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Comparison of census methods for black-browed albatrosses breeding at the Ildefonso Archipelago, Chile

Graham Robertson · Carlos A. Moreno · Kieran Lawton · Roger Kirkwood · José Valencia

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Abstract A breeding population of black-browed albatrosses has been known to exist at the Ildefonso Archipelago, Chile, for >90 years but the population has never been censused using scientifically defendable methods. To estimate population size, and examine the accuracy and practicality of various census methods, the population was censused in the 2002/2003 breeding season using (a) ground-truthed aerial photography, (b) yacht-based photography, (c) ground counts, (d) quadrat sampling and (e) point-distance sampling. Compared to ground-truthed aerial photography (judged the most accurate) yacht-based photography underestimated population size by 55%, ground counts by 13%, quadrat sampling by 11% and point-distance sampling by 9%. Ground-truthed air photography revealed that in the 2002/2003 breeding season 47,000 pairs of black-browed albatrosses bred at the Ildefonso Archipelago. A repeat aerial census in 2006 suggested the size of the breeding population had not changed in the 4 years between the two censuses. After the Falkland Islands/Islas Malvinas, South Georgia and Diego Ramirez, the Ildefonso Archipelago holds the fourth largest population of black-browed albatrosses in the world.

G. Robertson (✉) · K. Lawton
Australian Antarctic Division, Channel Highway,
Kingston, TAS 7050, Australia
e-mail: graham.robertson@aad.gov.au

C. A. Moreno
Instituto de Ecología y Evolución, Casilla 567,
Universidad Austral de Chile, Valdivia, Chile

R. Kirkwood
Phillip Island Nature Park, PO Box 97,
Cowes, VIC 3922, Australia

J. Valencia
Instituto Antárctico Chileno,
Plaza Muñoz Gamero 1055, Punta Arenas, Chile

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Introduction

Albatrosses and petrels have been counted at their breeding locations in the Southern Ocean since the early part of the twentieth century (e.g., Murphy 1936). Early population assessments were often made in the ethos of exploration and discovery, to acquire knowledge of the components and workings of the natural world. The imperatives of modern times require a more focused approach. Seabird population estimates are usually made to build food consumption and trophic pathway models for fisheries management purposes (e.g., Croxall et al. 1984; de Brooke 2004; Hill et al. 2006) and because of concerns about conservation status. With respect to the latter, threats to populations mainly pertain to the albatrosses and petrels which are especially vulnerable to mortality in longline (Robertson and Gales 1998; Delord et al. 2005) and trawl (González-Zevallos and Yorio 2006; Sullivan et al. 2006) fisheries, which have lead to population decreases at many breeding locations in the past two–three decades (Gales 1998; Poncet et al. 2006).

One species of seabird that has decreased markedly is the black-browed albatross *Thalassarche melanophrys*, an Endangered species according to IUCN criteria (BirdLife International 2004). Most of the world's black-browed albatrosses breed at the Falkland Islands, South Georgia and Chile (Brooke 2004). Populations at the Falkland

Islands (Huin 2001) and South Georgia (Croxall et al. 1998) have been censused for many years but those in Chile have rarely been censused using scientifically reliable methods. In this study we determined the population size of black-browed albatrosses at the Ildefonso Archipelago, Chile. We compared the accuracy and practicality of several census methods to determine the method most suitable for Ildefonso, a group of islands that is difficult to land and work on. Assessment of accuracy also provided a measure of the accuracy of previous attempts to census albatrosses at Ildefonso. The census methods compared were (a) ground-truthed aerial photography, (b) yacht-based photography, (c) ground counts, and the area-based methods (d) quadrat sampling and (e) point-distance sampling.

Materials and methods

Ildefonso

The Ildefonso Archipelago (55°48′S; 69°24′W) is a chain of six rock stacks lying 111 km west of Cape Horn (55°59′S; 67°16′W) and 93 km north of the Diego Ramirez Archipelago (56°31′S; 68°43′W) off the southern coast of Chile (Fig. 1). The Archipelago is broken into northern and southern groups, the northern group comprising five stacks and the southern group comprising a single stack. The southern-most stack—hereafter called Isla Grande—is the largest in the group, being 1.6 km long, 150–400 m wide, up to 143 m high and 20 ha in area (Fig. 2). It comprises about 60% of the total land area of the archipelago and holds the largest population of albatrosses. The north-east face of Isla Grande is near-vertical and the north-western face slopes sharply to the sea. The islets are ravaged by wind and sea spray and soil on most of Isla Grande is shallow and laden with salt. In the seabird-breeding season virtually all surfaces of Isla Grande above the wave zone are inhabited by seabirds. Seabirds nest in ‘pavement’ and tussock slope habitats (Fig. 3). Pavements are areas of bare rock with virtually no soil and tussock slopes are vegetated with open stands of tussock grass *Poa flabellata*. In addition to large numbers of black-browed albatrosses, in the 2002/2003 breeding season the archipelago held about 86,000 pairs of rockhhopper penguins *Eudyptes chrysocome*, 5,600 pairs of macaroni penguins *E. chrysolophus* (Kirkwood et al. 2007) and several hundred blue-eyed cormorants *Phalacrocorax* sp.

