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Expansion of albatross and petrel monitoring on South Georgia – feasibility study

Phase 1: Review of ACAP-listed species monitoring programmes

Anderson, O.R.J.[1], Poncet, S.[2] and Tierney, M.[1]

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Joint Nature Conservation Committee
Monkstone House
City Road
Peterborough PE1 1JY
https://jncc.gov.uk/
Communications@jncc.gov.uk

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Affiliations:
[1]JNCC, Monkstone House, Peterborough, PE1 1JY
[2] South Georgia Surveys, Stanley, Falkland Islands

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Summary

This report provides a synthesis of past and existing monitoring programmes of the seven ACAP (Agreement on the Conservation of Albatrosses and Petrels) listed species that breed on South Georgia. It also identifies all known colony locations for these species nesting on the archipelago and presents maps and information on these locations. Finally, the report presents a comparison of the different monitoring techniques that have been used on related species elsewhere and could be used in the future to monitor ACAP species at other locations around South Georgia for the purposes of enhancing monitoring schemes for these threatened seabird species.

Contents

Acronyms and Definitions

Acronyms

AGL	Above Ground Level
BAS	British Antarctic Survey
BBA	Black-browed Albatross
CAA PfCO	Civil Aviation Authority Permission for Commercial Operation
GHA	Grey-headed Albatross
GSGSSI	Government of South Georgia & the South Sandwich Islands
JNCC	Joint Nature Conservation Committee
LMA	Light-mantled Albatross
NGP	Northern Giant Petrel
RAP	Regulated Activity Permits
RPQ-S	Remote Pilot Qualification-Small
SGP	Southern Giant Petrel
SNR	Signal to Noise Ratio
UAV	Un-manned Aerial Vehicle (drone)
WCP	White-chinned Petrel
WNA	Wandering Albatross

Definitions

Active Nests: eggs or apparent incubation seen.

Apparently Occupied Nests: defined as a well-built nest (or burrow) capable of containing eggs, with at least one adult present.

Display Nests: one or more birds congregating around a nest. Usually younger birds that are practising courtship rituals, but which may pair and use the nest for breeding.

Loafing Birds: birds not actively connected with feeding or breeding. Around nest sites, this can be mates of birds on nests, failed breeders or non-breeders.

Planimetric: is the study of plane measurements, including angles, distances, and areas.

1 Project Rational and Overarching Objective

South Georgia hosts globally important breeding populations of seabirds, including seven of the 31 listed ACAP (Agreement on the Conservation of Albatrosses and Petrels) species. The functional position of these birds in the Southern Ocean system means they are often used as an early indicator of change and markers of wider ecosystem health.

Of the seven ACAP species, one is listed as Near Threatened, three as Vulnerable and three as Least Concern on the IUCN Red List. In line with this, long-term monitoring of three of the albatross species from multiple sites at South Georgia are showing continued declines in their populations, but that the rates differ even between closely situated study sites (Poncet *et al*. 2017; Rackete *et al*. 2021). To obtain an improved picture of trends from the full suite of ACAP-listed species additional monitoring data is required from across the species and breeding sites located on South Georgia. As identified in the South Georgia ACAP Implementation Action Plan (GSGSSI 2017), expanding to other species and sites is needed now more than ever, following the successful rodent eradication on South Georgia and other ongoing habitat restoration work, which may lead to a step-change in the population trajectories of some ACAP species (especially White-chinned Petrels). Population trend data for species such as these is also fundamental for informing complementary studies on foraging ecology, identifying possible causes of decline which may be from land or sea-based threats, and informing subsequent management decisions.

Therefore, the overall objective of this project is to identify the most feasible options for expanding the current albatross and petrel monitoring programme on South Georgia, taking into account the logistical challenges at locations and considering the range of potential methodologies now available. The project will consider refinement and prioritisation of existing and future monitoring programmes to make the best use of available resources.

Development and implementation of a robust and cost-effective seabird monitoring programme that incorporates all priority species and locations across South Georgia will help to ensure early warning signs of continued or accelerated rates of change in population parameters will be detected. In turn these may act as trigger points for remedial action to minimise wider biodiversity losses and to maintain functions which underpin essential ecosystem services.

The project will be undertaken in two phases. The first phase was undertaken in 2021/22 and is reported on here. The second phase, which will be dependent on further resource being secured, will take place in 2022/23. In this first phase of the project, past and ongoing monitoring programmes have been reviewed, colony locations collated, and an initial comparison of monitoring options has been completed. Phase 2 of the project will prioritise species and locations where monitoring is required and evaluate a suite of possible options to establish logistically practical and scientifically robust monitoring programme(s) for the identified priority species. A set of recommendations for the most effective monitoring programme will be provided to GSGSSI for their consideration and implementation.

Both phases of the project will contribute to meeting a number of the guiding values under the new GSGSSI Protect Sustain Inspire Strategy (Environmental protection, Evidenced-based decision making, and Sustainability) and integrates into the Strategy's Priority Areas of Marine Protection, Local Science/Global Impact, and Facilitating Sustainable visits (GSGSSI 2021). It is also anticipated that these programmes will be contribute to the monitoring of the planned South Georgia Terrestrial Protected Area (GSGSSI 2022).

Project outcomes will also support UK policy objectives within the UK Overseas Territories Biodiversity Strategy (UKOTBS; Defra 2009) and the 25 Year Environmental Plan (25YEP; Defra 2018). The overarching objective of the UKOTBS is 'to enable the UK and Overseas

Territory Governments to meet their international obligations for the conservation and sustainable use of biodiversity in the Overseas Territories'. One of the strategic priorities for the UK Government's support of this objective includes obtaining data on the location and status of biodiversity interests. The outcomes of this project will help GSGSSI to collect information on ACAP listed albatrosses and petrels. This in turn will guide management decisions to benefit the conservation of these species, thereby also contributing to one of the six key areas in the 25YEP to protect and improve the global environment.

2 Background and Aims of Phase 1

The seven ACAP-listed species that breed on South Georgia are shown in Table 1:

Table 1. Details of the seven ACAP-listed species that breed on South Georgia.

Common Name	Species Name	IUCN Threat Category	Population Trend	Proportion of Global Population
Wandering Albatross	*Diomedea exulans*	Vulnerable	Decreasing	2nd largest
Grey-headed Albatross	*Thalassarche chrysostoma*	Vulnerable	Decreasing	Largest
Light-mantled Albatross	*Phoebetria palpebrata*	Near-Threatened	Decreasing	Largest
Black-browed Albatross	*Thalassarche melanophris*	Least Concern	Decreasing	3rd Largest
Northern Giant Petrel	*Macronectes halli*	Least Concern	Increasing	Largest
Southern Giant Petrel	*Macronectes giganteus*	Least Concern	Increasing	2nd Largest
White-chinned Petrel	*Procellaria aequinoctialis*	Vulnerable	Decreasing	Largest

A range of monitoring programmes – both one-off surveys and longer-term programmes – have been conducted on South Georgia in the last 45 years. The first of the whole-island surveys was conducted in the early 1980s, and a number of others in the early-to-mid 2000s and mid-2010s. These have been single or multi-species surveys, and carried out by a range of practitioners, using a variety of methods – see further details in Section 4. The most comprehensive long-term monitoring programmes on South Georgia are those conducted on Bird Island. These programmes are managed by the British Antarctic Survey (BAS) and have been running since the mid-1970s. They involve monitoring of all seven ACAP-listed species at both the whole-(Bird)-island scale and more intense monitoring at specific study colonies/sites – see further details in Section 3.

