POPULATION SURVEY OF SOUTHERN BULLER'S ALBATROSS *THALASSARCHE BULLERI BULLERI* ON THE SOLANDER ISLANDS / HAUTERE, MARCH 2024

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ABSTRACT

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An aerial photographic survey of the Southern Buller's Albatross *Thalassarche bulleri bulleri* population breeding on the Solander Islands / Hautere was undertaken on 09 March 2024, mid-way through the birds' incubation period. Overall, 6,761 individuals were counted: 6,215 (92%) on Great Solander and 546 (8%) on Little Solander. Of these, 4,213 were sitting on nests, 368 were partners to sitting birds, 573 were standing near empty nests, and 145 were apparently loafing. The status of the remaining 1,462 individuals (22% of the total) was uncertain. Assuming that their status was in the same proportions to those of the clearly observed birds, 1,164 were judged to be sitting on nests, giving an overall estimate of 5,377 occupied nests. This is 4% fewer birds at nests than recorded during the last survey in 2016, when 5,620 apparently breeding pairs were reported in a combined aerial survey and ground count of sitting birds. During the 2024 survey, a check of 54 occupied nests along seven short non-random transects found only 33 nests (62%) contained eggs. The remainder (21 nests, 38%) comprised birds sitting on empty nests. The status of these latter birds is unclear. They could be pre-breeders occupying sites prior to nesting for the first time; recent failed breeders that have not yet abandoned their nest; or established breeders forgoing breeding for some reason but still occupying their nest site. Overall, the numbers of apparently occupied nests suggest a decline in the number of nesting Southern Buller's Albatross since 2016. This conclusion is tentative, however, given the many uncertainties surrounding counts and their interpretation.

Key words: aerial photographic survey, apparently occupied nests, mid-incubation period, Solander Islands, Southern Buller's Albatross

INTRODUCTION

Southern Buller's Albatross *Thalassarche bulleri bulleri* nests on only two island groups globally, The Snares / Tini Heke (48°02′S, 166°36′E) and the Solander Islands / Hautere (46°35′S, 166°54′E). Another subspecies, Northern Buller's Albatross *T. b. platei*, breeds on The Sisters / Rangitatahi (43°34′S, 176°49′E) and The Forty-Fours / Motuhara (43°58′S, 175°50′W) in the Chatham Islands, with a small third population of no more than a few tens of pairs breeding on Rosemary Rock (34°11′S, 172°03′E) in the Three Kings Island / Manawatāwhi archipelago (Frost et al., 2018; Schweizer et al., 2024; Fig. 1). The annual global breeding population of the species is estimated to be just over 32,000 pairs (Birdlife International, 2018).

At the time of the most recent full censuses of Southern Buller's Albatross on The Snares and Solander Islands, The Snares supported 8,704 breeding pairs in 2014 (Sagar, 2014), accounting for 61% of the global population, whereas the Solander Islands supported an estimated 5,620 breeding pairs in 2016 (Thompson et al., 2017), *ca*. 39% of the population total. The population on The Snares has been the subject of a long-term demographic study since the late 1960s, with most work focused on three sub-colonies on North East Island: Upper and Lower Punui Bay, and Mollymawk Bay (Sagar et al., 2017; Sagar et al., 2024; Thompson & Sagar, 2019, 2022; Fig. 1). Up to 2002, the combined population of North East Island and Alert Stack on The Snares grew at *ca*. 2.0% per annum, followed by a slight apparent decline of *ca*. -0.1% per annum through to 2014 (Sagar, 2014). Data from the three study colonies reflected a similar annual growth rate of 2.0% through to 2006, after which numbers fluctuated but declined overall by an average -0.8% per annum through to 2019. The number of breeding pairs in these study colonies increased briefly in 2022, reaching the highest level recorded—about 5% higher than in 2006 (Thompson & Sagar, 2022). Nonetheless, the most recent (2024) survey recorded *ca*. 39% fewer pairs present than in 2022, and *ca*. 36% fewer pairs nesting compared with 2006 (Sagar et al., 2024).

These changes primarily reflect a combination of a declining annual adult survival since 2005, which has been linked to incidental mortality from fisheries bycatch (Francis & Sagar, 2012). Whereas the decline in adult survival was initially offset, in part, by increased recruitment of new breeders (Sagar et al., 2017), this compensatory effect may now be diminishing as the pool of potential recruits shrinks (Sagar et al., 2024). Short-term variations in the number of breeding pairs could also reflect fluctuating food supplies, with some birds possibly taking a