The census involved estimating the number of nesting pairs that had laid and egg. The black-browed albatross population at the entire Archipelago was censused from the air and the sea but the comparison of the ground-based methods was conducted at Isla Grande only (Table 1). Three people were deployed on Isla Grande from 24 October to 1 November to conduct the ground-based censuses and ground truth the air photographs. Activities on the ground also involved monitoring the attendance patterns of

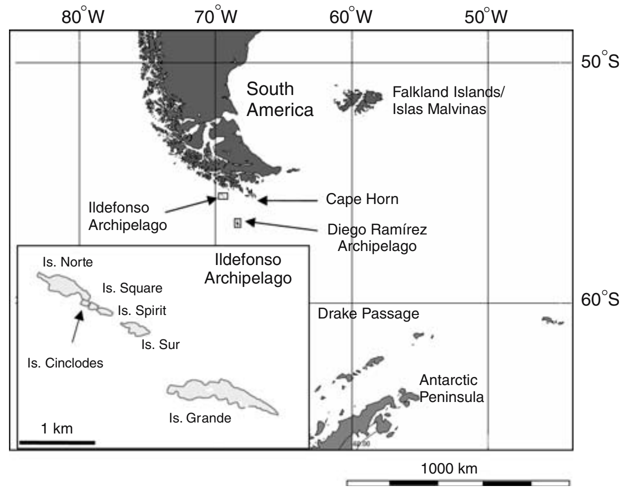

Fig. 1 Map showing the location of the Ildefonso Archipelago in relation to Cape Horn and the Diego Ramirez Archipelago

Fig. 2 Aerial photograph of the Ildefonso Archipelago showing the sizes and shapes of southern (Isla Grande, foreground) and northern groups of islets

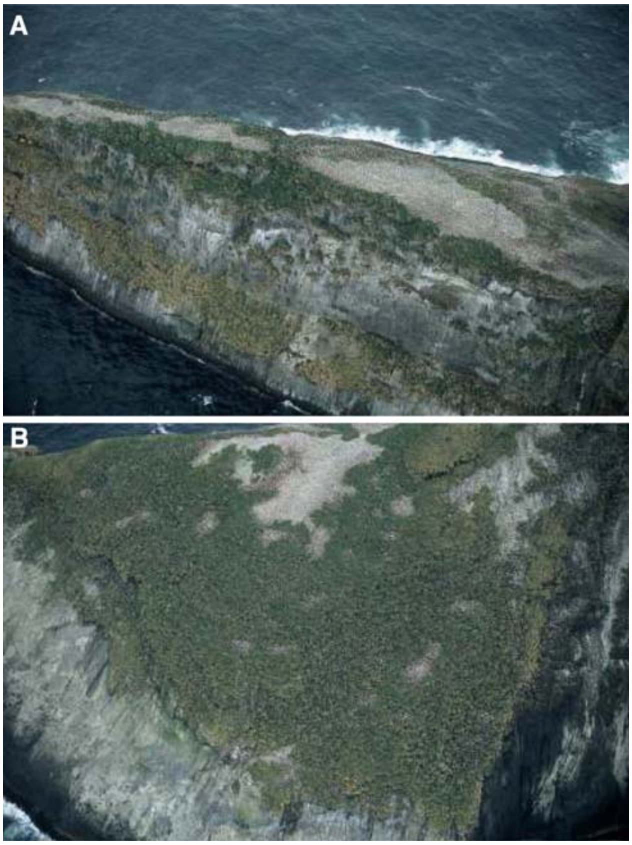

Fig. 3 Aerial photographs of **a** pavement and **b** tussock slopes habitat (with some pavement) at Isla Grande, Ildefonso, showing nesting black-browed albatrosses

albatrosses to determine the preferred time-of-day for the aerial census (see below).