To date, there has been no substantive synthesis of the breadth of past and existing monitoring programmes run on South Georgia. Keeping this in mind, and in-line with the overarching objective of this project, the **specific aims of Phase 1** of the project were to:

1. Conduct a review of monitoring programmes on South Georgia for the seven ACAP-listed species, collating background information on when, where, how and who conducts/ed them.

2. Collate colony locations for the seven ACAP species that breed on South Georgia.

3. Undertake a comparison of the different monitoring techniques that might be suitable for ACAP-listed species.

As well as providing a much-needed synthesis of South Georgia seabird monitoring programmes, the outputs from tasks carried out to address Aims 1 and 2 will be instrumental for providing the baseline information required for the prioritisation exercises planned for Phase 2 of the project. The outputs from tasks carried out to address Aim 3 will provide the building blocks for developing and evaluating the options which will be presented to GSGSSI at the end of Phase 2. GSGSSI will then be able to consider these options in terms of how monitoring of ACAP species may be expanded on South Georgia in the future.

In the remainder of this report, **Section 3** details past and ongoing programmes for each of the seven ACAP-listed species, and links to the dataset that has been created to collate standardised information on each monitoring programme reviewed; **Section 4** outlines the range of different monitoring methods that are available, and presents the pros and cons for each; and finally, **Appendix 1** contains maps from relevant surveys which show the current known breeding sites of the seven ACAP-listed species at the South Georgia archipelago.

3 Monitoring Programmes by Species

Below are a series of detailed accounts by species of the various past and ongoing monitoring programmes for ACAP listed species around South Georgia. In addition to the written accounts below, alongside this report is a dataset comprised of all known monitoring programmes or surveys, information on colony location or nest locations, dates and/or seasons surveys were conducted, types of survey conducted (e.g. active nests, breeding pairs, etc.), how the survey was conducted (e.g. ground counts, yacht counts), who conducted the survey, and any available information on costs, source of information, etc. This dataset can be found online alongside this report at: https://hub.jncc.gov.uk/assets/d352ed16-8188-415b-ae9b-6d515fab21cc#jncc-report-711-monitoring-review-dataset.xlsx

3.1 Northern Giant Petrel (*Macronectes halli*) and Southern Giant Petrel (*Macronectes giganteus*)

Northern Giant Petrel (NGP) and Southern Giant Petrel (SGP) nest throughout the archipelago at a large number of sites, sometimes together (Figure 1 in Appendix 1). Nests are located generally within the vegetated coastal strip, but some occur on beach shingle. Both species exhibit strong breeding site fidelity and rarely move more than a few tens of metres between sites from year to year (Poncet *et al.* 2020).

3.1.1 Annual Monitoring on Bird Island (2000 to present)

Giant petrel demography has been monitored at Bird Island since 2000/01. Approximately 350 pairs of NGP and 150 pairs of SGP, in a well demarcated study area, have been monitored annually from 2000/01 to present. All breeding birds are metal ringed and colour-ringed and sexed by visual observations (bill length). Un-ringed adults are ringed during incubation in the first season they breed. Active nests are checked every 4–5 days until both partners are identified and visited weekly for the remainder of the breeding season until the outcome of the reproductive attempt is known (Gianuca *et al.* 2019). All nests with an egg are marked with a stake, the location recorded with GPS, and the nest visited weekly until the ring numbers of both incubating adults are recorded (Brown *et al.* 2015; Gianuca *et al.* 2019).

Between 2002/03 and 2004/05, nests were visited 2–3 times during the hatching period to confirm successful hatching. Nests were visited again shortly before the fledging period, when the chicks were ringed, and mass and bill length recorded. From the start of the 2005/06 season, nests have been visited every 1–2 days during the egg-laying period to record laying dates, and then weekly thereafter to record dates of hatching and fledging, or failure (Brown *et al.* 2015).

Island-wide ground counts of active nests of both species of giant petrels in incubation have been conducted at Bird Island in 1978/79, 1979/80, 1980/81 (Hunter 1984), 1995/96 (BAS unpublished data in Gonzalez-Solis *et al.* 2000), 2005/06 and 2006/07 (Poncet *et al*. 2020) and 2014/15 (BAS unpublished data), with the intention of repeating every 10 years (R. Phillips, pers. comm.). Methods in 2005/06, 2006/07 and 2014/15 are as described in Poncet *et al*. (2020), and above.

3.1.2 Annual Monitoring on Albatross Island (2005 to 2019)

Annual monitoring of NGP and SGP has been undertaken on Albatross Island in the austral summer seasons between 2005/06 and 2018/19. Monitoring was carried out by South Georgia Surveys under contract to GSGSSI. Counts of breeding pairs were undertaken at two study colonies: the lower study colony (LTM01) on the island's south coast (5.8 hectares at 10–20 m elevation); and the upper study colony (LMT02) on the east coast (3 hectares at 50–70 m elevation). Breeding pairs on active nests were indicated by the presence of either an egg or a chick in the nest. Geo-referenced co-ordinates for each nest were recorded using a hand-held GPS (Poncet unpubl. data; BAS Data Portal). Annual fieldwork reports and census data are held by GSGSSI.

The monitoring programme on Albatross Island was discontinued in 2020 as it was felt that the data from nearby Prion Island (where all-island censuses of NGPs and SGPs are undertaken) are sufficient for monitoring purposes for these species in this region (Poncet 2020).

3.1.3 Annual Monitoring on Prion Island (2005 to current)

Annual monitoring of breeding pairs of NGP and SGP on Prion Island began in the 2005/06 season, the census being carried out in January of each season by South Georgia Surveys under contract to GSGSSI. The census area covers the entire island (34 hectares). Breeding pairs on active nests are indicated by the presence of either an egg or a chick in the nest. Geo-referenced co-ordinates for each nest are recorded using a hand-held GPS. Annual fieldwork reports and census data are held by GSGSSI.

3.1.4 Annual Monitoring in Cumberland Bay (2014 to current)

Annual monitoring of breeding pairs of NGP and SGP on Thatcher Peninsula in Cumberland Bay is carried out by BAS for GSGSSI as part of the KEP science plan. Sites monitored are Discovery Point, Maiviken, Harpon Bay and Greene Peninsula. Monitoring began at the first three locations in 2014/15 and on nearby Greene Peninsula in 2015/16. Nests positions are recorded using a hand-held GPS. Nests are monitored at three points throughout the season to give a count of nests, hatched chicks and chicks that survive to fledging. Weights and bill length are also recorded from chicks shortly before fledging.

3.1.5 Whole-Archipelago Survey – The South Georgia Breeding Birds Survey (1986/87 and 1987/88)

This was a comprehensive and systematic survey of the presence and absence of all breeding bird species (and rodents) at South Georgia. The surveys were carried out for P.A. Prince of BAS during the 1985/86, 1986/87 and 1987/88 austral summer seasons. Most of these surveys were undertaken in collaboration with S. Poncet, chartering SV *Damien II*. The survey was based on the 5 km × 5 km base grid and covered the entire coast and the accessible inland areas of South Georgia. Landings were also made on a large proportion of the isolated offshore islands and stacks. Breeding population estimates were made from breeding pairs counts for each species in each 5 km square, colony locations were noted on sketch maps and the 1957 DOS South Georgia map (Prince & Poncet, unpubl. data). Population data for giant petrels was presented in Patterson *et al*. (2008) and presence/absence data for 5 km squares in Trathan *et al*. (1996).

3.1.6 Whole-Archipelago Survey (2005/06 and 2006/07)

Both species of giant petrels breed around the entire coastline of South Georgia and on many offshore islands. Ideally, censuses of breeding giant petrels at South Georgia are best carried out after the end of egg laying and before hatching. The period November to January offers the best overlap in the breeding cycles of the two species.