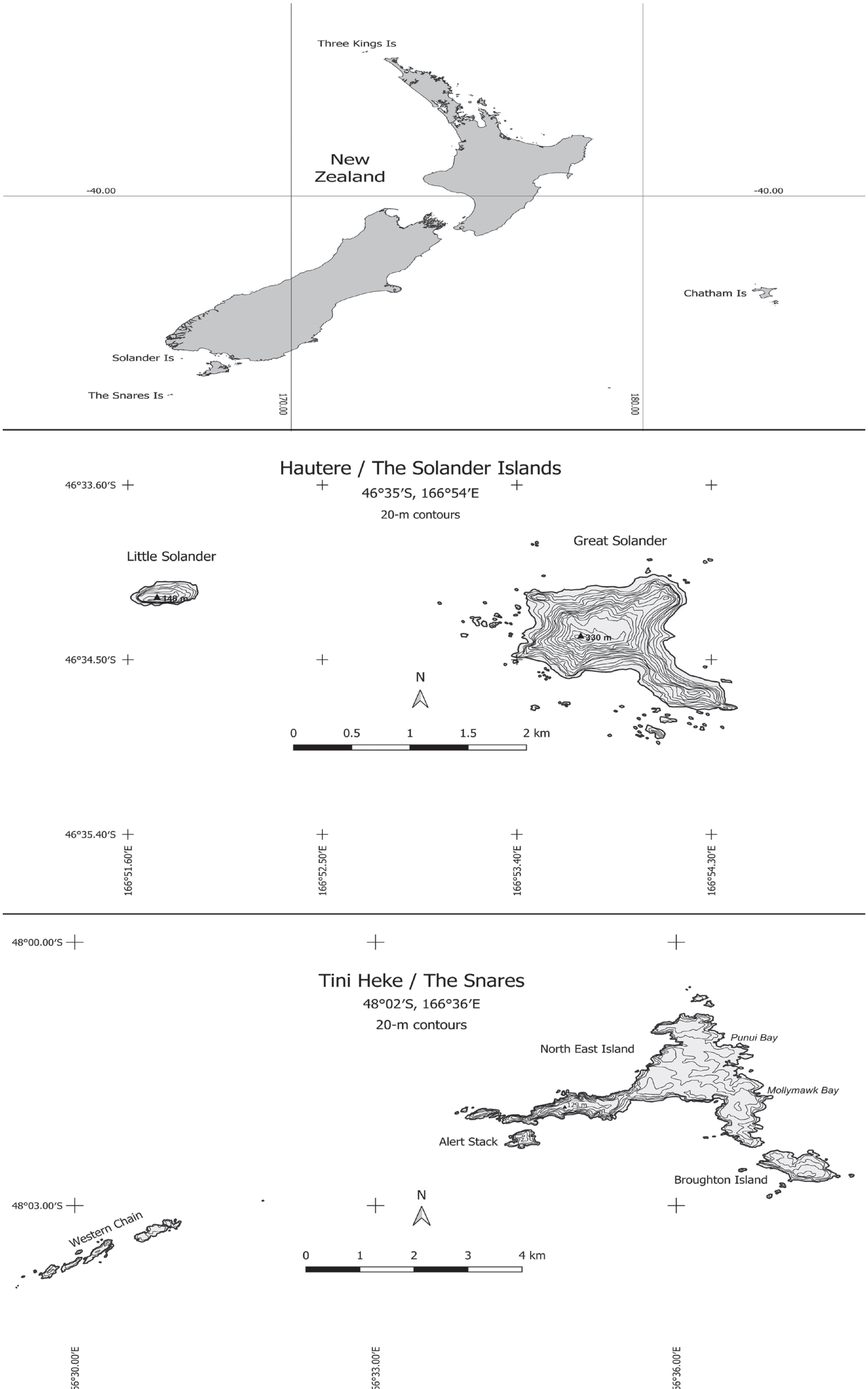

Fig 1. The location of the Solander and The Snares islands, New Zealand, and other places mentioned in the text.

sabbatical from breeding in years when poor nutrition results in inadequate body condition, potentially jeopardising long-term survival if they were to attempt to breed (Sagar et al., 2024).

The Southern Buller's Albatross population on the Solander Islands has been assessed less frequently. Between 1996 and 2002, the number of apparent breeding pairs rose from 4,147 to 4,912, an average increase of 3.1% per annum (Sagar & Stahl, 2005). Numbers rose further between 2002 and 2016, when a combined ground and aerial survey recorded 5,620 apparent breeding pairs, although the growth rate declined to *ca*. 1.0% per annum (Thompson et al., 2017).

In view of the recent decline in numbers recorded on The Snares, a new census of the Solander Island population is warranted to determine if a similar trend is occurring there. This is particularly urgent given that Buller's Albatross experiences substantial mortality from fisheries bycatch, estimated at several hundred birds per year in New Zealand waters alone (Edwards et al., 2023). Correspondingly, adult survival has declined noticeably in recent years (Sagar et al., 2024). A recent reassessment of the risk posed to seabirds by fisheries-related mortality within New Zealand's Exclusive Economic Zone (EEZ) identified Southern Buller's Albatross as the species at greatest risk (Edwards et al. 2023). This paper accordingly presents the results of an aerial photographic survey of Southern Buller's Albatross on the Solander Islands, conducted on 09 March 2024, approximately half-way through the incubation period. A limited on-ground survey was carried out concurrently to record the number of birds on nests, including those sitting on empty nests (Sagar et al., 2024)

STUDY SITE AND METHODS

Study site

The Solander Islands are the eroded remnants of a previously much larger middle–late Quaternary volcanic complex, dated between 0.40 and 0.15 million years old, lying close to the boundary of Australian and Pacific tectonic plates (GNS Science, 2012; Mortimer et al., 2013). The terrain on Great Solander is rugged with steep cliffs bounded only by a narrow coastal terrace behind the boulder-filled beaches. Along the South-East Peninsula, the cliffs rise sharply from around the 20-m contour to at least 140 m, reaching 180–200 m in the main island block, which has a peak elevation of 330 m above sea level (asl) (Figs. 1, 2). Little Solander, with a peak elevation of 148 m asl, lies 1.96 km due west of Great Solander and features nearly vertical cliffs along its southern side.