Aerial census

Photography and counting

Ildefonso was photographed from a twin otter aircraft from an altitude of 200 m on 26 October 2002. Flying speed was minimised to facilitate the photography and was 90 knots upwind and 140 knots downwind. During the overflights air and ground parties maintained radio contact so flights could be modified or suspended if birds showed signs of disturbance. The photographs were taken from 1400 to 1500 h local time, which included the period of the day (late morning to mid afternoon) when the ratio of nesting birds to total birds was highest (see below). The photographs were taken through an open cockpit window with a hand-held 35 mm camera, 70–200 mm vibration reduction lens and ISO 100 transparency film. Every effort was made to ensure the photographs were taken from an angle perpendicular to the land surface. To aid in the later construction of collages of images in the computer the focal length of the lens was kept constant. A total of eight circuits was made of the islets to produce a complete series of overlapping images which were used to compile a montage of all surfaces of the islands occupied by albatrosses.

Following digitisation of the images a montage of the complete island group was constructed from overlapping images "stitched" together using the image program Adobe Photoshop®. Albatrosses were counted individually on the montage displayed on the computer screen in Photoshop. To gain a measure of the repeatability of the counts and difference between counters, the number of albatrosses in a well-defined area on the southern end of Isla Grande (with habitat typical of the remainder) was counted twice by each of two observers (this area was also used to assess the accuracy of ground counts). 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 (stitched together to form 10 images) were compared to the number counted near the centre of photographs taken on subsequent overpasses. The proportion of montages of albatross habitat falling on the stitch lines was estimated using the grid tool in Photoshop.

On 4 October 2006 the aerial photography was repeated, but only at Ilsa Grande, to gain a measure of population change in the 4 years since the estimate in 2002. The photography was conducted from the same aircraft, same altitude, similar time-of-day (1400–1430 h local time) and used the same photographer, counter and computer processing methods as in 2002. In 2006 the photographic gear included the same lens as in 2002 and a 10 Mp digital camera. The results of the 2006 census are given in "Appendix 2".

Table 1 Summary of areas, habitat types and methods used (indicated by 'x') to census black-browed albatrosses at the Ildefonso Archipelago

Location and habitat	Census method				
	Air photo.	Yacht photo.	Ground counts	Quadrat × area[a]	Point-distance × area[a]
Entire archipelago	x	x			
Isla Grande					
Tussock slopes, all				x	x
Pavement, all				x	
Sub area; both habitats			x		

[a] Excludes the 1,715 nesting birds counted from air photographs on the inaccessible northeast face

Ground truthing

To simplify the counting process ground truthing was conducted to identify the time of day when the ratio of nesting birds to total birds was highest. Photographs taken during this period of the day should maximise the number of birds sitting on nests and minimise the number 'loafing' in the colony or sitting beside incubating partner birds. To identify this optimum time period the ratio of nesting-to-total birds in five study sites, each of 100 birds, was recorded daily at 2-h intervals from 0800 to 1600 h from 24 October to 1 November.

Ground truthing also involved quantifying at the same time as the aerial photography the proportion of albatrosses not on nests (as described above) and the proportion of birds sitting on nests that did not contain an egg. Knowing these proportions permitted the number of albatrosses counted from the air photographs to be corrected downwards to produce a more accurate estimate of the number of breeding pairs. Estimates were made immediately before and after the aircraft overflights and the values averaged. To determine the proportions of birds loafing in the colony or partnering birds on nests, the behaviour of 100 albatrosses at each of the five study sites was assessed. To determine the proportion of occupied nests with and without an egg, a total of 923 occupied nests was examined along 17 transects and the presence/absence of an egg, and egg shells, noted. The transects were distributed at random along the southern two-thirds of the islet. Transects started at the edge of a group of birds and ended when a preselected landmark was reached (usually a rock or tussock). The chest of each nesting albatross encountered on transect lines was gently raised and the presence/absence of an egg noted.

Disturbance

To determine if the albatrosses were disturbed by the aircraft overflights, counts in the five sites mentioned above were compared before and after the overpasses. Birds were also observed on the ground for visible signs of disturbance during the overflights.

Yacht-based photography

A complete photographic record of the archipelago was made in a series of 80 overlapping photographs taken from 100 to 150 m offshore from the S/V 'Spirit of Sydney' when the vessel circumnavigated the archipelago from 1300 to 1700 h on 24 October 2002. Ocean conditions during the circumnavigation were calm and the wind was <10 knots. The photographic gear, image processing and computer count methods were the same as for the aerial census.