The location of many giant petrel colonies was reported by BAS field parties in the 1960s and 1970s (BAS, unpubl. data), and by the 1985/86-1986/87 South Georgia Breeding Birds Survey (Prince & Poncet 1996; Patterson *et al.* 2008) and subsequent fieldwork (BAS and S. Poncet, unpubl. data). The first archipelago-wide census for these species was carried out by South Georgia Surveys for GSGSSI in 2005/06 and 2006/07, and with supplementary counts at some locations in 2007/08. The results of the survey are published in Poncet *et al.* (2020). The survey was conducted over two consecutive breeding seasons (2005/06 and 2006/07) owing to the wide geographical distribution and often difficult to access locations of giant petrels, and in order to cover all breeding locations during the recommended November to January period (S. Poncet, pers. comm.).

The 2005/06 and 2006/07 surveys took place during the early chick-rearing period for NGP, and the late egg-laying to early hatching period of SGP. The timing was chosen to ensure the most practical overlap between the staggered breeding phenology of the two species, and to avoid snow cover, which is common in early November and increases detection errors (Poncet *et al.* 2020). Specifically, the 2005/06 census was conducted from 17 November 2005 to 28 January 2006 (43 days), with most surveys completed by 13 January 2006. In 2006/07, counts were done from 19 November 2006 to 2 January 2007 (56 days). Two additional breeding locations were surveyed in January 2008. The majority of counts were obtained by recording the GPS position of each active giant petrel nest, which indicated a breeding pair. These counts were then corrected for egg loss using data derived on Bird Island, where nests were regularly monitored throughout the two seasons (BAS Datal Portal, Poncet *et al.* 2020), and for detectability (Poncet *et al.* 2020) – see further details on correction factors below.

The majority of breeding locations at South Georgia were surveyed by shore parties deployed by inflatable dinghy and sea kayaks from SV *Golden Fleece*, with additional support during 2005/06 provided by SV *Tara*. At each site, 2–6 people systematically surveyed the entire area from the shoreline to the upper limits of fellfield habitat (Poncet *et al.* 2020). In the first season, the teams surveyed over 150 locations around the island, estimated to contain approximately half of the island's giant petrel breeding sites. Fieldworkers walked a total of over 600 km and a total of 4,539 pairs of NGP and 3,253 pairs of SGP were counted. These are uncorrected counts (i.e. not adjusted for egg and/or chick losses) and do not include Bird Island counts (Poncet *et al.* 2020). SV *Golden Fleece* covered a total of about 1,700 km around the island, putting field parties ashore at the 150 landing sites, and the land-based party paddled a total of 481 km (S. Poncet, pers. comm.). In the second season, over 100 additional areas were surveyed, estimated to contain approximately the other half of the island's giant petrel breeding sites. SV *Golden Fleece* covered over 1,800 km; fieldworkers walked over 600 km and a total of 2,051 pairs of NGP and 1,554 pairs of SGP were counted (before correcting for egg and/or chick losses and not including counts for Bird Island or those areas previously surveyed in 2005/06) (Poncet 2007).

The majority (> 90%) of active nests were counted directly and the nest GPS co-ordinates and altitude were recorded. A small minority of breeding aggregations were surveyed from a greater distance, either on land or from the support vessel. The active nest count of these birds was less accurate. Finally, nesting birds at some locations were not counted directly, but the approximate area of occupancy and species were recorded by observers either during a landing or from the support vessel; the number of breeding pairs was then estimated from surface areas mapped using mapping software OziExplorer, assuming the same density as at adjacent sites with similar nesting habitat (Poncet *et al.* 2020).

In order to account for differences between the number of pairs that attempted to breed and the number counted or estimated during the survey period, two correction factors were applied. The first accounted for the proportion of nests (of each species) that would have already failed since laying, and for the small proportion of SGPs that would not have initiated breeding by the time of the survey. The values used on each survey date for the different species were based on data from the intensively monitored study areas at Bird Island where all nests were marked and monitored daily during the egg-laying period, then weekly thereafter to record failure or fledging. Mean failure rates over four seasons (2005/06–2008/09) for a total of 266/364 and 141/185 nests of NGPs and SGPs, respectively, were used as the correction factor for the survey data in order to produce estimates of the total numbers of giant petrel pairs that attempted to breed at South Georgia in the two survey seasons (Poncet *et al.* 2020).

The second correction factor served to account for detection errors and specifically the probability that observers may have missed some nests. To assess count accuracy, five observers independently counted the number of active giant petrel nests at three breeding locations: Grass Island (9 December 2005), Corral Bay (3 December 2006) and Cape Best (28 December 2006). These locations were considered to encompass a range of habitats and terrain similar to other areas where giant petrels breed at South Georgia. Each observer recorded the GPS coordinates of each nest found. GPS coordinates of all nests found by all observers were then compiled to obtain the total number of nests at the three locations. Individual observer detection probability was then calculated as the number of nests found by an observer divided by the total number of nests (Poncet *et al.* 2020).

In order to assess trends in the breeding population of each species, a subset of the 2005/06 and 2006/07 data was compared with selected count data from an earlier survey – the South Georgia Breeding Birds Survey 1986/87 and 1987/88 (Prince & Poncet 1996). Timing of breeding and failure rates in the 1980s were assumed to be the same as in the 2005/06 and 2006/07 surveys, and hence, the same correction factor was applied for the relevant survey date; a detection probability correction factor of 0.85 was also applied, based on the estimated survey accuracy at the time of 10–15% (Poncet *et al.* 2020).

A small number of known breeding locations were not surveyed in 2005/06 or 2006/07. Breeding pairs at these locations were estimated from the counts in the 1986/87 and 1987/88 surveys, first by correcting as above and then accounting for the population increase in each species by adjusting the corrected count by the mean percentage change in numbers of birds breeding in the relevant bioregion (Poncet *et al.* 2020).

A total of 169 NGP and 161 SGP breeding locations were surveyed during the 2005/06 and 2006/07 census. Of these, 137 and 121 had active NGP and SGP nests, respectively, which were widely distributed across the coastal zone of the archipelago. The total number of nests counted in the field (not including Bird Island) was approximately 6,600 NGP and 5,700 SGP. After applying correction factors for egg and/or chick loss and detectability, the estimated breeding population including Bird Island was 15,398 pairs of NGP and 8,803 pairs of SGP. The largest breeding aggregations of NGP were at Bird Island and Hope Valley, both in the north-west bioregion. The largest concentrations of SGP were at Cape

Charlotte (central north bioregion) and Bird Island. NGP had increased by 74% and SGP by 27% since the 1980s surveys (Poncet *et al.* 2020). South Georgia Survey data, geo-referenced co-ordinates for nests and population estimates by breeding location were forwarded to GSGSSI and BAS.

3.2 White-chinned Petrel (*Procellaria aequinoctialis*)

White-chinned Petrels (WCP) are found throughout the archipelago in suitable habitat, but predominantly on the north-eastern side of the main island (see Figures 2 and 3 in Appendix 1).

3.2.1 Annual Monitoring on Bird Island (2014/15 to present)

Annual counts for breeding pairs have been conducted in a small study plot on Bird Island since 2014/15 (R. Phillips, pers. comm.). The study plot is visited once a week from the date the first egg is laid to the date the first chick fledges. Occupancy is determined by tape playback, burrow scoping, and/or furkling wire. Correction factors are applied to determine number of occupied burrows and chicks fledged (breeding success) each year (R. Phillips, pers. comm).

There is a plan to install a network of PIT tag (micro-chip) detectors at Bird Island in the early 2022/23 season that will log attendance of white-chinned petrels at burrows. The data will be used to examine long-term changes in demography (survival, breeding frequency, breeding success, recruitment), mate change and nest attendance (providing data on foraging trip duration; chick provisioning rates; and arrival, laying, hatching, fledging and migration dates) in relation to environmental variation.

