over the targets, and the need to verify numbers of animals photographed with ground truth counts (Cawthorn 1993). Therefore, kite-born cameras were used to take aerial survey photographs of New Zealand sea lions at the Auckland Islands (Cawthorn 1993). This technique was considered to be a very cost-effective method of photographing breeding sea lions and could also be undertaken by ground teams when weather conditions were conducive to the work but would have not been appropriate for aircraft flights. In addition to on-ground surveys, ground teams could effectively collect large quantities of ancillary corroborative information (e.g. pupping dates) using the kite-born cameras (Cawthorn 1993).

c) Remote-controlled unmanned aircraft systems (UAS) to monitor black-headed gull (*Chroicocephalus ridibundus*) breeding colonies

Aerial surveys using manned aircraft can be expensive, be constrained by wider scale weather conditions and can have difficulties with the geospatial accuracy of the acquired data and survey repeatability (Sarda-Palomera et al. 2012). Black-headed gulls nest in dense colonies of up to several thousand pairs and repeated nest visits to a colony can systematically flush all adult birds and disturb the breeding colony. The use of remote-controlled unmanned aircraft systems (UAS) enabled the recording of georeferenced data on nest locations without causing colony disturbance was used to monitor temporal changes in breeding population size in a black-headed gull colony (Sarda-Palomera et al. 2012). This project used a manually radio-controlled model aircraft, an image acquisition device and a positioning and navigation system with the total weight being 2 kg. The UAS flew at 30–40 km/h and at 30–40 m above ground over the island colony with the camera trigger activated in continuous mode during flyover. The UAS used in this study was designed as a fieldwork tool applicable to a small geographical scale and the whole colony was able to be framed in a single image, whereas other UAS can cover larger ranges (Sarda-Palomera et al. 2012).

FACTORS RELEVANT TO CENSUS OF GIBSON'S ALBATROSS ON ADAMS ISLAND

The **static photography technique**, **kite-born camera technique** and **unmanned aircraft systems (UAS)** aerial photography techniques are not considered useful or practical for censusing the total population of Gibson's albatross on Adams Island for the following reasons:

- The albatross nests are not tightly colonial, are widely dispersed and, in addition, nests are often obscured by vegetation and/or topographical features. Therefore, it would be very difficult to get an adequate sample of nests in each shot.
- These techniques would require a ground-crew to be landed and based on the island for a substantial time period to cover enough on-ground area. This is costly as well as logistically challenging, given the protected status of the Adams Island.

2.2.2 Aerial census (fixed-winged aircraft or helicopter based) using whole colony photo-montages of colonially-nesting albatrosses and petrels

Aerial census techniques used for colonial-nesting seabird species have involved low altitude flights over colonies to take sequential, high resolution, overlapping photographs which are later stitched together using software to form photomontages and from which nests are counted on-screen (Wolfaardt and Phillips 2011). The technique has been well described (e.g. Arata et al. 2003; Robertson et al. 2008; Baker et al. 2014a) with variations between studies in use of aircraft (fixed wing, helicopter), altitude of flights and camera gear and settings. Aerial photography has been successfully 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; Robertson et al. 2008);
- black-browed albatrosses in the Falkland Islands (Strange 2008; Baker and Jensz 2012);
- white-capped albatrosses *T. steadi* in New Zealand (Baker et al. 2014a);
- shy albatross *T. cauta* in Australia (Alderman et al 2011);
- southern giant petrels *Macronectes giganteus* in the Falkland Islands (Reid and Huin 2008);
- Atlantic yellow-nosed albatrosses *Thalassarche chlororhynchos* at Gough Island (Cooper 2014); and
- Salvin's albatross at the Snares Western Chain (Baker et al. 2015) and the Bounty Islands Baker et al. 2012, 2014c).
- Auckland Island shag *Phalacrocorax colensoi* on Enderby Island (Chilvers et al. 2015).

a) Black-browed albatrosses at Ildefonso Archipelago, Chile: fixed-winged aircraft based census

Albatrosses, along with rockhopper penguins, macaroni penguins and blue-eyed cormorants, nest in 'pavement' (almost soil-less bare rock) and tussock slope (open stands of tussock grass) habitats (Robertson et al. 2010) at the Ildefonso Archipelago, Chile. Five different methods were assessed for censusing colonial breeding black-browed albatrosses at Ildefonso - ground-truthed aerial photography, point-distance sampling, quadrat sampling, ground counts and yacht-based photography (Robertson et al. 2008). Ground-truthed aerial photography was the most accurate methodology followed by point-distance sampling (underestimated the population by 9%), quadrat sampling (underestimated by 11%), ground counts (underestimated by 13%) and yacht-based photography (underestimated by 55%). Compared to nests counted from aerial photographs, the ground counts underestimated nesting albatrosses by 12.3% mainly due to the ground counts missing 30% of the albatrosses in the tussock slopes.

The aerial census for the entire Archipelago area involved estimating the number of nesting pairs that had laid an egg. Ground truthing was used to identify the most ideal time of day for taking photographs so that the ratio of nesting birds to total birds was highest. Ground truthing also quantified, at the same time as the aerial photography, the proportion of albatrosses not on nests and the proportion of birds sitting on nests that did not contain an egg (Robertson et al. 2008). However, landing a crew on the islands for ground truthing and ground-based census caused disturbance to wildlife on the island as well as adding substantially to the logistical difficulty and cost of the census (Robertson et al. 2008). Aerial photographs were taken from a twin otter aircraft with air and ground parties maintaining radio contact so flights could be modified or suspended if birds showed signs of disturbance. Photographs were taken at an angle perpendicular to the land surface using a hand-held 35 mm camera (ISO 100 transparency) through an open cockpit window. A digital montage of the complete island group was constructed from overlapping images "stitched" together and albatrosses were counted individually on the computerised montage. To measure the repeatability of counts and variability between counters, the number of albatrosses in a well-defined area was counted twice by each of two observers. Within-counter coefficients of variation (SD/mean) were 0.95 and 0.28% and the mean values for both counters differed by only 1.3%.