Ground counts

The accuracy of ground counts was determined in a 2–3 ha area comprising several thousand nesting albatrosses on the southern end of Isla Grande. The area was flanked on all sides by well-defined landmarks and included three areas of pavement habitat with high-density albatross nests and an area of open tussock with low-density albatross nests mixed with rockhopper penguin nests. Albatrosses on nests in pavement and tussock areas were counted separately using hand-held talliers while traversing the area on foot. Two counters were used and each person counted the area three times to gain a measure of differences within and between counters.

Quadrat sampling $\times$ area

Quadrat sampling involved counting the number of nests in 10×10 m quadrats distributed along the island, determining the mean density in each habitat type and multiplying up to the total area. All surfaces of Isla Grande were sampled except the sheer north-east face. Different methods were used to count birds in pavement areas (higher density nest distribution) and tussock slopes (lower density nest distribution) habitats. In pavement habitats nest density was estimated in 17 quadrats located about 50 m apart along the axis of the islet. The location point of each quadrat was selected by walking 30 paces into the pavement area in a direction perpendicular to its boundary. At the location point two 10-m tape measures were pegged out at right angles to form the two boundaries of the quadrat with the location point being at the apex of the boundaries. The locations of the remaining two boundaries were estimated by eye using the taped boundaries as a guide. The number of birds in quadrats was counted twice by each of two people.

In the tussock slope habitat nest density was determined by counting nests in 27 10×10 m quadrats distributed along the islet at about 100 m intervals. Quadrats were marked out using the 10 m tape measure and nests counted as described above. The number of albatross nests was counted twice by each of two people.

The total area occupied by albatrosses in each habitat type was estimated by walking around the perimeter of the entire nesting area and recording location and elevation data with a hand-held GPS. Co-ordinates for the perimeter were plotted using ArcGis software (ESRI, Redlands, USA) and a three-dimensional (3D) version of the total nesting area calculated. Information on slope was included in the analysis using a network of 3D polygons between GPS points on a Lambert Azimuthal projection. The proportion of pavement to tussock slope habitats was estimated by overlaying a fine scale grid on the aerial photographs in

Adobe Photoshop. The scale used resulted in small and large areas of habitat (both types) being divided into about 50 grid squares and about 100 grid squares, respectively. The proportion of each habitat type was calculated by counting the number of grid squares covered by each habitat type. Squares that included both habitat types were considered to be the habitat that dominated the square. These proportions were then used to estimate the proportion of each habitat type in the total nesting area.

Point-distance sampling × area

The point-distance method involves measuring distances from defined points to nesting birds that fall within line-of-sight only (birds not observed are ignored) and analysis using purpose-built software. Point-distance sampling was used to estimate the density of albatross nests only in the tussock habitat because in pavement habitats all nesting birds could be seen and counted. Point-distance sampling was used rather than line-distance sampling (see Bibby et al. 1992; Buckland et al. 1993) to minimize disturbance to nesting birds. The former method involves estimating distances from a fixed point, whereas the latter method requires that observers move along a transect line to estimate distances. Point-distance sampling was applied at the same time as the quadrat sampling following the method of Buckland et al. (1993). At the location points in each of the 27 quadrats, and using the tape measure as a guide, distances to albatross nests out to 20 m were estimated to the nearest 1 m in a 360° area around the location points. Data were later truncated at 11 m distance according to the requirements of the goodness-of-fit models (see below).

Nest density was estimated using the program DISTANCE 4.0 (Laake et al. 1994). This program offers a range of models that describe the data and uses the model projection to estimate the number of nests not detected. The program also assesses how well each model describes the data. Goodness-of-fit of each model was examined using Akaike's Information Criterion (AIC; Burnham and Anderson 1998) and the model with the lowest AIC value chosen to estimate nest density.

Results

Preferred time for air photography

During the period 25 October–1 November 2002, the 2-hourly checks for the ratio of nesting birds-to-total birds revealed a significant interaction between 'day' and 'hour' (ANOVA: $F_{42,279} = 1.5$; $P = 0.035$), suggesting that the ratios for any given hour differed among days (Fig. 4). In general the ratios were highest from 1 h before solar noon

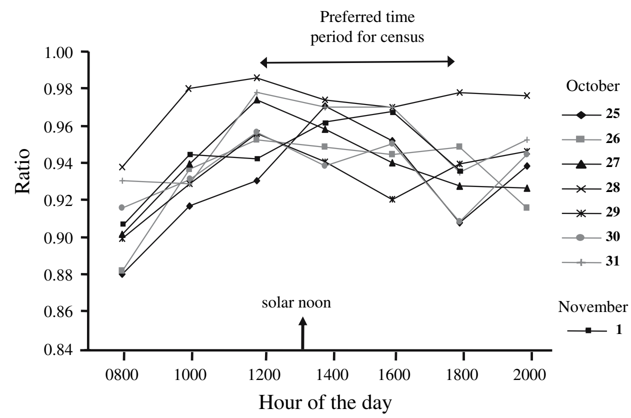

Fig. 4 Preferred time-of-day (highest proportion of birds on nests) for aerial censusing of black-browed albatrosses at the Ildefonso Archipelago in the period 25 October–1 November 2002. Air photography for the census was conducted at 1500 h on 26 October