Despite their steep topography and rocky slopes, both islands are well vegetated. Dense scrub, primarily of *Macrolearia lyallii*, forms a compact canopy on the peaty soils of the plateau of Great Solander (Johnson, 1975). Whereas the subcanopy is relatively open, the ground is densely covered by mosses, ferns, and megaherbs. *Macrolearia* also dominates the tree cover on deeper soils of the island's more exposed upper slopes. Soils are shallow or virtually absent on many of the middle to lower slopes. The deeper soils on the lowest slopes of the coastal platform are covered with the vigorously growing grass *Poa foliosa*. The vegetation of Little Solander Island is similar but less diverse, with shrubs covering much of the interior of the island, replaced by an extensive, dense sward of *Poa foliosa* on the gentler slopes of the eastern third of the island (Johnson, 1975). Overall, these

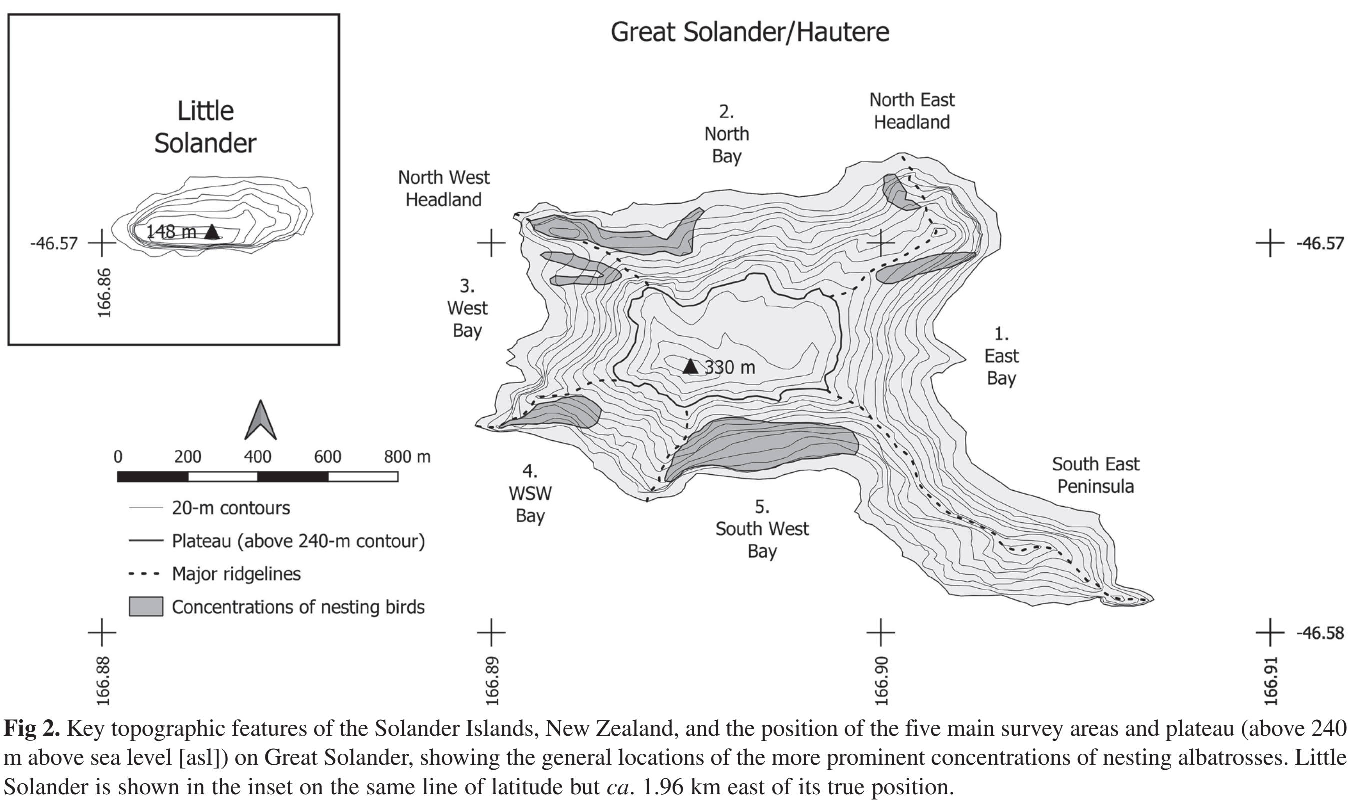

Fig 2. Key topographic features of the Solander Islands, New Zealand, and the position of the five main survey areas and plateau (above 240 m above sea level [asl]) on Great Solander, showing the general locations of the more prominent concentrations of nesting albatrosses. Little Solander is shown in the inset on the same line of latitude but *ca*. 1.96 km east of its true position.

plants provide substantial cover for nesting seabirds, making it difficult to easily detect individuals nesting beneath them. Outside these wooded areas, nesting albatrosses are mostly scattered across steep and rugged topography, aside from some small concentrations associated with the larger debris fans.

The vertical elevations of these islands belie the extent of potential nesting surface available to the birds if judged solely on the islands' planar areas (Great Solander, 84.7 ha [0.877 km^2]; Little Solander, 6.7 ha [0.067 km^2]). Because no digital elevation model was available to determine the actual surface area, a three-dimensional (3D) model was built using publicly available geospatial data sets (Appendix 1, available on the website). While only approximate, the resulting model is sufficient for the purpose of identifying differences in the densities of nesting albatrosses across the islands.

Aerial photography

Images were taken by GBB with a NIKON D6 camera and a Nikkor VR 70–200 mm f/2.8G lens during anticlockwise circuits of both islands flown in a twin-engine Kawasaki BK-117 helicopter. The images, originally in Nikon Electronic Format (RAW), were then converted to JPG fine files. The Exif metadata recorded on the RAW images was transferred when the files were converted to JPG and used to extract information about each image. Shutter speed and sensor sensitivity (ISO) were preset at 1/2000s and 500, respectively. The geocoordinates and approximate altitudes from which each image was taken were recorded on the camera's global positioning system (GPS), enabling calculation of various flight parameters: locations of the image sets; duration and distance moved during each; and mean air speed and altitude. The survey lasted 30 minutes, from 14h26 to 14h57 New Zealand Daylight Time (NZDT; equivalent to UTC+13).