This aerial census proved to be accurate largely due to:

- black-browed albatross being colonial breeders;
- both the northern and southern island groups in the Ildefonso Archipelago were long and narrow with only two flanks inhabited by albatrosses making the flight path required of the aircraft easy to follow;
- there was no concealing vegetation to obscure views of albatrosses from the air and high quality montages of the landscape could be produced with albatrosses clearly visible and easily counted (Robertson et al. 2008).

The main potential errors associated with the aerial photography were:

- the effect of parallax in the image stitching process was thought to have had a minor overall effect but could be reduced further by taking each photograph from a position as close as possible to perpendicular to the landscape. To determine if albatrosses near stitch lines were omitted or counted twice due to parallax, the number of nests within about 50 m of the edges of 20 images was compared to the number counted near the centre of photographs taken on subsequent overpasses. Overall, 1.3% of birds were "lost" on stitch lines but, given that the total area of albatross habitat affected by stitching was only 5.9%, the effect of parallax was considered to be minor;

- other species (penguins and cormorants) interspersed with the black-browed albatrosses meant that misidentification of albatrosses compared to the other species on the island was an issue when images were not sharp.

Robertson et al. (2008) recommended future use of digital photography to take photographs at a larger scale to increase the size of albatrosses in the images which may enable nesting and loafing birds to be counted separately and could reduce or eliminate the need for ground truthing.

b) White-capped albatrosses at Disappointment Island: helicopter-based census

Aerial photography was used to undertake repeated population censuses of white-capped albatrosses on Disappointment Island between 2006/07 and 2013/14 (Baker et al. 2014a). Disappointment Island in the Auckland Islands group is 4 km long by up to 1 km wide, and is covered in *Poa* grassland and giant herbs, with scattered areas of shrubland and fellfield around the top of the island (Peat 2006). The island rises steeply from the sea to a plateau, with white-capped albatrosses breeding extensively on the slopes but avoiding the plateau. Aerial photographs were taken from a single-engine helicopter with two photographers positioned on the open port side of the aircraft to permit each to take photographs of the island simultaneously. Every effort was made to ensure that the photographs were taken perpendicular to the land surface. Photographic montages were constructed from overlapping photographs and counts were made by magnifying each montage to view and count birds. There was no evidence of a difference between observers and hence an observer bias based on an analysis of multiple counts of photomontages undertaken for the December 2006 census. Ground-truthing was undertaken within a week of the 2007 and 2008 aerial counts and it was noted that the timing of aerial and on-ground counts needs to be synchronous if meaningful correction factors are to be developed (Baker et al. 2014a). The observed strong inter-annual fluctuations in estimated breeding pairs (116,025 annual breeding pairs in 2006 to a low of 73,838 in 2009) are likely due to a range of factors including counting error, the presence of non-breeding birds during counts, environmental stochasticity and other unknown variables that are not easily quantified. Despite this, it was considered the data were useful for tracking change in the white-capped albatross since they have been collected at roughly the same time of the breeding cycle (either December, early incubation; or January, late incubation) each year, allowing inferences about long-term trends to be made (Baker et al. 2014a).

c) Southern giant petrels (*Macronectes giganteus*) in the Falkland Islands: fixed-winged aircraft based census

In 2004/05, the breeding population of southern giant petrels within the Falkland Islands was estimated from 38 locations around the islands (colony size varying from one to 10,936) using either ground counts or aerial photographs (Reid and Huin 2008). Aerial counts were made from multiple digital photographs taken from a fixed-wing aircraft which passed parallel to the colony at a height of approximately 300 m. At all sites, multiple counts were conducted until all counts fell within 5–10% of each other. Variation in individual counts of adults produced a source of error which was estimated by calculating the minimum and maximum number of adults counted at each site (Reid and Huin 2008).

d) Salvin's albatross (Thalassarche salvini) in The Snares: helicopter based census

In September 2014 Baker et al (2015) conducted an aerial survey of the Western Chain, The Snares, and all albatross colonies were photographed. Salvin's albatross was breeding on two (Rima and Toru) of the five islets in the Western Chain archipelago. The photographs were used to compile photo-montages of each colony, and these images used to count birds on each islet. Ground counts of nesting Salvin's albatrosses were also undertaken on Toru Islet on concurrently. Raw counts of birds ashore were adjusted to account for the presence of loafers. This provided an estimate which was 32% higher than the ground counts undertaken on the same day of the aerial survey. The use of close up aerial photographs has proven useful in correcting raw counts to estimate the number of annual nesting pairs at other albatross colonies, but their utility for this purpose at the Western Chain, appeared to be limited. Ground counts indicated the proportion of loafing birds in colonies (33.3%) was high, but consistent with that observed at the Bounty Islands (25.8%) in 2013 (Baker et al 2014c). These values exceed those previously recorded for other *Thalassarche* albatrosses during the early to mid-incubation period, but may be normal for Salvin's albatross because of the nature of their nesting sites where egg loss appears to be very high. The cause of many nest failures appeared to be a combination of the lack of substrate with which to construct a nest, and interference from birds attending the colony.

e) Salvin's albatross (*Thalassarche salvini*) at the Bounty Islands: fixed-winged aircraft based census

Baker et al (2012, 2014c) completed aerial surveys of the Bounty Islands in October 2010 and 2013 using a fixed wing aircraft as an aerial platform. On both trips all albatross colonies observed were photographed The photographs were used to compile photo-montages of each colony, and these images were used to count the breeding birds on each island. Ground counts of nesting Salvin's albatrosses were also undertaken on Proclamation Island on 23 October 2013, to determine the proportions of nests containing eggs and non-breeding birds present in the colony. These ground counts indicated that the mean proportion of breeding birds in the colony between 1000 to 1600 hours was 0.74 (range 0.71 — 0.77). The mean proportion of occupied nests that contained eggs over the same period was 0.90 (range 0.88 — 0.91). Estimated annual counts for all breeding sites in the Bounty Islands were adjusted to account for the presence of non-breeding birds using the correction factors.