(mean: 0.96; 1300 h local time) up until about 3 h after solar noon (mean: 0.95); this was the preferred time period in which to conduct the air census. Over all days and hours sampled the ratio averaged 0.94 ± 0.03.

Air photography

Stitching error

The number of albatrosses counted within 50 m of the joins of the 20 stitched photographs ranged from 2 to 144 compared to 2–147 in the ten separate (unstitched) images of the same areas. Overall, 1.3% of birds were "lost" on stitch lines. Given that the total area of albatross habitat affected by stitching was only 5.9%, the overall effect of parallax and stitching was minor.

Variation within-and-between counters

The duplicate counts of the number of nesting birds on the southern end of Isla Grande were 4,529 and 4,589 by one counter and 4,489 and 4,507 by the other. Within-counter coefficients of variation (SD ÷ mean) were 0.95 and 0.28%, respectively. The mean values for both counters differed by only 1.3%, so the scores for both counters were averaged, which gave a total of 4,528 nesting albatrosses in the area examined. The variation between counters was mostly due to imperfect image resolution of a small number of birds on the montages, which meant positive species identification was not possible.

Disturbance

In the five nesting groups each of 100 albatrosses examined for signs of disturbance, immediately before the flights all but 21 were sitting on nests. Immediately after the overflights 29 of the 500 birds counted were not sitting on nests. During the flights, the birds were watched intently by two people and no bird was observed to leave its nest or show other signs of disturbance, such as neck craning or sitting upright on nests. The slight increase in the number of 'unattached' birds after the flights is considered to be consistent with the normal movements of unattached birds in the colony and not considered to be the result of the aircraft overflights.

Air census and ground truthing

Ground truthing conducted at the same time as the air photographs were taken revealed that the proportion of birds in the colony on a nest averaged 0.95 ± 0.02 (SD), suggesting that for each bird on a nest there was, on average, 0.05 (5%) of birds not on a nest. Of the nests with albatrosses sitting on them, on average 0.93 ± 0.03 contained an egg, revealing that for every occupied nest with an egg there were 0.07 (7%) occupied nests without an egg. Multiplying these two sources of error, the difference between the total number of albatrosses counted on the photographs and the number of nests estimated to contain an egg was about 12%.

The results of the aerial photographic counts are shown in Table 2. The first correction column shows the number of birds estimated to be sitting on nests during the census. The second correction column shows the number of occupied nests with an egg.

Since well-formed nests in healthy black-browed albatross colonies are usually occupied immediately after egg laying (the census was conducted about 3 weeks after the commencement of egg laying), the number in the first correction column is most likely to be indicative of the size of the breeding population (occupied nests that did not have eggs had likely already failed). Hence in the 2002/2003 breeding season there were an estimated 47,000 pairs of black-browed albatrosses breeding at the Ildefonso Archipelago. Of these Isla Grande and Isla Norte held 62 and 22%, respectively.

Table 2 Total number of black-browed albatrosses counted on air photographs (total count), sitting on nests (first correction) and sitting on nests with an egg (second correction) at the Ildefonso Archipelago on 26 October 2002

Group/islet	Estimates		
	Total count	First correction[a]	Second correction[b]
Northern group			
Isla Norte	10,920	10,374	9,648
Isla Cinclodes	775	736	685
Isla Square	488	464	431
Isla Spirit	1,383	1,314	1,222
Isla Sur	5,222	4,961	4,614
Southern group			
Isla Grande	30,680	29,146	27,106
Total for Ildefonso	49,468	46,995	43,706

[a] Total count × 0.95 (=number of occupied nests; see text)

[b] Number of occupied nests × 0.93 (=number of nests with an egg; see text)

Comparison of methods

Given the high quality of the air photographs, the suitability of Ildefonso for this method of censusing (see "Discussion") and the thoroughness of the ground truthing the results of the air photography were used as the "control" against which the other methods were compared.

Yacht-based census

The result of the census from the yacht was corrected downwards to equal the number of birds sitting on nests as for the air census. The yacht-based census revealed a total of 22,376 pairs of albatrosses on the entire archipelago, 55% fewer than counted from the air.