The photographs were taken systematically, starting from the bottom left of a scene and moving upwards more-or-less perpendicularly, toward the top of a cliff face, with each successive image overlapping vertically. Once the upward strip was completed, the camera view was shifted horizontally, and a second strip of images was captured parallel to the first—this time moving down to the water's edge. Vertical overlap was maintained within the image series, along with horizontal overlap with the preceding upward strip. At the end of the descending strip, the view was shifted laterally again, retaining about one-third overlap with the previous strip, before repeating another parallel ascending and descending cycle. The aim was to ensure sufficient overlap between any image and its immediate neighbours so that photomosaics could be constructed of each cliff face. At the end of each set covering a particular face, one or more photographs were taken of the sea to indicate a move to a new position to photograph the next cliff face.

Although the helicopter was notionally stationary at each photographic site, it actually was moving forward at 9.5 ± 5.2 m/s (mean ± 1 standard deviation [SD]) around Little Solander Island and 4.4 ± 3.5 m/s around Great Solander Island. This movement resulted in subtle shifts in viewpoint in each set.

Little Solander was photographed first, from an average altitude of 198 m (SD ± 5 m) at 70–120 mm focal lengths. Average distance, measured from the photopoint to the 100-m contour on the island, was 373 ± 52 m (range 295–429 m). The photographs covered all areas of the island at various oblique angles, with the central areas captured at the shallowest angle below the horizontal. This approach ensured reasonable visibility of birds nesting beneath the extensive tree cover.

The flight around Great Solander Island started from the South-East Peninsula and proceeded anticlockwise, passing East Bay, then continuing around the North East and North West Headlands, with North Bay located between them. It then continued around West and West South West Bays, ending at South West Bay. Images were taken predominantly at 135 mm focal lengths, extended to 155–185 mm when photographing the South East Peninsula from further offshore, and the plateau above 240 m. Photographs were taken from an average altitude of 256 ± 66 m (range: 191–401 m), which was higher than around Little Solander Island due to Great Solander's greater elevation. At the end of the circuit around Great Solander, the helicopter was flown up to 390–400 m to capture slightly less oblique photographs of the island's densely forested plateau above 240 m, thereby ensuring comprehensive photographic coverage of the island. Average distance from the photopoints to the 100-m contour on the island was 431 ± 130 m (range 184–644 m). The edge of the island's plateau was, on average, 296 ± 135 m beyond this.

Image processing

Images were processed using proprietary software to enhance contrast, colour, and detail, where necessary. After processing, either individual vertical sequences of images or, occasionally, several adjacent vertical sets were stitched into photomosaics using Microsoft's Image Composite Editor™. These photomosaics overlapped their neighbours to varying extents. Accordingly, a single count zone was demarcated in each strip, usually extending from the shoreline to the island's horizon, but sometimes to a smaller discrete area within a mosaic. Each zone was unique, abutting adjacent similarly unique zones on either side and demarcated by lines drawn digitally on the images, connecting prominent features visible in both the main and neighbouring mosaics (e.g., rocks, fissures, bare patches, dead branches, and grass or sedge tussocks). Each line was drawn simultaneously on the two adjacent mosaics to ensure that they were identical. Some deletions and duplicates (ghosting) were noted. Ghosting was removed by redoing the stitching using different image combinations. The few obvious deletions of birds were reinserted manually before counting.

Counting

All definite or possible Southern Buller's Albatrosses seen in each zone were counted and their status catalogued using DotDotGoose (version 1.7.0; Ersts, 2024). Individuals were classed as follows:

1. Bird sitting on a nest
2. Bird sitting on a nest with presumed partner next to it
3. Bird standing on an apparently empty nest or nest site
4. Two birds standing together on an empty nest
5. Birds not associated with a nest (i.e., loafers or transient individuals)
6. Bird present but status indeterminate
7. Adult flying (recorded but not dealt with subsequently)
8. Possible albatross (noted for completeness but not dealt with further)
9. Empty nest or site, no adult present.

Each category was assigned a unique colour, so that individuals or duos could be marked appropriately on a digital overlay of the scene being surveyed. DotDotGoose places a re-sizable grid onto the image being analysed. In this analysis, grid size was set at 400 × 400 pixels. The image could be magnified to any level required, with the grid and tally marks scaled accordingly. Each grid square was examined systematically and in sequence. Any birds seen were then categorised before moving on to the next grid square. Counts for each category were tallied automatically as birds were marked, and then the data were saved as CSV files for later analysis.

The positions of the marked birds and other relevant features were saved and could be recalled, if needed. An overlay of the image of each area, with the variously coloured marks in place, was saved as a PNG file. This provided a useful overview of where the birds were, and whether there was any clustering of activity in particular areas.

Ground survey

Two small field teams were on the ground at the time of the aerial survey, primarily to fit satellite trackers on several nesting birds. This provided an opportunity to assess what proportion of birds at nests were sitting on eggs. The duration of stay of the field teams—only about five hours—was too short to undertake any wide-ranging, systematic ground counts aside from examining a small sample of occupied nests along seven short transects in South West Bay and North Bay, concurrently with the aerial survey (Sagar et al., 2024). Cumulatively, the ground surveys lasted 66 min (the times taken to complete each section were not always recorded) and covered a total of *ca*. 2 km (data from GPS Exchange Format files). The transects were not randomly selected; sampling was largely ad hoc, based on accessibility. The aim was to establish what proportion of birds on nests were actually incubating eggs as opposed to sitting on empty nests. If these results are considered representative of the larger population, the aerial counts would need to be adjusted downwards to avoid overestimating the actual number of breeding pairs.

Data analysis

Data analysis was straightforward because each count zone was unique and non-overlapping. The number of apparently active nests (N_{obs}) was the sum of all nests with one bird sitting, with or without an accompanying partner. These are referred to here as occupied nests, without any implication that this means the presence of an egg. We cannot tell the exact number of incubating pairs from the aerial photographs. Sites where one or two birds were present but standing on or next to an obviously empty nest are referred to as occupied empty sites, with the occupants assumed not to be breeding at that time.