Aerial survey of the Bounty Islands proved to be an effective method of rapidly assessing the population size of Salvin's albatross in the Bounty Islands, and the population estimates derived from the two studies represented the first complete population surveys of the species on the Bounty Islands. The proportion of loafing birds in the colonies (25.8%) was high, but may be normal for this species or at the mid-incubation stage of the breeding cycle for Salvin's albatross. The authors recommended that future surveys be conducting earlier in the breeding cycle when the proportion of non-breeding birds present was likely to be lower.

The authors commented that helicopters remained their preferred platform for aerial photography of albatross colonies (Baker et al 2014c), but the distance between New Zealand and the Bounty Islands precluded their use. There is no conveniently located fuel available near the Bounty Islands, and fixed wing aircraft were the only viable option at present. Aerial survey of the Bounty Islands was feasible using fixed wing aircraft but the aircraft used in this study was not ideal, because it was difficult to keep air speed below 120 knots. It was also difficult to obtain accurate weather conditions on the Bounty Islands immediately pre-flight unless fishing or other vessels in the vicinity could be contacted.

f) Auckland Island shag (*Phalacrocorax colensoi*) on Enderby Island: helicopter-based census

During the 2011/2012 breeding season, an assessment of three survey methods to census the cliff-nesting, colonial breeding Auckland Island shag population on Enderby Island showed that helicopter-based aerial photographic survey identified 1,889 breeding pairs of shags whereas boat-based surveys underestimated the population size by 27% and ground counts by 26% (Chilvers et al. 2015). An added benefit of undertaking aerial photography was that it produced an archival record of the colonies for future comparison and repeatability of counts.

FACTORS RELEVANT TO CENSUS OF GIBSON'S ALBATROSS ON ADAMS ISLAND

- Difficulty in compiling photomontages of widely dispersed population. At some sites nests may be obscured by vegetation and/or topographical features.
- Aerial surveys may more accurately detect breeding birds at some sites. In one study ground counts underestimated nesting albatrosses by 12.3% mainly due to ground counts missing 30% of the albatrosses present in thick vegetation on slopes.
- Given the spatial extent of the Gibson's albatross population, with nests dispersed in a large, often quite featureless landscape, it may be more appropriate to use transects to systematically photography the population.

- Fixed-winged aircraft are more limited in terms of manoeuvrability, and cannot readily fly at a speed slow enough to easily photograph colonies. Higher flight speeds (>120 mph) may also compromise the production of clear images. Fixed wing aircraft are unlikely to be feasible for aerial photography of albatross populations in the Auckland Islands because of the difficulty of predicting suitable weather windows for photography, particularly where conditions change rapidly.
- Small fixed wing aircraft are more cost-effective to run than helicopters, but require an airstrip from which to operate. At present there are no airstrips constructed on the Auckland Islands.

2.2.3 Fixed-wing aircraft-based aerial census of seabirds using line and strip transect surveys

With digital technological advances, strip transect surveys of seabird colonies can be conducted to efficiently quantify abundance and distribution of seabirds (Buckland et al. 2012). Buckland et al. (2012) compared the following three types of aerial survey from a fixed-wing aircraft using surveys of a large aggregation of common scoters *Melanitta nigra* in Carmarthen Bay, Wales as a case study:

1. *Aerial visual surveys conducted using line transect sampling:* Line transect sampling is an extension of strip transect sampling in which not all individuals in the strip need be detected. It is assumed that all individuals on the track-line are detected, but the probability of detection is assumed to fall off smoothly from unity as a function of distance from the trackline. This function is termed the detection function. A systematic grid of transects was placed over the study region with 2 km separation between successive lines. The plane flew at 200 km h^{-1} at an altitude of 76 m, and observers were unable to see immediately below the plane. Detected birds were recorded in four perpendicular distance bands: 44–163 m, 163–282 m, 282–426 m, and 426–1000 m.
2. *Aerial digital video surveys conducted using strip transect sampling:* The design comprised a systematic grid of parallel transects with 1 km separation. The plane had four forward-looking cameras (30–45º from vertical) each recording images 50 m in width at an altitude of 609 m; these four strips were separated by gaps in cover, to spread the spatial cover of the survey – the total width of video footprint was 200 m, but spread over a wider strip. As more lines were flown (and so more segments were available for analysis) for the digital video surveys than for the digital stills surveys, it was expected to yield higher precision.
3. *Aerial digital stills surveys conducted using either strip transects or a grid (a systematic sample of plots):* For the strip sampling, a systematic grid of parallel transects was defined with 2 km separation between successive transects and the plane had a vertically-mounted (downward-pointing) camera which recorded images 330 m in width from an altitude of 457 m.

More details on sampling regimes, testing for inter-observer variability and detection factors are provided in Buckland et al. (2012). The precision of each method for surveying common scoters was largely driven by the proportion of the survey region that was surveyed and how the sampling units were spread through the region. There was no ability to undertake ground truthing as part of this survey. The two digital survey methods gave similar abundance results although with large confidence intervals whereas the visual surveys gave much lower abundance estimates (Buckland et al. 2012).

FACTORS RELEVANT TO CENSUS OF GIBSON'S ALBATROSS ON ADAMS ISLAND

- Aerial digital video surveys conducted using strip transect sampling or aerial digital stills surveys conducted using either strip transects or a grid could be applied to censusing Gibson's albatross. However, there may be issues regarding the assumptions of detectability and any assumption of constant density within and between areas containing albatross nests.
- Topography of Adams Island is not uniform like the bay where the scoters were surveyed on the water. Maintaining a constant height above varying terrain, which is essential for maintaining strip width coverage for subsequent analysis of video footage may not be feasible.
- Use of vertically-mounted cameras fixed to the aircraft may possibly reduce, but not completely eliminate, issues with maintaining transect widths over varying terrain.