Ground counts

The average of three counts of nesting albatrosses by each of the two counters in the 2–3 ha area of the southern end of Isla Grande (all pavement and tussock habitats combined) was 4,000 ± 462 (CV = 11.5%) for one counter and 3,949 ± 365 (CV = 9.3%) for the other. Overall, the counts by both people were statistically similar (paired t test: $t_{(2)} = 0.92$; $P = 0.45$), so the estimates were pooled. The ground counts yielded 3,973 (±374 SD) nesting albatrosses compared to 4,528 (±57) nests counted from the air photographs, an underestimate of 12.3%. The cause of this discrepancy was the ground counts in tussock slope habitat (Table 3). The estimates from the air and ground in pavement habitat were statistically similar, whereas in tussock slopes the ground counts underestimated the number of albatross nests by 30%.

Quadrats × area

The quadrat sampling on Isla Grande excluded the sheer north-east face where 1,715 nests were photographed. Quadrat sampling in both habitat types yielded 0.84 ($CL_{95\%}$: 0.77–1.0; $n = 17$ sites) nests/m^2 and 0.10 (0.07–0.13; $n = 27$) nest/m^2 for pavement and tussock slopes habitats, respectively. The total land area of Isla Grande (except the north-east face) was estimated to be 20 ha, 30% of which was in the wave zone and did not contain nesting

Table 3 Comparisons of the number of nesting albatrosses counted from the ground in pavement and tussock slopes habitats with the number counted from the aerial photographs

Habitat	Air census[a] (mean ± SD)	Ground count (mean ± SD)	*t* Statistic	*df*	*P*
Pavement area A	912 ± 41	925 ± 115	−0.19	7	0.85
Pavement area B	515 ± 23	482 ± 49	1.07	7	0.32
Pavement area C	1,436 ± 9	1,401 ± 129	0.45	7	0.66
Tussock slopes	1,665 ± 22	1,164 ± 120	6.97	7	<0.001

Counts from air photographs are repeated counts of the same photographs

[a] Estimates multiplied by 0.95 (see text and Table 1)

habitat. Of the remaining 14 ha 10% (14,000 m^2) was pavement habitat and the remaining 126,000 m^2 tussock slopes. Multiplying these two areas by their respective nest densities yields a combined total of 26,360 albatross nests for Isla Grande compared to 27,431 from the aerial photographs, a difference of 11%.

Point-distance sampling × area

The comparison of models with high goodness-of-fit values is shown in the "Appendix 1". The model with the best goodness-of-fit (lowest AIC value) was the half-normal model, which was used to estimate nesting density. Distance data was truncated at 11 m from reference points because observations beyond this distance (to 20 m) did not enhance the goodness-of-fit of the models. Point-distance sampling in tussock habitat (except the north-east face) yielded 0.12 ($CL_{95\%}$: 0.08–0.17; $n = 27$ sites) nests/m^2 or 15,120 nests for all tussock slope habitat on Isla Grande (except the north-east face). This estimate is 9% less than the 16,629 nests counted in the tussock slopes habitat from the air photographs.

Discussion

Comparison of methods

In the comparison of methods air photography was used as the standard against which other methods were compared. Since it is not possible to validate the accuracy of the air photography, confidence in the results must be derived from assessment of the suitability of the method and potential errors. Unlike some other albatross breeding islands, which are irregular in shape and many sided, both northern and southern groups in the Ildefonso Archipelago are long and narrow with only two flanks inhabited by albatrosses (north-east and north-west faces), making the flight path required of the aircraft easy to follow. The full width of the islets can be captured in overlapping photographs, thereby avoiding the difficulty of having to capture (and stitch together later) from a fast moving aircraft images in both horizontal and vertical planes. Critically, there is no concealing vegetation to obscure views of albatrosses from the air. Consequently high quality montages of the landscape can be produced with albatrosses clearly visible and easily counted.

The main potential errors associated with the air photography were parallax in the image stitching process and misidentification of albatrosses. Parallax error occurred when photographs were taken in quick succession at angles forward of the position of the aircraft in relation to the position on the ground. The effect of parallax was minor overall (only 1.3% of birds missed on stitch lines and <6% of the albatross habitat affected by stitching) but could be reduced further by taking each photograph from a position as close as possible to perpendicular to the landscape. With respect to species misidentification, separating albatrosses from other seabird species on the computer screen was relatively straightforward. Macaroni penguins breed in discrete colonies on pavement habitat, were discernible on the air photos and the locations of colonies known to ground parties. Similarly, the locations of cormorant colonies were well known and recognised on the photographs, as were individual birds—cormorants are smaller than albatrosses and have a different shape. Black-browed albatrosses and rockhopper penguins were identified by their different size, shape and colouration—rockhoppers are much smaller, their heads are black (as against white) and they lack the distinctive albatross bill shape. Separating albatrosses and rockhopper penguins became difficult when images were not critically sharp. This was probably the main source of the 1.3% difference between counters of the number of albatrosses on the air photographs. However, since the great majority of photographs were sharp this source of error is unlikely to have significantly affected the accuracy of the counts.