In addition, in each zone, there were birds whose status could not be confidently resolved (indeterminate, *U*). Some of these birds would likely have been present at a nest, either sitting or as a partner to a sitting bird. The number of additional occupied nests was therefore estimated as the product of *U* and two probabilities from the observed numbers of birds clearly seen at nests: (1) the probability that a bird was present at an occupied nest, either sitting or as a partner ($p[nest_{occ}]$); and (2) given the presence of partners at some occupied nests, the conditional probability that an individual associated with such nests was actually sitting ($p[sitting \mid nest_{occ}]$). That is, the number of additional occupied nests was $N_{add} = U * p[nest_{occ}] * p[sitting \mid nest_{occ}]$, and the overall estimated number of occupied nests was $N_{obs} + N_{add}$. For Great Solander, this adjustment was determined separately for each of the five main areas on the island, to account for any differences in aspect, topography, land surface, and vegetation cover. The total number of apparently active nests in each area was then estimated using the averages of the area probabilities weighted by the initial number of occupied nests counted in each area and applied to the total number of indeterminate birds. For Little Solander, because of the smaller number of birds involved, the adjustment was based simply on probabilities calculated from the overall observed numbers of birds seen clearly at nests.

To express the uncertainty in the counts for each island, 95% confidence limits (CL) were calculated for the totals of each category in each of the five areas on Great Solander and for Little Solander overall. These confidence limits were calculated using the *poisson.exact* function in the R package "exactci" (Fay, 2017), which corresponds to the exact central confidence interval of Garwood (1936). This method is widely used for calculating this parameter in one-sample cases—here, the counts in each category. It assumes that the data follow a Poisson distribution, where the mean and variance of a sample are equal (Baker et al., 2013).

The temporal trend in the numbers of apparent breeding pairs, based on 'unadjusted counts' of birds occupying nests between 1996 and 2024, was analysed using *rtrim* (version 2.0.6), the R version of the Trends and Indices for Monitoring Data (TRIM) software programme (Pannekoek et al., 2018; Bogaart et al., 2024). Here, 'unadjusted counts' refer to the number of apparently occupied nests without any adjustment for the proportion of birds sitting on empty nests, which is uncertain and was not estimated in every earlier survey. The TRIM programme models frequent counts as a log-linear Poisson regression, a form of Generalised Linear Modelling. It is widely used for assessing trends in wild bird populations from time-series data and has been adopted by the Agreement for the Conservation of Albatrosses and Petrels (ACAP) as the standard tool for analysing long-term trends in the populations of albatrosses and petrels (ACAP, 2012). The sparse data were analysed using Model 2 of the programme. This is a linear (switching) model that estimates the imputed values as $\ln \mu_{ij} = \alpha_i + \beta(j\text{-}1)$ in which the lognormal counts μ_{ij} for each site *i* (the two Solander islands were treated as separate sites) are linear functions of time, *j*, with slope β, the mean growth rate across all sites over time. Because of the paucity of the counts (only four in 28 years), only the minimal version of the model was run. With these limited data, the fitted and imputed indices of change, calculated by the model, are identical.

RESULTS

Great Solander

We counted at least 3,873 nests occupied by Southern Buller's Albatross (95% CL, 3,752–3,997) on Great Solander Island, comprised of 3,537 nests with single birds sitting alone plus 336 nests with two birds present: one sitting, the other alongside and assumed to be its partner (Table 1). In addition, there were 1,356 birds (95% CL, 1,285–1,430) whose status was

TABLE 1
Numbers of Southern Buller's Albatross *Thalassarche bulleri bulleri* on the Solander Islands, New Zealand, counted from aerial photographs taken on 09 March 2024 (95% confidence limits shown in italics below each count)

Status	Great Solander (total)	Little Solander	Solander Islands (total)
Bird sitting on nest	3,873	340	4,213
	3,752–3,997	*305–378*	*4,087–4,343*
Partner to a sitting bird	336	32	368
	301–374	*22–45*	*331–407*
Bird at empty nest or site	451	48	499
	410–495	*35–64*	*446–545*
Partner to bird on empty nest	64	10	74
	49–82	*5–18*	*58–93*
Loafing bird	135	10	145
	113–160	*5–18*	*118–178*
Indeterminate (U)	1,356	106	1,462
	1,285–1,430	*87–128*	*1,388–1,539*
Total birds on ground[a]	6,215	546	6,761
	6,061–6,371	*501–594*	*6,601–6,924*
$p(nest_{occ})$[b]	0.867	0.845	0.865
$p(sitting \mid nest_{occ})$[b]	0.920	0.914	0.920
Total apparently occupied nests[b]	4,955	422	5,377
	4,818–5,095	*383–464*	*5,234–5,523*

[a] Includes birds whose status was initially unclear (indeterminate)
[b] For definitions and calculations see text

indeterminate, around 22% of all individuals present on land. Some of these unknown individuals would have been associated with an occupied nest. Assuming these indeterminate birds were in the same proportion as the observed singles and pairs at such nests, an additional 1,176 individuals were present at an estimated 1,082 additional nests. The total estimated number of occupied nests on Great Solander was therefore 4,955 (95% CL, 4,818–5,095; Table 1). Of the 6,215 individuals seen on the ground on Great Solander, including loafers and birds of indeterminate status, counts were proportionally assigned into breeding and non-breeding categories. Among these, 5,385 individuals (87%) were at occupied nests—either sitting or acting as a partner to a sitting bird—while 830 (*ca*. 13%) were non-breeding birds. The non-breeders included those present at empty nests or sites (658, *ca*. 10%) and those not obviously associated with a nest (172, *ca*. 3%), here termed 'loafers', which could include birds in transit to or from nest sites. This estimate does not include birds that might have been nesting on the tree-covered plateau or were undetected under plant cover elsewhere. Birds visible under trees near the edge of the plateau were accounted for in the zone counts, but no birds were detected in images of the plateau above *ca*. the 240-m contour taken at the end of the regular survey. No Buller's Albatross were found nesting in this densely vegetated area in 1996 (G. A. Taylor, personal communication, August 13, 2024). The numbers within these social categories varied across the five main survey areas around the island (Appendix 2).