2.2.4 Aerial census (based from fixed-winged aircraft or helicopter) of 'great albatross' populations

a) Northern royal albatross (*D. sanfordi*) on the Chatham Islands

Aerial photography is the only cost-effective method of monitoring breeding populations of the biannually breeding northern royal albatross on the Forty-Fours and The Sisters, which are small island groups off the main Chatham Island (Scofield 2011). A fixed-wing aircraft was used to circle the islands 3-4 times (height of 500 m) at the lowest speed the pilot was prepared to fly at, with photos taken continuously (Scofield 2011). A digital montage was constructed from overlapping images "stitched" together and albatrosses were counted individually on the computerised montage. As the birds nest in relatively tightly-packed colonies, are mostly white and often nest amongst green vegetation, the aerial census technique worked well. A one-off ground-count in November 2007 showed that aerial and ground counts were broadly comparable and there was neither any significant underestimation due to obscured birds nor overestimate due to counting of non-breeding birds. Four seasons of count data was collected and the estimated total number of breeding pairs ranged from 5,388 to 5,744. It was considered legitimate to compare between years as the counts were thought to be very accurate and at the very least internally consistent due to the consistency of counts all being made by the same observer, at a constant time of day. In addition, using the photographic images, there was the ability to check individual nest sites on subsequent and previous counts (Scofield 2011).

b) Southern royal albatrosses (*D. epomophora*) on Enderby Island

In January 2013 and January 2014, a helicopter based aerial photography census of nesting southern royal albatrosses on Enderby Island was conducted by flying a series of nine transects spaced at 200 m centres running from west to east, and taking a series of overlapping photographs as each transect was traversed (Baker et al. 2014b). Transect start and end points were programmed into the on-board GPS system and the helicopter was flown along each transect at a constant flight height of 600 ft (Baker et al. 2014b). Photographic montages of each transect were constructed from overlapping photographs and counts of all royal albatrosses on each montage were made using standard methods (Arata et al. 2003; Baker et al. 2014b). Each single bird was assumed to represent a breeding pair and, while most birds were alone at nest sites, the instances when two birds were sitting close together (assumed to both be members of a nesting pair) were also recorded. Although corresponding comprehensive ground counts were undertaken, in 2014, the ground counts occurred three weeks after the aerial photography whereas in 2013, the ground counts occurred within a week of the aerial census (Baker and Jensz 2013; Baker et al. 2014b). In 2013, the counts of nesting royal albatross breeding pairs derived from aerial photography were very similar to those resulting from ground searches, whereas in 2014, the estimate of breeding birds based on aerial photography was 21% higher than the estimate derived from ground counts. It was considered important to accurately assess the spatial coverage (transect width) obtained by a particular camera/focal length/flight height combination. Although this could be calculated theoretically using camera and lens specifications for a specified flight height, experience showed that such data were not always accurately stated by gear manufacturers and it was recommended that this be determined by measurement in the field prior to commencing the aerial surveys (Baker et al. 2014b).

c) Gibson's albatross on Disappointment Island

In January 2014, Baker and Jensz (2014) took aerial photographs of the Gibson's albatross colony on Disappointment Island to estimate the number of pairs breeding at that time. Photographers in a helicopter flew in circuits around the island at an altitude of approximately 500 m taking a series of overlapping aerial photos of the entire area of the island plateau. Twelve photographic montages of the upper slopes and plateau habitats of Disappointment Island were constructed from overlapping photographs and counts of all Gibson's albatrosses on each digital montage were made (Baker and Jensz 2014). Stitching of the images and relating photomontages to one another was time-consuming as it was difficult to determine cut-off points along ridgelines when two photomontages depicted the same ridge but from different sides. The authors recommended trialling the use of photographic transects as an alternative method for improving photographic coverage of the albatross breeding habitat on Disappointment Island as this was likely to be easier for photo analysis (Baker and Jensz 2014).

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- Similar issues with using fixed-winged aircraft for undertaking aerial photography when compared with helicopters, as identified under Section 2.2.2.
- Compiling photomontages of the whole population of Gibson's albatross on Adams Island using techniques developed for colonial-breeding species is likely to be difficult as the albatross nests are not tightly colonial, are very spread out and, in addition, nests are often obscured by vegetation and/or topographical features.
- Gibson's albatross on Adams Island are probably less detectable than the northern royal albatross at the Chatham Islands' sites and the southern royal albatrosses at Enderby Island
- Given the spatial extent of the albatross population, it may be more appropriate to use transects to systematically photograph the population.
- Need to develop correction factor based on proportion of birds breeding compared to total number of birds on the ground.
- Consistency in methodology (date of photograph, time of day of photograph, people involved, gear used, flight height and flight path) from year to year is important for monitoring changes in the population i.e. developing an index of abundance for monitoring populations over time

3. Preliminary exploratory aerial census trials of Gibson's albatross population at Adams Island

3.1 Methods

In January 2015, while in the Auckland Islands to photograph white-capped albatross colonies, we used available helicopter time to take photographs of Gibson's albatross colonies as time and weather permitted. The photos were taken as a series of transects designed to provide full photographic coverage of two areas on Adams Island (referred to here as the Northern and Southern Study Blocks, Figure 1, left panel) and Disappointment Island. The photographic methods employed followed those developed by Baker and Jensz (2013) and Baker et al (2014b) although different camera/lens and flight height combinations were used. The aircraft, a single-engined Squirrel AS350B3, was piloted by Mark Deaker (Southern Lakes Helicopters Company). On board was Barry Baker (photographer and project coordinator), Mark Holdsworth (back-up photographer), and Louise Chilvers (Department of Conservation representative).

We flew a series of transects (Table 1) spaced at 200 m centres that ran from either west to east, or east to west, depending on the slope of the ground being photographed. We aimed to be taking oblique photos that were looking up slope and took a series of overlapping photographs as each transect was traversed. Transect start and end points (Table 1) were programmed into the on-board GPS system and the helicopter was flown along each transect at a constant flight height of c.1000 ft above ground level.