3.2.2 Bird Island-wide Survey (1997/98, 1995/96, 2016/17)

Repeats of the 1980/81 survey conducted by Hunter *et al*. (1982) on Bird Island were undertaken in the breeding seasons of 1997/98 (Berrow *et al*. 2000a) and 2016/17 (BAS unpublished data). In the original 1980/81 survey, Hunter *et al.* (1982) randomly selected sampling quadrats within a 60 m x 60 m grid covered the entirety of Bird Island (which is *c.* 500 hectares). Quadrats surveyed in 1997/98 were not an exact repeat of those done in 1980/81 but were within 50–100 m and in a similar habitat (Berrow *et al*. 2000a). Quadrats surveyed in 2016/17 were also in similar habitat, but not necessarily within 50–100 m of those in the previous surveys. For each quadrant, habitat information was recorded, alongside aspect and slope.

Breeding success was monitored in a sample of burrows in 1995/96. Breeding success was determined by inspecting these burrows every two days prior to incubation until an egg was laid and again towards the end of chick rearing (Berrow *et al.* 2000a).

All birds found in 29 burrows were ringed during summer 1995/96 and their identities and reproductive performance recorded in each of the following two years. Both partners were ringed in four additional burrows in 1996/97 and monitored in 1997/98. Breeding frequency was defined as the proportion of birds breeding again in subsequent seasons and was calculated using recaptures in subsequent years (1997/98 and 1998/99).

3.2.3 Whole-Archipelago Survey (2005/06 and 2006/07)

(WCPs are very difficult to survey in their entirety around South Georgia due to being burrow-nesting, the difficult terrain involved, the scale of survey required and large number of birds. Therefore, a whole island survey means that the population estimate has to be heavily extrapolated from small study plots. In the 2005/06 and 2006/07 surveys, the size of the population was calculated based on the area of suitable habitat and the density of occupied burrows in different regions. From these surveys, 670,000 occupied nests were estimated for the whole island at mid-incubation, representing 0.9 million pairs of breeding-age birds (Martin *et al.* 2009).

Density estimates were obtained by walking straight-line transects across areas of suitable habitat and stopping every *c*. 10 m to examine the ground within a sampling plot of 3 m radius. The location and altitude of each sampling plot was recorded using a hand-held GPS unit, and the angle of slope at that point was estimated by eye. Transects were always walked from the coast up to the upper limit of tussac (or vice versa) in order to sample across the likely density gradient of WCP nests, and not parallel to the coast or along ridges (where many colonies occur). Starting points of these transects were spread around the coast of the island to give as representative a coverage as possible in the time available. Landings were made in areas of suitable nesting habitat (i.e. tussac-dominated vegetation), and at each site transects were as widely separated as possible (Martin *et al.* 2009).

Very little of South Georgia is flat, so planimetric data substantially underestimates the surface area of habitats on the island, especially that of tussac which invariably occurs on slopes. Conversion from planimetric land area to contour area in each zone was made by dividing the zone into 50 x 50 m planimetric squares, then multiplying the area of each square by the reciprocal of the cosine of the slope of that square, taken from a digital elevation map with 50 m contours (Martin *et al.* 2009).

A recording of WCP burrow-calls (both sexes combined) was played down each potentially occupied burrow with a digital voice recorder for 15 seconds or until a response was heard, whichever was the shorter (Berrow 2000a). To calibrate the effectiveness of the playback technique in determining whether a burrow was occupied or not, a sample of burrows from which no response was heard was then examined using an infra-red illuminated scope (Sandpiper Technologies, CA, USA). This sample was obtained from numerous sites at different times during the study (Martin *et al.* 2009).

The total number of pairs of WCPs that occupied a burrow during the incubation period (and were therefore assumed to have laid an egg) on South Georgia was, therefore, estimated from the total vegetated area in the zone corrected for slope, the proportion of vegetation that is tussac-dominated in that zone, the number of occupied burrows in all transects in that zone (i.e. number of vocal responses), the number of non-responsive burrows, the proportion of the sample of scoped non-responsive burrows that were occupied, and the area of ground searched for burrows in each zone. For more information on the exact methods used to quantify the whole island count for WCP see Martin *et al.* (2009).

3.2.4 Post-rat and Reindeer Eradication Monitoring (2012 to present)

Rodents were likely introduced to South Georgia with the first sealing expeditions. As human exploration and exploitation on South Georgia prospered, and shore-based whaling and sealing camps were established throughout much of the northern and south-western coast, rats spread to infest nearly two thirds of the island's coastline while mice were known to be present in just two areas on south-western coast. Rats and mice eat the eggs and chicks of many ground-nesting bird species including potentially WCPs. The South Georgia Heritage Trust undertook an operation to eradicate rodents from South Georgia. In 2011, 2013 and 2015, three phases of baiting were conducted to counter the invasive threat, mainly using aerial baiting by three helicopters alongside hand baiting inside former whaling stations. Following extensive monitoring, South Georgia was declared rodent free in 2018.

Reindeer were introduced to South Georgia by Norwegian whalers in order to provide a familiar food source and to vary an otherwise limited diet. The reindeer were also a reminder of home and hunting them provided a recreational activity. Reindeer were introduced to two discreet areas of South Georgia, the Barff and Busen Peninsulas. Combined, the areas occupied by reindeer equate to the largest snow free, and consequently most biologically productive, part of the island. Extensive overgrazing of tussac grassland caused large areas to become completely denuded of vegetation. The removal of the vegetation cover and topsoil had negative consequences for native burrowing birds such as prions and petrels as nest entrances are exposed and burrows are more prone to collapse. Between 2013 and 2016 GSGSSI used a combination of herding and ground shooting methods to successfully eradicate reindeer from the island.

Baseline data on burrowing seabird abundance commenced in December 2012 for GSGSSI (GSGSSI, unpubl. Data). From 2012 onwards, burrowing petrel transects, including for WCP, have been conducted at four sites – Maiviken on the Thatcher Peninsula; Carlita Bay on the Busen Peninsula; Sörling Valley on the Barff Peninsula; and Albatross Island in the Bay of Isles (GSGSSI, unpubl. data). The purpose of these surveys was to monitor recovery of burrow-nesting seabird species (as well as vegetation and other habitats and species) following the removal of invasive species, notably reindeer and rats from South Georgia.

At each of the four sites, the distribution of burrowing petrel colonies was determined on the ground, as well as at Hestesletten. Eight transects were generated in Garmin's Basecamp software to cover areas with existing burrows and adjacent areas of apparently suitable habitat (see Figures 4 and 5). The transect co-ordinates were transferred to handheld GPS units. Each member of the team was allotted two transects, that were walked with the aid of tracks on the GPS. Any burrows encountered within 1 m of the transect line, on both sides, were marked with a waypoint. The occupancy of each burrow was determined by playback and, in some cases, a burrow-scope. Each burrow was categorised as follows:

1. Confirmed active (playback response)
2. Apparently active (sign of digging, fresh droppings, etc.)
3. Apparently inactive (overgrown)
4. Collapsed (GSGSSI, unpubl. data).

WCP burrows are very patchily distributed, and it was decided to use a combination of quadrats and transects to record nest density in a manner that would allow changes in density and/or distribution in the future to be recorded. At each site, five WCP quadrats were sampled (GSGSSI, unpubl. data). The centre of each quadrat was marked with a wooden stake. With the aid of a 5 m long piece of string, a circular area with a radius of 5 m was walked. Any burrows within this area were investigated and the status of each recorded. The occupancy of each burrow was determined by playback. Additionally, four 15 m long transects radiating out from the central quadrat were sampled. Any burrows within 1 m either side of these transects were recorded in 5 m sections.