Little Solander

A total of 340 Southern Buller's Albatross nests were initially counted as occupied on Little Solander Island (95% CL, 305–378), of which 32 nests had two birds present, assumed to be partners of the sitting bird (Table 1). Additionally, there were 106 birds whose status could not be determined directly (95% CL, 87–128), representing 19% of the 546 individuals seen on the ground. If these indeterminate individuals include some birds on nests and they occur in the same proportion as those counted directly, then the total estimated number of occupied nests was 422 (95% CL, 383–464; Table 1). Among the remaining birds, including 16 non-breeding individuals within the original 106 indeterminate birds, 74 (14% of all birds on the ground) occupied sites as non-breeders—standing on or alongside visibly empty nests—with an additional 10 individuals appearing to be loafing. Most birds on nests were concentrated in the more open, densely grassed, eastern end of the island (Fig. 2).

Overall counts

An estimated total of 5,377 occupied nests (95% CL, 5,234–5,523) were present on both islands combined, including 1,164 nests likely occupied by individuals initially classified as indeterminate. The estimated total number of breeding individuals—those associated with an occupied nest—was 5,846, *ca*. 86% of the 6,761 total birds counted on the aerial photographs, excluding those in flight. Non-breeding individuals—birds occupying obviously empty nests or loafing—comprised the remainder, totaling 915 individuals, of which 299 (*ca*. 33%) were initially classified as indeterminate (Table 1). Of these non-breeders, 185 (20%) were loafers—birds not visibly associated with a nest but sitting or standing instead on ridges, prominent rocks, or grass tufts. The remaining 730 individuals were present at an estimated 636 empty nests or sites. In addition, at least 1,739 vacant nest sites—obvious, large, excavated hollows on slopes—were noted on the islands, accounting for *ca*. 24% of all observed nests and nest sites (including the unoccupied ones). The number is likely an underestimate, as some vacant sites were undoubtedly missed. It is not known whether these represent failed or abandoned nests, or simply ones that had not been reoccupied in the current season.

The albatrosses nested across most of both islands, but densities varied, both within and between areas. Using the calculated 3D surface area (see Appendix 1) of each of the five areas into which Great Solander had been partitioned in earlier studies, up to the 240 m contour (above which a sixth area, the plateau, was defined), the number and density of all apparently occupied nests (AON) varied considerably. The density of apparently nesting birds was highest in North Bay (0.57 AON/100 m^2), followed by South West Bay (0.52 AON/100 m^2) and West Bay (0.51 AON/100 m^2), all of which had more nesting birds per unit area than West South West Bay (0.34 AON/100 m^2) or East Bay (0.27 AON/100 m^2). Overall density on Great Solander Island was 0.39 AON/100 m^2, only slightly more than on Little Solander Island (0.34 AON/100 m^2; Table 2). The greatest concentrations of occupied nests were generally in the more open areas: gentler slopes with shallow soils; large talus; or grassy areas (e.g., lower slopes of South West Bay, Great Solander; eastern end of Little Solander) (Fig. 2).

TABLE 2
Densities of apparently nesting Southern Buller's Albatross *Thalassarche bulleri bulleri* on the Solander Islands, New Zealand, overall and by survey area on Great Solander (in italics), based on 3D surface area estimates

Island survey area[a]	Planar surface area (m^2)	3D surface area (m^2)	Apparently occupied nests (AON)[b]	Apparent nest density (AON/100 m^2)
Great Solander	847,108	1,279,870	4,955	0.39
2. North Bay	*180,494*	*252,308*	*1,445*	*0.57*
5. SW Bay	*178,817*	*279,725*	*1,446*	*0.52*
3. West Bay	*92,869*	*152,289*	*783*	*0.51*
4. WSW Bay	*67,479*	*105,903*	*359*	*0.34*
1. East Bay	*206,855*	*343,579*	*923*	*0.27*
6. Plateau	*120,594*	*146,067*	*0*	*0*
Little Solander	67,439	123,017	422	0.34

[a] Numbers refer to those originally given to these survey areas (Thompson et al., 2017)
[b] The number of apparently occupied nests are those estimated after adjusting for the proportion of birds, classed initially as 'indeterminate', that were presumed to be nesting

The counts of occupied nests include some birds sitting on empty nests. Of the 54 nests checked along seven short, non-random transects in South West Bay and North Bay, an average of 62.3% (95% CL, 54.9–69.6%; 33 nests) contained birds sitting on eggs. The remaining 21 nests (37.7%) were occupied by birds sitting on empty nests (Sagar et al., 2024).

Compared with previous surveys, the 2024 counts, corrected to account for birds initially classified as indeterminate, show *ca*. 30% and 10% increases in the number of apparently occupied nests relative to 1996 and 2022, respectively, but a 4% decline since 2016 (Table 3). These trends are supported by the TRIM Model 2 analysis, which is based on total counts of birds occupying nests between 1996 and 2024. Although the analysis is based on only four widely spread counts over a 28-year period, the overall net annual growth rate averaged only 0.8%, which TRIM classifies as a "Moderate increase ($P < .01$)." This classification is due almost entirely to the significant 2.8% per annum increase recorded between 1996 and 2002 (Wald test statistic [WT]: 64.447, $P < .001$, $df = 1$). Changes between other time points in the series were also statistically significant, with growth slowing to just under 1% per annum from 2002 to 2016 (WT: 18.064, $P < .001$, $df = 1$), followed by a −0.5% per annum decline between 2016 and 2024 (WT: 29.894, $P < .001$, $df = 1$).