For the photography, two photographers were positioned on the port side of the aircraft to permit each to take photographs of the island simultaneously. All photographs were taken through the open port side of the aircraft using a Nikon D800 digital cameras and a fixed focal length Nikkor 50 mm F1.8 lens. Shutter speeds were set at 1/1000 s or faster to minimise camera shake, and the camera held facing downward at an angle of 70 degrees. This ensured the plane of focus was as parallel to the surface as possible without allowing the aircraft landing skid to appear in the camera viewfinder. To assist with spatial resolution of each photo, a Garmin GPSmap 60CSx GPS was connected to one of the cameras, ensuring a latitude and longitude stamp was recorded with the metadata for each photograph. All photographs of the colony were saved as Raw NEF files and subsequently converted to fine JPG format files. The combination of flight height and focal length was derived from an earlier trial of lens/flight height combinations designed to ensure complete ground coverage (adequate overlap between transects) when used with 200 m transects, and analysis of photographs from Enderby Island taken at 700 feet, where overlap was found to be excessive (Baker and Jensz 2013; Baker et al. 2014b). By increasing the height and transect width we hoped to reduce processing and flight time and improve survey efficiency.

Weather conditions at both Disappointment and Adams Islands can vary considerably throughout the day and change rapidly. We aimed to fly when we thought cloud cover would be absent or minimal, and based our assessment on real-time weather reports from field researchers based on Adams Island, and the crew of support vessel *Tiama* which was based in Carnley Harbour. Nonetheless, we were not able to photograph all areas as and when planned because weather conditions changed either while we were in transit from Enderby Island, or during the flights themselves. This meant that we had to abandon runs occasionally, and re-fly these areas later. We were able to complete photographic coverage of the three areas, with photos taken on 18 January 2015 between 1139 and 1626 NZ Summer Time. The entire sets of photographs were subsequently replicated to ensure that complete back-up sets existed both on portable hard drives and in at least three different locations. A full collection of photographs has been submitted to the Department of Conservation, and an archival set of photos has also been retained by Latitude 42.

Only photos from the Southern Study Block on Adams Island (Figure 1, left panel) were analysed. Using the image editing software package ADOBE PHOTOSHOP (http://www.adobe.com/) we produced a series of overlapping images for each transect that covered the entire length of the transect. Counts of all Gibson's albatrosses on each montage were then made by first quickly assessing each image to identify likely birds (marked with an open circle or square), and then magnifying the image to view birds and using the paintbrush tool in PHOTOSHOP to mark each bird with a small coloured circle as they were counted (Figure 1, right panel). Yellow was used to denote birds that could be clearly identified, and blue used to identify white objects on the ground that we were initially unsure were birds (Figure 1, right panel).

Each single bird was assumed to represent a breeding pair. While most birds were alone at nest sites, we also counted instances when two birds were sitting close together and assumed to both be members of a nesting pair. In this situation, both birds were counted, and the number of pairs recorded. The number of pairs was subsequently deducted from the total number of birds to derive an estimate of annual breeding pairs.

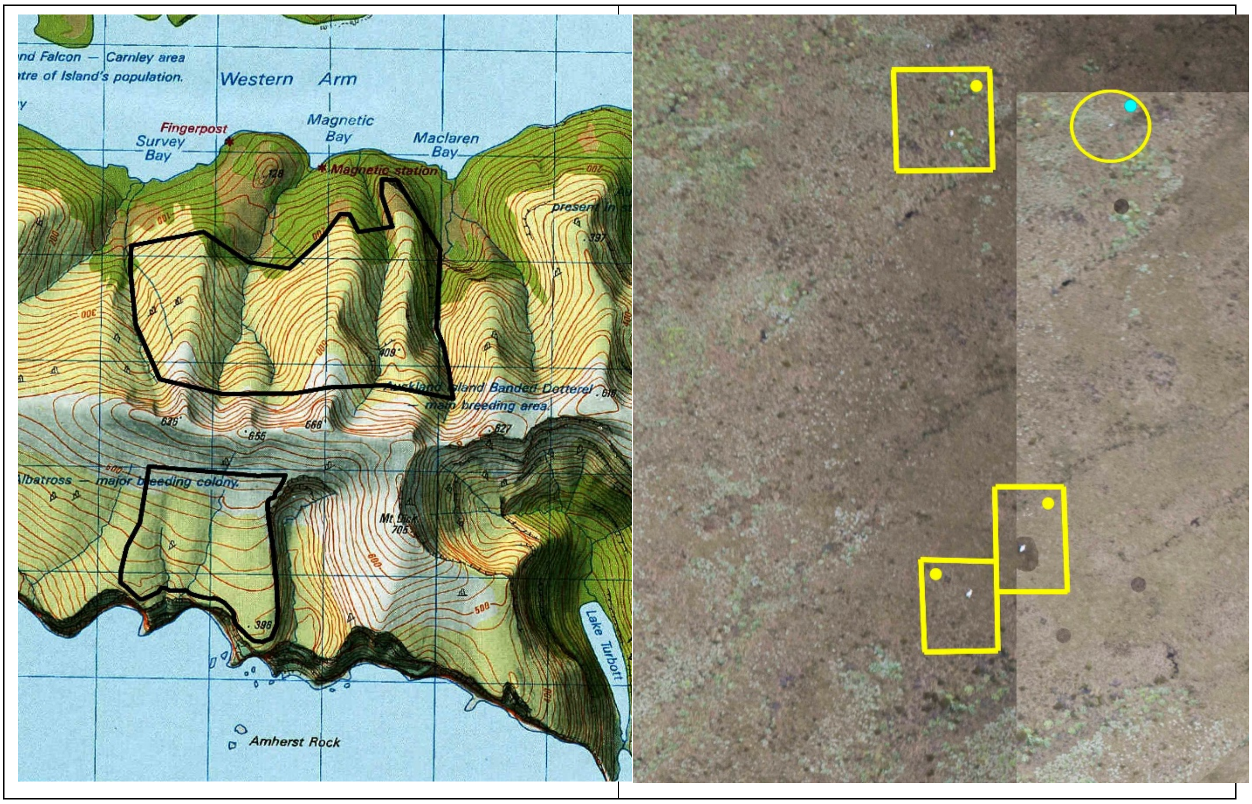

Figure 1. Left panel –Northern and Southern areas on Adams Island which were overflown and photographed in January 2015. Only photos from the Southern block, which encompasses the study site used for fine-scale demographic studies undertaken by Walker and Elliott (1999) were analysed as part of this current study. **Right panel** – section of a transect photo montage showing the convention used to identify Gibson's albatrosses. Yellow dot – nesting bird, blue dot – potential birds. The larger squares and circles were used in initial assessment of photos to identify on-ground objects likely to be birds and requiring closer inspection.