3.3 Wandering Albatross (*Diomedea exulans*)

The majority of the Wandering Albatross (WNA) population breed in the northwest of the archipelago, including Bird, Albatross and Prion Islands, and on Annenkov Island. The remainder breed at widely scattered sites along the south coast (Poncet *et al*. 2017; GSGSSI 2016). (See Figures 7 and 8 in Appendix 1).

3.3.1 Annual Monitoring on Bird Island (1972 to present)

At Bird Island, which supports the majority (*c.* 60%) of the South Georgia population (GSGSSI 2016), annual monitoring of WNA demographic parameters, including breeding success, began in 1980 (Pardo *et al.* 2017).

All-island counts of breeding pairs of wandering albatrosses were made in 1961/62 to 1963/64, and annually since 1971/72 to present, with the exception of 1974/75 (Croxall 1979; Pardo *et al.* 2017).

WNA have been studied intensively in the Wanderer Ridge study area since 1972. The identity of all ringed breeding adults and non-breeders is recorded, and any un-ringed adults are ringed. All chicks are ringed each year, and nests visited daily to weekly, depending on the stage, to record breeding outcome. All other areas on Bird Island are visited every 1–2 weeks in the early season to record active nests (with eggs), and at monthly intervals thereafter to record breeding outcome (Pardo *et al.* 2017). All nests with eggs are staked and mapped with handheld GPS units (Fretwell *et al.* 2017).

The ringing of chicks and adults has enabled examination of juvenile (0–3 years), immature (from first return to first breeding) and adult survival rates, as well as individual reproductive success (Froy *et al.* 2013, Pardo *et al.* 2017).

3.3.2 Annual Monitoring on Albatross and Prion Islands (1999 to current)

Annual monitoring of WNA on Albatross and Prion Islands began in 1999. It continued until 2020 on Albatross Island and is ongoing for Prion Island. Fieldwork involves ground counts in January to obtain the number of active nests with eggs. The position of each nest is recorded using a hand-held GPS in association with various environmental parameters including presence of fur seals and habitat type. Breeding success data was collected for Prion Island birds in 1998/99 and 1999 to 2000, with routine annual monitoring commencing in 2007/08 and continuing until the present (Poncet 2021). Young chicks are censused on a day visit to Prion Island in late March/early April and surviving chicks in late October/early November just prior to fledging.

The programme is managed by South Georgia Surveys for the GSGSSI with transport on FPV *Pharos SG*. January fieldwork is carried out by personnel from South Georgia Surveys. From 1998/99 to 2019/20, fieldworkers camped for up to two weeks on Albatross Island during the first half of January, followed by a day visit to Prion Island on or about 12 January. The twice annual chick counts on Prion Island are carried out for GSGSSI in late March/early April by BAS personnel from King Edward Point on a day visit. Census data are collated and managed by South Georgia Surveys and forwarded to GSGSSI with an annual report.

The decision to discontinue fieldwork on Albatross Island in 2020 was in part driven by the results of analyses of the 20-year WNA dataset (1999–2018) completed by Carola Rackete. This study showed no difference in population trends between Albatross and Prion Islands (Rackete *et al.* 2020). In addition, the ability to obtain census data using Un-manned Aerial Vehicles (UAV) (drone) imagery was successfully demonstrated by John Dickens from BAS in 2019 and 2020 (Dickens *et al.* 2021), and the potential for satellite imagery to provide equivalent precision data is currently being investigated by BAS (P. Fretwell, R. Phillips and M. Atard, pers. comm.). A day's fieldwork on Prion Island in January would still be required for ground-truthing UAV and satellite imagery, and to continue the annual ground counts of breeding pairs of NGP, SGP and Brown Skuas (Poncet 2021).

3.3.3 Whole-Archipelago Survey (austral winters of 1984 and 1985)

Wandering albatross chicks at all known breeding sites were counted between 2 September and 12 October 1984 (Clark 1984) and between 3 and 28 August 1985 (Clark 1985). BAS personnel counted birds on Bird Island, while the remainder of sites were surveyed by two fieldworkers deployed from the yacht SV *Totorore*. The counts were adjusted using nest failure rates at Bird Island, to give a breeding pair estimate of 2,230 (BAS Data Portal).

3.3.4 Whole-Archipelago Survey (2003/04)

Wandering albatrosses were surveyed by ground counts carried out during mid-incubation between 30 December 2003 and 31 January 2004. The number of nests found was then multiplied by a correction factor of 1.0297 to account for nests that failed prior to the survey. This correction factor was derived from the long-term study area on Wanderer Ridge on Bird Island where daily records are made of nests and when they fail (BAS unpubl. data). This produced an overall breeding pair estimate of 1,553 pairs (BAS Data Portal; Poncet *et al.* 2006). Annenkov Island and Albatross Island were censused from field camps, Bird Island by BAS personnel and the remaining 27 sites were censused by shore parties deployed from the yacht SV *Ada*. Landings were made at all known breeding sites, with the exception of Chaplin Head and the westernmost headland on Saddle Island where no birds were seen when viewed with binoculars from the yacht. At each site, at least two people walked the entire area searching for nesting birds and made observations from high ground to ensure that none were missed. The grass near each nest was colour-marked to prevent double counting. Positions of nests with eggs, empty nests and display nests were recorded on large-scale sketch maps and their locations recorded using a handheld GPS. Full details of the methodology and results can be found in Poncet *et al.* (2006).

3.3.5 Whole-Archipelago Survey (2014/15)

Twenty-eight of the 34 known WNA breeding locations were surveyed during mid-incubation in January 2015 using a similar methodology to the whole island survey of 2003/04. The census of breeding pairs of WNA on Albatross Island was conducted from a field camp in January 2015. The majority of remaining locations were surveyed by shore parties based on the MV *Hans Hansson* (S. Poncet, pers. comm.). Small numbers of birds were recorded at four additional locations not reported in the 2003/04 survey. The number of nests was adjusted for areas not surveyed and for failures prior to the survey, using data from the long-term study area on Wanderer Ridge on Bird Island, to produce an estimate for all of South Georgia, with the exception of Annenkov Island (BAS Data Portal).

Survey methods and corrections for egg loss prior to surveying followed Poncet *et al.* (2006). Observers worked systematically across each site, searching for, and counting, all nesting birds. All active nests (with an egg), empty nests (with egg-shell fragments) and displaying birds were counted separately, and the coordinates for each were recorded using a hand-held GPS unit. Rough sea conditions prevented landings at six locations: Chaplin Head and Ranvik, where no birds were observed during the 2004 survey (Poncet *et al.* 2006); Nilse Hullet and Trollhul North where four nests and one nest, respectively, were reported in 2007 (S. Poncet, pers comm.); Aucellina Point where two nests were reported in 2013 (D. Poncet, pers. comm.); and at Proud Island. Although it was not possible to land on Proud Island, a count of apparently occupied nests was made using binoculars from the vessel. This count comprised three nests, and although it is possible that some of these nests were occupied by loafing birds, it was assumed that they all had eggs. Due to logistical constraints, Annenkov Island was not surveyed in 2014/15. The Bird Island population was surveyed by BAS personnel. Full details of the methodology and results can be found in Poncet *et al.* (2017).

3.4 Black-browed Albatross (*Thalassarche melanophris*) and Grey-headed Albatross (*Thalassarche chrysostoma*)

Black-browed and grey-headed albatrosses are known to breed at 22 locations on the mainland and offshore islands of South Georgia. There are about 15 principal Black-browed Albatross (BBA) and five principal Grey-headed Albatross (GHA) breeding locations (see Figures 9 and 10 in Appendix 1), with sometimes mixed colonies of both.