DISCUSSION

Aerial photographic surveys are currently the only practical method for censusing populations of surface-nesting seabirds on remote, uninhabited, largely inaccessible islands such as the Solander Islands. Even when a ground survey is possible, the rugged nature of the islands makes thorough coverage difficult. Over the past 28+ years, only three reasonably comprehensive surveys of the Southern Buller's Albatross population have been conducted, each combining aerial photographic counts with limited ground-based observations. All were carried out between the end of egg-laying and early incubation (mid-February to early March) (Sagar et al., 1999; Sagar & Stahl, 2005; Thompson et al., 2017). Earlier estimates (e.g., Cooper et al., 1985; Falla, 1948) were based on visits towards the end of the nesting season (July), when nests contained well-grown chicks. Such counts would not have included nests that had failed earlier in the season.

Although aerial photographs provide a permanent record of what was visible at the time, enabling detailed and independent examination, they are not a panacea. As with all surveys, the results are subject to uncertainty, with multiple sources of potential bias and error (Wolfaardt & Phillips, 2013). In aerial surveys, these may include incomplete detection, misinterpretation of imagery, and questionable extrapolation. Detection errors arise when not all nesting individuals are observed, often due to concealment by vegetation and topography. Interpretation errors, such as misjudging the status of an individual seen in an image, can be influenced by ground conditions, image quality, and the analyst's expertise. This includes being unable to distinguish between non-breeding birds at nests from those whose breeding attempts have recently failed or who have not yet laid eggs. Such errors are particularly problematic, not least because of the difficulty in determining their extent.

The scale of such errors can be reduced by conducting surveys at the same stage of the breeding season each year—ideally near the end of egg-laying (if breeding is reasonably synchronous within in a colony)—at the same time of day, under similarly favourable weather conditions, and using skilled personnel with comparable equipment. Carrying out surveys regularly depends on the availability of an aircraft (or drone) and pilot, suitable weather conditions, and experienced photographers, all of which can vary between years. Without concurrent ground studies, reliance solely on aerial surveys introduces unquantified variation associated with these factors. Ground surveys, sometimes misleadingly referred to as 'ground-truthing' (G. A. Taylor, personal communication, December 19, 2024), are valuable, but they are not error-free, particularly when limited in scope or non-randomly distributed. Extrapolation from such samples is valid only if they represent appropriate random subsets of the wider area. This is often difficult to achieve in rugged, heterogenous landscapes. Reconciling differences between aerial and ground counts, each with inherent limitations, remains a significant challenge.

TABLE 3
Comparison between the number of Southern Buller's Albatross *Thalassarche bulleri bulleri* occupying nests on the Solander Islands, New Zealand, in 2024 and those counted in earlier years[a]

	Year						
	1996[b]	2002	2016		2024		
Date (aerial survey)	15 Feb	20 Feb	29 Feb		09 Mar		
Date (ground survey)	16–22 Feb	22 Feb–08 Mar	25–29 Feb		09 Mar[c]		
	Source						
Area	Sagar et al. (1999)	Sagar & Stahl (2005)	Thompson et al. (2017)		This study		
			Combined	Adjusted[d]	Raw count	Combined	Adjusted[e]
Great Solander	3,885	4,579	5,280	4,302	3,873	4,955	3,027
1. East Bay	*709*	*876*	*666*	*543*	*694*	*923*	*564*
2. North Bay[f]	*1,086*	*1,162*	*778*	*634*	*1,113*	*1,445*	*883*
3. West Bay	*387*	*489*	*819*	*667*	*559*	*783*	*478*
4. WSW Bay[g]	*306*	*362*	*481*	*392*	*279*	*359*	*219*
5. SW Bay[h]	*1,397*	*1,690*	*2,536*	*2,066*	*1,228*	*1,446*	*883*
Little Solander	262	333	340	277	340	422	258
Solander Is. total	4,147	4,912	5,620	4,579	4,213	5,377	3,285

[a] For 2024, three sets of figures are given: the original count, not adjusted for indeterminate individuals (raw count); a combined figure, taking account of the proportion of initially indeterminate birds likely to be on nests; and an adjusted figure, assuming that only 61% of birds on nests were sitting on an egg (see text for details)
[b] Corrected figures to account for missed colonies (see Sagar & Stahl, 2005)
[c] Sagar et al. (2024)
[d] Adjusted downwards in line with an estimate that *ca*. 82 % birds were sitting on eggs (Thompson et al., 2017); see text for discussion
[e] Assuming that only 61% of birds on nests were sitting on an egg (Sagar et al., 2017)
[f] Referred to as North East to North West Headland in earlier reports (Sagar et al., 1999; Sagar & Stahl, 2005; Thompson et al., 2017)
[g] Referred to as West Bay to South West Bay in earlier reports
[h] Referred to as South West Bay to South East Peninsula in earlier reports

All these issues are apparent in the present survey. Of the 6,761 Southern Bullers Albatross counted on land from aerial photographs taken on 09 March 2024, 62% (4,213 individuals) were sitting on nests; 5% (368 birds) were presumed to be partners of birds sitting on nests; *ca*. 7% (499) were individuals at empty nests or sites, of which 1% (74) were accompanied by a second bird, presumably also a partner; 2% (145) were not obviously associated with any nests (so-called 'loafers' or 'transients'); and 22% (1,462) were indeterminate. Given that over one-fifth of all birds were initially considered indeterminate, it is likely that some were, in fact, sitting on nests but could not be confidently identified as such. Any estimate of the total number of nesting birds, therefore, depends on how these indeterminate individuals are treated. The most parsimonious approach was to assume that the indeterminate birds were distributed in the same proportions as those whose status could be clearly determined. Using this method, an estimated 5,377 occupied Southern Buller's Albatross nests were present on the Solander Islands in March 2024: 4,955 (92%) on Great Solander and 422 (8%) on Little Solander.