Table 1. Details of photo transects flown in January 2015 at Gibson's wandering albatross colonies in the Auckland Islands. Units of latitude and longitude are shown as degrees and decimal minutes.

Transect	WP #	Latitude		Longitude Western boundary	WP #	Latitude		Longitude Eastern boundary
Adams Is Northern Block (WPs numbered for flying East to West, North to South)								
1-2	2	50	52.000	165 59.000	1	50	52.000	166 02.000
3-4	4	50	52.108	165 59.000	3	50	52.108	166 02.000
5-6	6	50	52.216	165 59.000	5	50	52.216	166 02.000
7-8	8	50	52.324	165 59.000	7	50	52.324	166 02.000
9-10	10	50	52.432	165 59.000	9	50	52.432	166 02.000
11-12	12	50	52.540	165 59.000	11	50	52.540	166 02.000
13-14	14	50	52.648	165 59.000	13	50	52.648	166 02.000
15-16	16	50	52.756	165 59.000	15	50	52.756	166 02.000
17-18	18	50	52.864	165 59.000	17	50	52.864	166 02.000
19-20	20	50	52.972	165 59.000	19	50	52.972	166 02.000
21-22	22	50	53.080	165 59.000	21	50	53.080	166 02.000
23-24	24	50	53.188	165 59.000	23	50	53.188	166 02.000
25-26	26	50	53.296	165 59.000	25	50	53.296	166 02.000
Adams Is Southern (Study) Block (WPs numbered for flying West to East, South to North)								
27-28	27	50	54.500	165 59.000	28	50	54.500	166 01.000
29-30	29	50	54.392	165 59.000	30	50	54.392	166 01.000
31-32	31	50	54.284	165 59.000	32	50	54.284	166 01.000
33-34	33	50	54.176	165 59.000	34	50	54.176	166 01.000
35-36	35	50	54.068	165 59.000	36	50	54.068	166 01.000
37-38	37	50	53.960	165 59.000	38	50	53.960	166 01.000
39-40	39	50	53.852	165 59.000	40	50	53.852	166 01.000
41-42	41	50	53.744	165 59.000	42	50	53.744	166 01.000
43-44	43	50	53.636	165 59.000	44	50	53.636	166 01.000
45-46	45	50	53.528	165 59.000	46	50	53.528	166 01.000
47-48	47	50	53.420	165 59.000	48	50	53.420	166 01.000
Disappointment Is								
49-50	49	50	37.000	165 57.000	50	50	37.000	166 00.000
51-52	51	50	36.892	165 57.000	52	50	36.892	166 00.000
53-54	53	50	36.784	165 57.000	54	50	36.784	166 00.000
55-56	55	50	36.676	165 57.000	56	50	36.676	166 00.000
57-58	57	50	36.568	165 57.000	58	50	36.568	166 00.000
59-60	59	50	36.460	165 57.000	60	50	36.460	166 00.000
61-62	61	50	36.352	165 57.000	62	50	36.352	166 00.000
63-64	63	50	36.244	165 57.000	64	50	36.244	166 00.000
65-66	65	50	36.136	165 57.000	66	50	36.136	166 00.000
67-68	67	50	36.028	165 57.000	68	50	36.028	166 00.000
69-70	69	50	35.920	165 57.000	70	50	35.920	166 00.000

The transect montages were assessed by G. Elliott and K. Walker, who roughly geo-referenced these photos by lining them up with features visible on satellite images of Adams Island, and then comparing the albatrosses identified in our initial assessment with the nests found in the same area when a detailed census was undertaken on 25-27/1/2015, some 7-9 days after the aerial photos were taken.

The satellite image of the Auckland Islands had a resolution of 0.5m, i.e. each pixel is 0.5m x 0.5m and is roughly geo-referenced. G. Elliott and K. Walker corrected the geo-referencing of this image by lining up the streams and coastline in the image with those on the Auckland Islands topo-map using the geo-referencing tools in Arcmap 10.2. They then roughly geo-referenced the photo montage images by lining up features recognisable on both the photos and the satellite image. (Figure 2). All the nests found in the area during the census and study area work were then overlaid on the image. Note that this was based on the on-ground situation known 7-9 days after the time of the aerial survey. The number of birds Identified in the aerial photos were then compared with the number of nests located on ground and in eight rectangular areas within the study area and census block that had been photographed (Figure 2).

3.2 Results

The camera/lens/flight height combination did not lead to transects that completely overlapped, and thus provide complete coverage of all areas overflown. We estimated that we achieved only about 80-85% coverage of the Southern Study area, and this can perhaps best be assessed when the transect photo-montages are overlaid on satellite images of Adams Island (Figure 2).

The resolution of the photos was also insufficient to permit all birds to be easily detected on the images. In our initial assessment we counted a total of 590 birds ashore on the transects, of which 16 appeared to be the partners of other nesting birds. We therefore estimate that there were 574 potential annual breeding pairs in the area we photographed, which exceeds the demographic study site area used by Walker and Elliott (1999). We also counted a further 43 white objects located on our photomontages which we could not confidently determine as being birds (Table 2).