3.4.1 Annual Monitoring on Bird Island (1976 to current)

3.4.1.1 Black-browed Albatross

BBA have been studied intensively in three colonies at Bird Island. In colony H from 1976, colony J from 1996, and colony N from 2008 (see Figure S1 in Pardo *et al.* 2017), all breeding adults and non-breeders are identified on daily rounds in the early season. Nests are then visited from the egg-laying period onwards at daily to weekly intervals, depending on the stage, to record breeding outcome, and all chicks are ringed each year (Pardo *et al.* 2017).

Annual demographic monitoring takes the form of ringing chicks and adults to look at juvenile (0-3 years), immature (from first return to first breeding) and adult survival rates, as well as individual reproductive success (Froy *et al.* 2013; Pardo *et al.* 2017).

In addition to the demographic monitoring conducted in the study colonies, BAS initiated a programme in 1976/77 to census all nesting BBA at Bird Island. These counts have been repeated at roughly ten-year intervals, and serve to complement the more detailed demographic monitoring, thereby enabling an accurate assessment of the population trend of BBA at Bird Island (GSGSSI 2016).

The colonies at Bird Island are surveyed by direct ground counts, and numbers adjusted for breeding failure using data from the study colonies that are visited regularly (Poncet *et al.* 2006, 2017). The error associated with these counts is therefore expected to be very low.

For future reference it is noted here that the Conservation Action Plan for BBAs at South Georgia (GSGSSI 2016) recommended that in order to improve the representativeness of the monitoring strategy for BBA at South Georgia, it would be useful to initiate more regular (annual) counts at additional sites away from Bird Island, including colonies at the south-east end of the island, to monitor numbers of birds breeding and breeding success. The expansion of the annual monitoring programme would also help facilitate a better interpretation of the results of the decadal archipelago-wide surveys.

3.4.1.2 Grey-headed Albatross

There are annual counts of GHA at 11 colonies at Bird Island (*c*. 62% of the total Bird Island population) (GSGSI 2016).

In addition, GHA have been studied intensively in two colonies at Bird Island. In colony E (see Figure S1 in Pardo *et al.* 2017) from 1976 to the present, all breeding adults and non-breeders are identified on daily rounds in the early season. Nests are then visited at daily to weekly intervals, depending on the stage, to record breeding outcome, and all chicks are ringed each year. In colony B (see Figure S1 in Pardo *et al.* 2017) from 1997 to 2007, monitoring involved three checks to identify known-age breeding adults during the breeding season; since 2008, the monitoring protocol is the same as in colony E. This annual demographic monitoring enables determination of juvenile (0–3 years), immature (from first return to first breeding, 3–12 years of age) and adult survival rates, as well as individual reproductive success (GSGSSI 2016).

In addition to the annual monitoring conducted in the study colonies, BAS initiated a programme in 1976/77 to census all nesting GHA at Bird Island. These counts have been repeated at roughly 10-year intervals and serve to complement the more detailed annual monitoring efforts, thus enabling an accurate assessment of the population trend of GHA at Bird Island (GSGSSI 2016).

The colonies at Bird Island are surveyed by direct ground counts, and numbers adjusted for breeding failure using data from study colonies that are visited regularly. The error associated with these counts is therefore considered to be very low.

3.4.2 Whole-Archipelago Survey (1980s)

The first census of breeding pairs of South Georgia BBA and GHA populations was conducted in 1985/86 using yacht-based counts (Prince *et al.* 1994; Prince & Poncet 1996). However, this survey did not assess counting error, nor account for diurnal variation in attendance or previous breeding failure and loafing birds, and it did not include a census of Clerke Rocks (S. Poncet, pers. comm.).

3.4.3 Whole-Archipelago Survey (2003/04)

With the exception of a small inland colony on Annenkov Island, and Bird Island, all known breeding sites of BBA and GHA were photo-surveyed between 23 November and 7 December 2003 (Poncet *et al.* 2006). Colonies were photographed from the deck of the yacht SV *Ada*, at a distance of 100–200 m, the exact distance and angle varying according to the topography, and the prevailing wind and sea conditions. The inland colony on Annenkov was photographed from onshore. The photos from each colony were subsequently stitched using Adobe Photoshop and drawing software was used to mark each individual albatross on a nest. The counts were then adjusted according to the time of day the photograph was taken and the value was then corrected to account for nest failures using data from Bird Island where colonies are regularly surveyed for failures throughout the breeding season (Poncet *et al.* 2006).

Each colony and section of coast occupied by BBA and GHA was photographed with a D100 Nikon Digital SLR camera using JPEG Fine resolution (2 MB file size) and images were downloaded to computer. Colonies or areas with albatrosses were photographed twice, initially with a wide-angle lens (digital equivalent = 25–52 mm) and then close-up with a vibration reduction lens (105–300 mm). The wide-angle photographs of the coastline enabled collages of close-up colonies to be located in the landscape. Groups of albatrosses in colonies were photographed at a resolution that permitted identification of individual birds as albatrosses (and not as white-coloured rocks or snow), and in most cases identification of species. To achieve consistency in the scale of birds and landmarks in the photographs, close-up images were taken from similar distances. The lens was usually set at 200 mm digital equivalent except when colonies were greater than about 500 m from the yacht, in which cases the lens was set at 300 mm (Poncet *et al.* 2006).

In cases where colonies lacked distinct boundaries, count areas were defined by means of lines drawn across ridges and spurs. Counts of all nesting albatrosses were then made by magnifying the image to view all individual birds on the computer screen, marking each with a coloured circle as they were counted. All photographic counts were conducted by the same two people, one of whom had overall responsibility for the on-screen counts. Images which contained birds that could not be identified to species level were counted separately. In single-species colonies, unidentified birds were assumed to be of that species; in mixed colonies, unidentified birds were apportioned based on the ratio of BBA and GHA that were identified. Full details of the methodology, correction factors applied (e.g. diurnal variation and nest failures), and results can be found in Poncet *et al.* (2006).

3.4.4 Partial-Archipelago Survey (2014/15)

Thirteen of the 22 BBA and GHA breeding locations surveyed in November-December 2003 were resurveyed in December 2014 using the 2003/04 protocol (Poncet *et al.* 2017).

Colonies at 12 of the 13 breeding locations were photographed from a rigid hull inflatable boat (RHIB), supported by the GSGSSI's fisheries patrol vessel, FPV *Pharos SG*, and were later counted in their entirety (Poncet *et al.* 2017). Colony positions within the breeding locations were already well documented from previous censuses (Prince *et al.* 1994; Poncet *et al.* 2006).

At Bird Island, a subset of seven BBA and 11 GHA colonies were counted (on the ground) in November 2014 as part of the annual monitoring programme and compared to the ground counts of the same study colonies in 2003/04. Five of the colonies were also photo-surveyed in order to estimate the error associated with the photographic survey methodology (see below) (Poncet *et al.* 2017).

The photographic protocols followed those used in 2003/04 (Poncet *et al.* 2006). The position from which the photographs were taken, and hence the angle at which the colony was photographed, was matched as closely as possible with the positions used in 2003/04. This was achieved during the survey by aligning reference photographs and annotated marine charts from the 2003/04 census with the colonies being photographed in 2014/15. The coordinates of all these positions were recorded with a GPS unit, to serve as a reference for future surveys (Poncet *et al.* 2017).

To determine potential observer bias, albatrosses from a subset of 12 colonies (ten BBA and two GHA colonies), chosen to represent a range of colony sizes and locations, were counted independently by the two counters, and the results compared. All individual birds on the photographs were counted, which may have resulted in inflated estimates of breeding pairs if a substantial number of 'loafing' birds were in the colony at the time of the survey; no correction factor was applied to this. To account for diurnal variation in attendance of non-breeding birds (Poncet *et al.* 2006), photographic counts of a BBA colony at Bird Island were conducted at two-hourly intervals from 10:00h to 20:00h during the survey period.