The air photography required simultaneous ground truthing to maximize accuracy. The ground truthing revealed that 5% of the birds photographed were loafing in the colony and a further 7% were sitting on empty nests (the size of these errors would be increased if the census was conducted other than during the preferred time period, see Fig. 3). While ground truthing improved the accuracy of the estimate of population size a sailing vessel had to be chartered to land the ground party, adding substantially to the logistical difficulty and cost of the census. Ildefonso is not an easy island on which to land and deploying a ground party in future censuses may be neither practical nor affordable financially. Ildefonso is also laden with seabirds and difficult to work on without causing disturbance. In the future, one possibility is to use digital photography and take photographs at a larger scale to increase the size of albatrosses in the images. Larger scale photographs can be magnified on the computer screen with minimal loss of quality, providing clear, detailed, images of each bird and its behaviour/posture when photographed. This might enable nesting and loafing birds to be counted separately (e.g., Arata et al. 2003), which would reduce/eliminate the need for ground truthing.

The final point about air photography is the archival quality of the data. Air photography was the only method tested where future researchers can re-examine the original digitized air photographs, repeat the stitching process, recount the albatrosses and draw their own conclusions about accuracy. This adds a level of objectivity to the assessment that is not possible with other census methods.

The yacht-based photographic census was included in the comparison because this was the method used by Aguayo-Lobo et al. (2001), who counted albatrosses on a video tape of the islands. The yacht-based photography underestimated population size by 55%. This discrepancy is not surprising given the large number of birds on the ridge line of Ildefonso—the location of most of the pavement habitat—not visible from sea level. Note, however, that this finding does not question the suitability of yacht-based censuses of islands where albatrosses breed on steep ocean-facing cliffs, such as Chile's Diego de Almagro (51°11′–51°39′S; 75°07′–75°19′W, Lawton et al. 2003) and South Georgia (53°30′–55°00′S; 35°30′–38°40′W, Poncet et al. 2006), islands that were recently censused using yacht-based photography. Rather, it highlights the unsuitability of boat-based counts for islands with topographical features that prevent line-of-sight views of all birds from sea level.

The ground counts yielded 12.3% fewer nesting albatrosses than air photography of the same area. Ground counts in pavement habitat were statistically similar to counts from the air, but counts in tussock slopes fell 30% short of the number derived from the aerial counts. On each of the three counts by both counters a similar number of birds were missed. This result is surprising because the counters had considerable prior experience in censusing albatrosses and thought they had covered the area thoroughly. Although accessible by foot, the area missed sloped away from the remaining habitat, making it difficult to observe, and be aware of, from the ground. That so many albatross nests were missed highlights the importance of air photographs or maps of albatross distributions as a guide to ground parties, especially for islands with complex terrain where the existence of albatross nesting sites may not be easily detected from the ground.

Quadrat sampling underestimated population size in pavement and tussock slopes habitats by 11% and point-distance sampling underestimated population size in tussock slopes by 9%. The accuracy of both techniques may have been improved by classifying breeding areas into more than two habitat types. This was the initial intention but would have required substantially more habitat mapping and an increased number of albatross density estimations. With virtually all available nesting spaces on Isla Grande occupied by albatrosses and penguins a more detailed approach would have been too disruptive to the seabirds (a concern that also applies to ground counts). These two techniques are likely more suited to albatross breeding colonies where birds are more patchily distributed than at Ildefonso.

Previous censuses

In the past 92 years there have been three other albatross censuses at Ildefonso, which are listed in Table 4. It is important to appreciate that these censuses were conducted in a region of the world (Cape Horn) that experiences extreme weather conditions and has a history of ships being wrecked. Hence with these censuses it is conceivable more attention was paid to crew and vessel safety than to counting albatrosses. Murphy's (1936) visit in 1914 simply confirmed the existence of albatrosses at Ildefonso. Clark et al. (1992) visited the islands by yacht in 1985 in the middle of the chick-rearing period, by which time considerable breeding failure would have occurred. Nonetheless their estimate of 8,500 chicks for Isla Norte, made by a ground party, roughly equates to our estimate of 10,734 nesting pairs (Table 2) for the same islet three months earlier in the breeding cycle. These two estimates were made 17 years apart and suggest the population size at Isla Norte during Clark's visit and our own visit was similar. There is little doubt the boat-based census by Aguayo-Lobo et al. (2002) is inaccurate. Albatrosses at Ildefonso cannot be censused from a boat because most albatrosses cannot be seen from positions offshore at sea level.