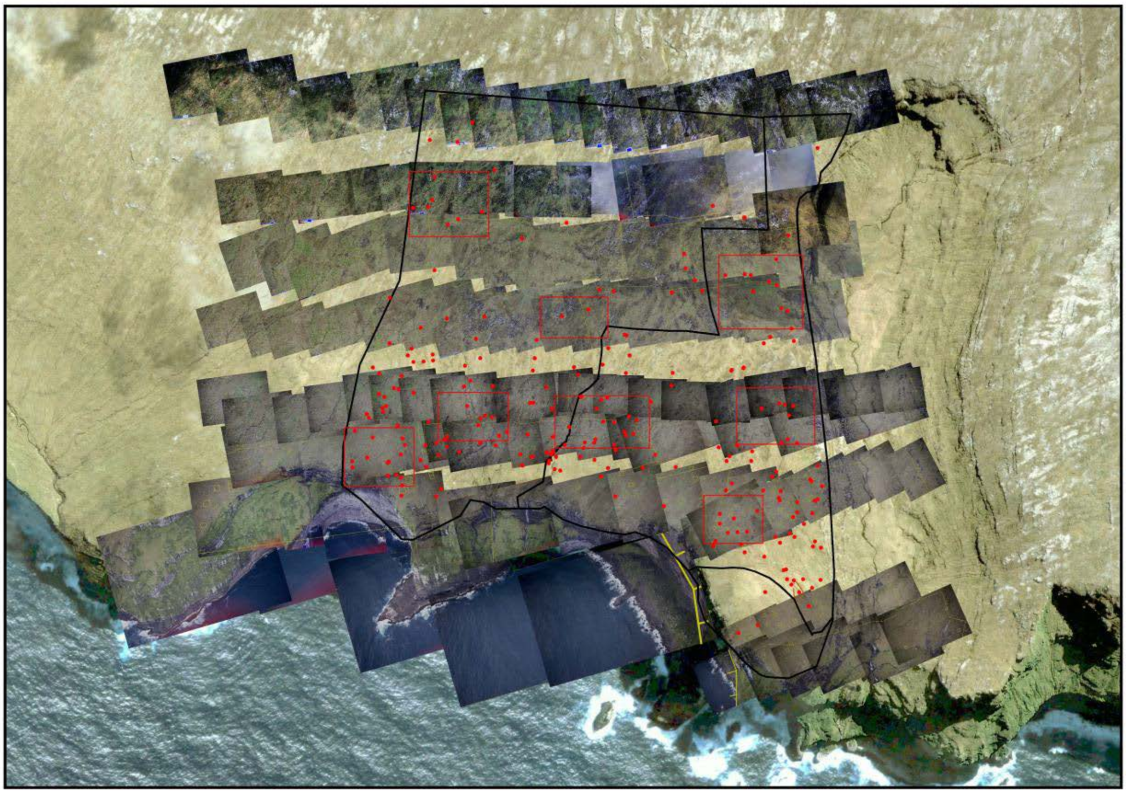

Figure 2. Courtesy of Graeme Elliott and Kath Walker. Census block and study area on Adams Island in the Auckland Islands group, showing aerial photo coverage and eight rectangles in which the number of birds in the aerial photos was compared with the number of nests counted and mapped in the census. The black line marks the edge of the albatross study area (on the right) and Amherst to Astrolabe census block (on the left) and the red dots indicate the position of each bird on an egg.

Table 2. Counts of Gibson's wandering albatross in the Southern area on Adams Island which was overflown and photographed on 18 January 2015, showing the total number of birds and their partners detected. Also shown is a number of potential birds for which identification could not be confirmed due to insufficient image resolution.

Transect	Stitched image	Total birds	Pairs	On nest	Possible birds
T27-28	a	0	0	0	0
	b	4	0	4	0
	c	3	0	3	0
T29-30	a	0	0	0	0
	b	16	0	16	1
	c	0	0	0	1
T31-32	a	12	0	12	3
	b	12	1	11	1
	c	37	0	37	2
	d	0	0	0	0
T33-34	a	41	1	40	7
	b	56	1	55	5
	c	28	1	27	5
T35-36	a	56	0	56	3
	b	42	1	41	2
	c	16	0	16	2
	d	9	0	9	0
	e	0	0	0	0
T37-38	a	52	5	47	0
	b	21	1	20	0
	c	27	0	27	1
T39-40	a	58	1	57	0
	b	16	1	15	1
	c	17	0	17	2
T41-42	a	37	2	35	0
	b	11	0	11	1
	c	3	0	3	2
T43-44	a	12	1	11	1
	b	3	0	3	1
	c	1	0	1	2
T45-46	a	0	0	0	0
	b	0	0	0	0
	c	0	0	0	0
T47-48	a	0	0	0	0
	b	0	0	0	0
	c	0	0	0	0
Total		**590**	**16**	**574**	**43**

Since the aerial photographs did not cover the whole of demographic study area or census block there can be no estimate from the photos of the number of birds in the study area or census block. When comparing the aerial photo counts with the number of nests located on ground and in eight rectangular areas, the number of birds identified in the aerial photographs was much greater than the number of nesting birds, and the ratio between the number of birds in photos and the number of nests varied considerably. In summary, where 130 birds were identified on the aerial photos, only 77 pairs were known to be subsequently nesting at the time of the on ground census undertaken 7-9 days later (ratio aerial count:nests 1.67).

3.3 Discussion

The aerial photographs were taken when only about 89% of the eggs had been laid (G. Elliott and K. Walker pers. comm.) and therefore this series of photos does not provide a good assessment of the ratio between the number of birds identifiable from the air and the number of nests. In previous work on other species (Baker et al 2014a, 2014c) we have attempted to distinguish between nesting and non-nesting birds in a series of close-up photographs (while noting that the best information about the ratio between birds seen and birds nesting will always come from ground counts taken close to the time of an aerial survey). The albatrosses counted in our photographs from this study over estimated the number of nests by 68% but there was considerable variation between areas (G. Elliott and K. Walker pers. comm.). This would have been reduced if the photo quality had been better, as in our work on southern royal albatrosses (Baker et al 2014b) we were able to detect to a greater degree if birds were associated with nests or clearly loafing and not sitting on nests.