To account for diurnal variation, counts at colonies were standardised to represent the number of birds likely to be present at 14:00h, by multiplying the photographic count by the reciprocal of these proportions. Photographic counts of colonies in November 2014 were corrected simultaneously for breeding failure and the presence of loafers following the approach of Poncet *et al.* (2006) (Poncet *et al.* 2017).

The accuracy of the photographic survey methodology was assessed by comparing estimates of the total number of breeding pairs from the vessel-based photographic counts (corrected for diurnal variation, including loafing birds, time of day and breeding failure) with those derived from ground counts corrected for breeding failure at four BBA colonies (comprising a total of 1,073 breeding pairs) and two GHA albatross colonies (comprising 1,298 breeding pairs) at Bird Island (Poncet *et al.* 2017).

Of the colonies photographed at two locations, Paryadin North and Paryadin South, ten could not be counted due to poor visibility and the presence of snow, which made it difficult to distinguish individual albatrosses. Counts for these colonies were extrapolated using the mean change in the number of breeding pairs from 2003/04 to 2014/15 at the remaining colonies within the Paryadin North and South locations that were counted in both years. The extrapolated figures for these 10 colonies amounted to 153 BBA and 931 GHA, representing 3.9 and 5.8%, respectively, of the combined estimate for these two locations in 2014 (Poncet *et al.* 2017).

3.5 Light-mantled Albatross (*Phoebetria palpebrata*)

Light-mantled Albatross (LMA) are distributed throughout the archipelago, wherever suitable cliff sites are present (see Figure 11 in Appendix 1).

3.5.1 Annual Monitoring on Albatross and Prion Islands (1999 to 2005)

Counts of breeding pairs of LMAs were carried out in January on Albatross and Prion Islands from 1999 to 2005. However, initial numbers were very low, and often no birds were present in January at the time surveys were conducted, so a decision was taken to stop conducting the surveys (S. Poncet, pers. comm.).

3.5.2 Annual Monitoring on Bird Island (2000/01 to present)

Monitoring of Apparently Occupied Nests (AON) for LMA began in 2000/01. In 2002/03 it was extended to include monitoring of hatched chicks and (nearly) fledged chicks, thereby enabling population and productivity (breeding success) to be calculated (R. Phillips, pers. comm.). Surveys are conducted in the dedicated study plot extending from Cave Crag to Mountain Cwm in mid-November, mid-January and early-May.

3.5.3 Whole-Archipelago Survey (1971 to 1981)

A census of Light-mantled Albatross (LMA) was conducted during the austral summer of 1976-77 at Elsehul (54°00'S, 37'58'W) on the north-west mainland of South Georgia and on the Barff Peninsula (54°20'S, 36'20'W) in the Cumberland Bay area (Figure 12 in Appendix 1). Supplementary information was obtained in 1977/78 and 1978/79 at Schlieper Bay and Bird Island, respectively. Figure 12 (Appendix 1) shows the general breeding distribution of LMA on South Georgia. This species, unlike GHA and BBA, breed all around the island, nesting wherever suitable cliff sites are present. To obtain a coarse estimate of the size of the South Georgia population, breeding pairs along *c*. 60 km of coastline at Elsehul, Barff Peninsula and Schlieper Bay were counted, primarily in November during incubation (Thomas *et al.* 1983). This number was then multiplied by the estimated 800 km of coastline suitable for breeding. With a mean breeding density of 6.0 pairs km^{-1}, the total annual breeding population at the time of the survey was estimated to be about 5,000 pairs. However, given LMA is a biennial breeder, Thomas *et al.* (1983) estimated the total breeding population to be *c.* 7,500 pairs.

4 Comparison of Monitoring Techniques

4.1 Introduction

The aim of this section of the report is to provide a broad comparison of methods that have or could be used to monitor ACAP species breeding at South Georgia.

The first step to consider is the aim of each monitoring programme. If the aim is to carry out a census of breeding birds, then it is necessary to obtain an estimate of the total number of pairs that attempt to breed (lay an egg) in a given year. Therefore, it is important that the counting unit is clearly defined, and the census is timed to take place as close as possible to the optimum period to measure the identified parameter. In the case of a breeding birds census, if the census is conducted too early in the breeding season, the count will not include all the birds that attempt to breed. If it is conducted too late it will not include birds that have laid eggs but failed and left the colony prior to the census. In both cases, the census results will underestimate the number of birds attempting to breed. However, it can be possible to apply suitable correction factors. It should also be noted that censuses can overestimate breeding population size if loafing birds are included in the count (Wolfaardt & Phillips 2013).

Censuses and counts of breeding pairs can be conducted using a number of different methods. However, monitoring of other demographic parameters, such as adult/juvenile survival or breeding success, require a range of other techniques and usually require people to be ‘on the ground’.

The following sections provides an overview of available monitoring methods, subdivided into methods for ground-nesting species and burrow-nesting species, as the methodologies are necessarily divergent for the different species. There then follows a comparison of pros and cons for each method.

4.2 Methods for Ground-Nesting Species

4.2.1 Satellite Imagery

Very high resolution (VHR) satellite imagery (e.g. WorldView-3 (WV-3)) has been used recently to count WNA at South Georgia (Fretwell *et al.* 2017). This study was the first to use 30 cm resolution imagery from WV-3 to count wildlife directly. Counts from this method were directly compared to ground counts at Bird Island, South Georgia for validation. WNA have a body length of 107–135 cm (BirdLife International 2022). Individual birds are therefore likely to show as several white pixels in the satellite imagery, given the 31 cm cell size (Fretwell *et al.* 2017).

Individuals were counted by eye on screen directly from WV-3 images, in separate polygons of 200 x 200 m (roughly the area that fits within a single screen at the scale the birds were counted in). Matching individual nests from ground counts to those in the satellite imagery was not possible, so comparisons are for total counts (Fretwell *et al.* 2017).

A recent study has looked into automating image counts of WNA using Deep Learning (Bowler *et al.* 2020). The study used convolutional neural networks (U-Net) and found that it could detect individuals as accurately as human observers for two out of four islands studied. The other two islands were subject to misclassifications, due to the presence of noise, cloud cover and habitat (Bowler *et al.* 2020).

4.2.2 Yacht-based Counts

This method involves taking photographs of colonies from a vessel. It is often the only practical method available for remote, cliff-nesting species at South Georgia as yachts are able to operate close into shore at sites where charts are potentially unreliable. The photographs are later merged and counted (e.g. Lawton *et al.* 2003; Poncet *et al.* 2006). Typically, a series of overlapping images are taken from *c.* 100 to 150 m offshore (Robertson *et al.* 2008). Lawton *et al.* (2003) found that printed photographs were sharp enough to define individual BBA even in densely packed colonies. They re-counted each colony until the counts fell within 5% of each other; at all colonies only two counts were required to achieve this level of precision. However, it was not possible, from the photographs taken, to determine the breeding status of each bird, so in this study every bird was counted. This census of BBA at Diego de Almagro Island in Chile stands as the number of birds at the colony at the time of the census (i.e. no correction factor was applied in this study, unlike other similar studies).

Robertson *et al.* (2008) found that yacht-based photography counts of BBA at Ildefonso Archipelago in Chile (the fourth largest population in the world) underestimated population size by 55% compared to groundtruthed aerial photography.

For more detailed methods on yacht-based censuses see Poncet *et al.* (2006) and Section 3.4.2 and 3.4.3 of this report.