Importance of Ildefonso

In addition to Ildefonso, black-browed albatrosses in Chile breed at Diego de Almagro (15,594 pairs in 2001/2002;

Table 4 List of known population estimates, dates and methods used to census the black-browed albatross population at the Ildefonso Archipelago, Chile

Source	Census date	Census method	Data treatment	Population size
Beck, cited in Murphy (1936)	18 December 1914	Estimated by eye from boat; whole archipelago	None	'Several thousand'
Clarke et al. (1992)	28 January 1985	Estimate by eye from yacht; Isla Norte only	Number of chicks (8,500[a]) extrapolated to whole archipelago	50,000
Aguayo-Lobo et al. (2001)	6 February 2001	Boat-based survey using video recorder; whole archipelago	9,039 chicks counted; survivorship data in Prince et al. (1994) used to derive population size	20,086
This study	26 October 2002	Aerial photography; whole archipelago	Ground-truthed to derive # birds on nests (see Table 2)	47,000
This study	3 October 2006	Aerial photography; Isla Grande only	None	As in 2002 (see "Appendix 2")

Estimates are of the number of breeding pairs except for Murphy (1936) which most likely refers to the total number of albatrosses

[a] Used by Gales (1998) to erroneously indicate 17,000 breeding pairs for the whole archipelago, an estimate subsequently cited by Tickell (2000), Brooke (2004), Aguayo-Lobo et al. (2001) and (2003)

Lawton et al. 2003), the Evangelistas islets (4,670 pairs in 2002/2003; Arata et al. 2003), Diego Ramirez (55,300 pairs in 2002/2003; Robertson et al. 2003) and the newly discovered colony (18 January 2003) of <50 pairs in the Straits of Magellan (57°27′20 S; 69°01′12 W; Aguayo-Lobo et al. 2003). The total breeding population in Chile is about 123,000 pairs, of which Ildefonso contains 47,000 pairs or 38%. Ildefonso is not only important in the Chilean context but globally. After the Falkland Islands/Malvinas (382,000 pairs in 2000/2001; Huin 2001), South Georgia (74,296 pairs in 2003/2004; Poncet et al. 2006) and Diego Ramirez the Ildefonso Archipelago holds the fourth largest population of black-browed albatrosses in the world.

Ildefonso also holds a small population of grey-headed albatrosses *T. chrysostoma*. In February 1982 Clark et al. (1992) sighted six grey-headed albatrosses from their yacht at the north-east end of Isla Grande. In October/November 2001, the year before our census, we searched Isla Grande by foot and found eight pairs of grey-headed albatrosses nesting in the same vicinity as recorded by Clark's party, thereby confirming the persistence of this small colony of grey-headed albatrosses at Ildefonso.

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Appendix 1

Table 5 Models and associated number of Akaike's Information Criterion (AIC) values, goodness-of-fit (GOF) *P* values for point-distance estimates of the density of albatross nests

Model	Adjustments	AIC	GOF	D	SE (D)	$CL_{95\%}$
Half-normal	Simple polynomial	1,210.91	0.64	0.117	0.023	0.080–0.172
Hazard rate	Hermite polynomial	1,210.93	0.65	0.108	0.023	0.071–0.165
Uniform	Simple polynomial	1,211.26	0.83	0.123	0.024	0.084–0.181

The half-normal model (lowest AIC value) was used in the analysis of point-distance data

D number of nests/m^2, *SE (D)* standard error of D

Appendix 2

In 2006 a total of 31,770 black-browed albatrosses were counted on the air photographs of Ilsa Grande. This figure corresponds to the 30,680 albatrosses counted on Isla Grande in 2002 (see Table 2). Both are raw (uncorrected) counts. The estimate in 2006 is 3.6% higher than in 2002 but was conducted three weeks earlier in the breeding season. There is also considerable within-hour variation in the ratio of nesting-to-total birds for any given days (see Fig. 4), which confounds the assessment of differences between years. For these reasons the result for 2006 is not considered to indicate an increase in the size of the breeding population at Ildefonso in the 4 years between the censuses.

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