It was clear upon stitching the photo transects that overlap between transects had not been fully achieved. As helicopter hire rates are expensive, we had sought to reduce flying time by using 200 m transects, but this did not produce photos that were fit for purpose. If carrying out this work again we would vertically-mount our camera in a pod underneath the aircraft, and trial the following lens/flight height combinations using Nikon D800 or D810 36 mp cameras:

- 500, 600 and 700 ft flying height above ground level
- 50 mm, 60 mm, 70 mm lens
- 100 m and 150 m transects.

Vertically mounting the camera would improve resolution and precision of transect coverage because it removes parallax and camera-operator error. If existing pods are available, they could be set up for this purpose at minimal cost. We would propose to trial the lens/flight height combinations suggested above before conducting future trials at Adams Island. This set-up would also permit photos to be geo-referenced.

Resolution of aerial photographic methods is a critical factor to consider, but it is important to consider how this is defined. Resolution is the camera's ability to classify and effectively present discrete image information, such as details, patterns and textures within a given photographic image. It corresponds to how large a photo can become without becoming unacceptably blurry or grainy. Resolution is a function of lens magnification, distance from the object being photographed, and the ability of the camera to record detail. The 36.3 megapixel cameras we use far exceed the resolving ability of many cameras routinely used for aerial photography to date (usually 24 mp). The Rule of Thumb here is the greater the number of pixels in an image, the denser the picture information and therefore the higher the resolution. The 'low resolution' photo mosaics (Walker and Elliott 2015) used for counting white-capped albatrosses are fit for the purpose intended, but the same camera used with a longer lens produces high resolution 'close-up' photos used to determine the proportions of loafers and breeding birds in colonies (Baker et al 2014a).

The photos taken on Adams Island in January 2015 were geo-referenced with GPS equipment. This has been routinely done with all our photographic work in the Auckland Islands over the last 10 years.

4. Recommendations for future work

Accurate estimation of population size is critical for determining conservation status, and for identifying the key factors influencing changes in population size and demography of albatrosses. While a ground count of all of Adams Island has been undertaken previously, access to much of the island is difficult on foot, and habitat is likely to more comprehensively counted from the air (Walker and Elliott 2015). Adams Island is also a restricted access site. For these reasons it is recommended that if the population size of Gibson's albatross is to be re-estimated, a mix of on-ground and aerial techniques would be appropriate.

Based on the literature review and our preliminary field work on Adams and Disappointment Island, we recommend the following approach for conducting aerial photographic surveys of Gibson's wandering albatross.

1. Helicopters are the only feasible aerial platform available at this stage. The remoteness of the site, lack of an airport within the Auckland Islands and frequently changing weather conditions over Adams Island precludes the efficient use of fixed wing aircraft for this purpose.
2. The type of photography undertaken should be fit for purpose. Production of ortho-rectified and corrected photomaps is excessive for the purpose of counting seabirds and we were unable to find examples of where this technique has been employed for this purpose. Production of ortho-rectified photomaps will require extensive field time and exceptional weather in the Auckland Islands to generate such a product.
3. Use of standard digital photography has been used to estimate great albatross population estimates previously but techniques need to be refined for use on Adams and Disappointment Islands. The use of a series of transects to provide spatial coverage of target areas is recommended Photography should be undertaken using a digital camera vertically-mounted in a pod underneath the aircraft, and trials undertaken to determine appropriate lens/flight height and transect width combinations that will provide photographs fit for purpose. All photographs taken should be geo-referenced using suitable GPS equipment.
4. Auto-stitching of photographs is unlikely to be fully effective. Auto-stitching software essentially performs a smoothing function designed to produce aesthetic rather than strictly accurate results, and is effective when managing larger objects and distinctive features rather than small objects like albatrosses. It may be possible to stitch high definition photos of Gibson's albatross but we feel the photo-resolution necessary would involve excessive flying time to achieve a satisfactory result. If this is to be pursued it will need to be tested and refined. However, we would advocate manual stitching and overlaying stitched images on satellite photos using GIS software. Manual stitching, particularly along transects is relatively easily performed and assessing overlap between transects should also be simplified if vertically-mounted cameras are used.
5. Photography needs to be supported by ground-truthing to develop meaningful correction factors that account for loafers/non breeders in colonies. Maintaining and potentially expanding the existing Amherst – Astrolabe census block, as suggested by Walker and Elliott (2015) is recommended for this purpose.
6. Ideally, aerial surveys should not be conducted until egg laying is complete (c 25 January), although logistical constraints may mean there is a need for some flexibility around this date.
7. The ever-changing nature of the weather on Adams Island is such that it may not be possible to fly all areas targeted for aerial survey in one breeding season, particularly if the project is to rely on the presence of a helicopter in the Auckland Islands for other work e.g. sea lion research. We recommend a survey schedule is drawn up that would plan to have all the island surveyed over three or four years, with flexibility built in so that advantage can be taken of good weather conditions when they arise.

Acknowledgements

This project was funded by the Department of Conservation's Conservation Services Programme. Southern Lakes Helicopters and Mark Deaker provided an excellent photographic platform for the study. The support of Igor Debski and Kris Ramm of the Department of Conservation (DOC) Wellington during the course of the project was appreciated, as was the invaluable logistic support provided by Mark Holdsworth and Louise Chilvers. Thanks to Kath Walker and Graeme Elliott for providing mapping of their study site, contributing to the analysis of aerial photographs, and useful discussions during the course of this review. We also appreciate the efforts of their on-ground research assistants Peter Moore and Moira Pryde, and Henk Haazen and crew of *RV Tiama*, for providing real-time weather reports for Adams Island around the time of our visit to the Auckland Islands.

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