Previous surveys used a combination of methods: ground counts, in which individual nests were visited and tallied; vantage-point counts using binoculars, in which the number of birds sitting on empty nests could not be reliably distinguished from those incubating eggs; and counts of birds on nests visible on aerial photographs, in which birds sitting on empty nests were again indistinguishable from incubating birds (Sagar et al., 1999; Sagar & Stahl, 2005; Thompson et al., 2017). In 1996 and 2002, surveys recorded the number of birds present with and without eggs in colonies accessible by foot (Sagar et al., 1999; Sagar & Stahl, 2005). No details were provided, however, about the proportions of each, or how—or to what extent—this information was incorporated into overall counts. Because a correction for birds sitting on empty nests was not consistently applied in the 1996 and 2002 surveys, Thompson et al. (2017) did not adjust their final 2016 population assessment. Treating the unadjusted counts of occupied nests as population indices suggests that *ca.* 36% more birds occupied nests on the Solander Islands in 2016 than in 1996, followed by a 4% decline by 2024.

The present assessment necessarily excludes any nesting birds that were completely obscured from view by vegetation, but it does include some birds sitting on empty nests. Based on checks of 54 nests in two areas covering < 1 ha (0.01 km^2) on Great Solander, the proportion of birds sitting on eggs along seven short, non-random transects was only 0.62 (33 nests overall); the remaining 21 nests were empty (Sagar et al., 2024). Given that the nests were sampled opportunistically, the false positive rate of *ca*. 38% may not be representative. If it is at least broadly indicative, however, and assuming no birds nesting under the tree canopies were missed, then the number of active nests at the time of the 2024 survey was *ca*. 3,350.

In 2016, the proportion of birds sitting on nests with eggs was recorded during two separate surveys of 49 and 74 nests near the western end of North Bay on Great Solander Island. The proportion was *ca*. 0.82 in both cases (Thompson et al., 2017). Applying this to the overall count of 5,620 nesting birds in 2016 yielded 4,579 incubating birds. In contrast to the modest 4% decline suggested by comparing the unadjusted counts, the adjusted 2024 count—3,350—represents a decrease of *ca*. 27% from the 2016 figure. This implies a sharp decline in the number of active nests between 2016 and 2024. A comparable decline (*ca*. 23%) was recorded at the three study colonies on The Snares over the same period (Sagar et al., 2017, 2024). Nevertheless, at these Snares colonies, the number of active nests fluctuated considerably in the intervening years, rising by 26% between 2016 and 2022 before falling by 39% between 2022 and 2024 (Sagar et al., 2024). Given the similarity in the overall percentage decline in active breeding pairs on both The Snares and the Solander Islands between 2016 and 2024, and assuming the *ca*. 38% false positive rate reported from Great Solander in 2024 is broadly applicable, it is likely that similar factors are affecting the species' population dynamics at both sites.

Whereas the phenomenon of birds sitting on empty nests at some stage during incubation is widely recognised in albatrosses and petrels (Baker et al. 2015, 2023; Bell et al., 2023; Parker et al., 2023; Robertson et al. 2008; Thompson et al., 2017; Walker et al., 2020), little is known about the nature of these birds or how their numbers vary across years. Some birds may be pre-breeders, returning to the islands and occupying a site prior to nesting for the first time. For example, on The Snares in 2001, when just over half the birds present in study plots were non-breeders, 80% of these were pre-breeders, of which 30% attended a nest site (Stahl & Sagar, 2006). These birds clearly had not yet entered the breeding population and should therefore be excluded from any estimate of the current breeding population. Others sitting on empty nests could be recently failed breeders that had not yet abandoned their nest, instead continuing to occupy their site to prevent takeover by prospecting pre-breeders. Such failed breeders can be detected during ground surveys if eggshells or chick carcasses remain in or around the nest and are counted. In this context, failed Southern Buller's Albatross breeders on The Snares accounted for *ca*. 13% of all birds present on the ground, with some individuals remaining in the colony for up to three months following nest failure (Stahl & Sagar, 2006). Failing to account for these birds risks underestimating the breeding population for the current season.

Individuals that lose a mate, through death or divorce, and have not re-paired, may also occupy empty nests (Sagar et al., 2002). In 2001, remating adults at The Snares made up just under 5% of birds ashore, a proportion similar to that of individuals skipping a breeding season. Among unsuccessful breeders, 16% skipped the following breeding season, compared with 9% of successful pairs. Notably, over 20% of first-time breeders skipped the next season regardless of their breeding outcome (Sagar et al., 2002; Stahl & Sagar, 2006). These rates likely vary from year to year, raising questions about whether data from a single year can be used reliably to adjust aerial counts in other years (*cf*., Walker et al., 2020).

This highlights uncertainties in interpreting population estimates based solely on aerial photographs, particularly for remote seabird colonies (Wolfaardt & Phillips, 2013). Whereas such surveys are undoubtedly valuable and often necessary, their limitations mean that demographic trends based on raw counts should be interpreted with caution. Accordingly, our findings suggest a possible decline in the number of Southern Buller's Albatross nesting on the Solander Islands in 2024 compared with 2016, although the causes and true extent of this decline remain uncertain.

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AUTHOR CONTRIBUTIONS

PGHF: Photo processing and analysis, methodology, writing—original draft & editing. GBB: Methodology, aerial photography, writing—review & editing. JHF: Conceptualisation, funding acquisition, ground-based survey, writing—review & editing. PMS: Conceptualisation, ground-based survey, writing—review and editing.

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