4.2.3 Ground Counts

4.2.3.1 Direct Counts

Direct counts are ground counts of all incubating birds. Each nest is inspected for presence of an egg (Cuthbert & Sommer 2004a). Direct counts have generally been conducted when researchers have easy access to the colony, where a species is unlikely to be unduly disturbed by the presence of field workers, in colonies of up to several thousand birds and when the counting team has sufficient time at the breeding site. This approach is often used in combination with scan counts (Wolfaardt & Phillips 2013) (See Section 4.2.3.2). In larger colonies, direct counts of nesting birds can be done by walking a series of parallel transects (e.g. 15–25 m wide). In one study, the edges of transects were demarcated with spray paint on vegetation at regular intervals to avoid recounting nests on the following transect (Cuthbert & Sommer 2004a).

Robertson *et al.* (2008) found that direct ground counts of BBA in Chile underestimated population size by 13% compared to groundtruthed aerial photography. Ground truthing in this study also involved quantifying, 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. 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.

4.2.3.2 Scan Counts

Scan counts are visual (in situ) counts of occupied, or apparently occupied, nests conducted from a distance (outside the colony), either because of topography, or the large size of the area to be surveyed, or because the species is prone to disturbance (e.g. SGPs). Scan counts can be conducted on land (e.g. Cuthbert & Sommer 2004a; Ryan *et al.* 2009), or from a vessel (Poncet *et al.* 2006; Wolfaardt & Phillips 2013).

4.2.4 Quadrat Sampling

The 'Area and Density' quadrant method has been used at very large colonies that are difficult to fully count directly. This method involves measuring the areas of the colonies, the densities of nests within the colonies using transects or quadrats and combining these two measurements to estimate the total number of active nests (Huin & Reid 2007; Wolfaardt & Phillips 2013).

A manageable area of quadrat is selected (e.g. 10 m x 10 m) and used to determine the mean density of birds in each habitat type if there is more than one (e.g. 'pavement' or 'tussac slopes'). These figures are then multiplied up to total areas (Robertson *et al.* 2008). Quadrats can be located set distances apart and tape measures pegged out to form boundaries. The number of birds in quadrants can be counted by two people twice to validate numbers (Robertson *et al.* 2008).

The total area occupied by birds in each habitat type can be estimated by walking around the perimeter of the entire nesting area and recording location and elevation data with a hand-held GPS. In a study by Robertson *et al.* (2008) on BBA in Chile, co-ordinates for the perimeter of an entire nesting area were plotted using ArcGis software (ESRI, Redlands, USA) and a 3-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 (Robertson *et al.* 2008).

Robertson *et al.* (2008) found that quadrat sampling of BBA colonies in Chile under-estimated population size by 11% compared to ground-truthed aerial photography.

4.2.5 Point Distance Sampling

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 can be used over line-distance sampling (see Bibby *et al.* 1992; Buckland *et al.* 1993, in Robertson *et al.* 2008) 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 (Robertson *et al.* 2008).

Robertson *et al.* (2008) found that point-distance sampling underestimated population size of BBA colonies in Chile by 9% compared to groundtruthed aerial photography.

4.2.6 Un-manned Aerial Vehicles (UAVs)

Un-manned Aerial Vehicles (UAVs), otherwise known as drones, have been used in recent years to survey populations of seabirds in remote locations (e.g. Ratcliffe *et al.* 2015; Pfeifer *et al.* 2019; Oosthuizen *et al.* 2020, in Dunn *et al.* 2021; Dickens *et al.* 2021). Dunn *et al.* (2021) compared ground counts with manual counts of nesting birds on images collected simultaneously by low-altitude aerial photography from multi-rotor UAVs. Both methods provided breeding pair counts of three Antarctic species (Chinstrap Penguin, Gentoo Penguin, South Georgia Shag) that were generally within *c.* 5% of each other. However, there were significant differences at some locations (Dunn *et al.* 2021). Where this occurred, it appeared related to inaccuracy in the ground counts due to observers being unable to see nests on cliff ledges.

UAVs can capture data accurately at a high spatial resolution that would otherwise be unobservable, such as offshore stacks. In rugged or uneven terrain, it can reveal nests that might otherwise be hidden from on land observers doing ground counts. Images can also be re-analysed later, as photos provide a permanent record. It can also sometimes provide additional useful information such as colony distribution, area, shape, nest spacing and nest/colony habitat selection (Henriksen *et al.* 2015; Chabot & Francis 2016; Rush *et al.* 2018, in Dunn *et al.* 2021).

Although the application of UAVs in sub-Antarctic regions continues to increase, there are concerns about potential flight disturbance at colonies, with some studies looking to establish safe operating procedures to minimise disturbance. Based on data from existing studies using UAVs, recommendations on the use of UAVs on Antarctic wildlife by the Scientific Committee on Antarctic Research (SCAR) highlight the need for further studies on the potential for disturbance (Dunn *et al.* 2021). But if used correctly, they can cause less disturbance than intrusion into colonies on foot, which can be a particular problem for some species like the giant petrels (Cuthbert & Sommer 2004b). There is also the possibility of weather conditions impacting on ability to use UAVs, and for potential failure of technology, thereby stopping surveys from going ahead (Dunn *et al.* 2021).

There are two main types of UAVs – fixed-wing and multi-rotor. Fixed-wing offers longer flight time and greater survey range but requires a flat area for launch and landing. Higher flight speeds, lower manoeuvrability, and operation beyond line of sight, requires higher safe operational heights, which means a reduction in image resolution, resulting in impaired identification of similar species in mixed species breeding colonies (Dunn *et al.* 2021). Fixed-wing platforms are therefore most suited to surveys of single-species colonies (Dunn *et al.* 2021).

Multi-rotor UAVs are small, portable and have vertical take-off and landing capability allowing for deployment from vessels or rugged terrain. Slow flight speed and high manoeuvrability allow low-altitude surveys and higher-resolution images compared to fixed-wing. Both platforms therefore have complementary roles in surveying seabird colonies, with fixed-wing UAVs being most suitable for long-range surveys of single species colonies from a flat launch site and multi-rotors for short-range surveys of mixed species colonies from boats or rough ground (Dunn *et al.* 2021).

Moreover, Hayes *et al.* (2021) concluded that UAVs could be used in combination with Deep Learning techniques, namely Convolutional Neural Networks (CNN) to produce accurate and efficient monitoring of large-scale seabird colonies. Looking at a large colony of BBA and Southern Rockhopper Penguins in the Jason Island group, Falkland Islands, they concluded that 90% of automated counts were within 5% of manual counts from imagery.

There has already been one study of WNA on South Georgia using (rotor) UAV (Dickens *et al.* 2021). The study found that UAV was effective at surveying populations of WNA in aerial imagery. However, for those species nesting in tussock habitat on South Georgia (e.g. Macaroni Penguins) the method using a standard camera was ineffective as individuals were obscured or hidden by vegetation (Dickens *et al.* 2021); however drones equipped with Infra-red cameras are showing greater promise at being capable of surveying some species (e.g. Macaroni penguins) in tussock habitat (J. Black, pers. comms).

As part of this study, Southern Elephant Seal populations on South Georgia were surveyed along the coastline within King Edward Cove on the Thatcher Peninsula, and at Hound Bay and St Andrews Bay on the Barff Peninsula. Nine islands within the Bay of Isles were also surveyed with a focus on the WNA population. Additionally, a king penguin colony at St Andrews Bay and a macaroni penguin colony at Rookery Bay were surveyed (Dickens *et al.* 2021).

The study used a mix of platforms from which to launch the UAV. The majority of flights involved terrestrial take-off and landing, apart from those to survey the Bay of Isles, Hound Bay and Beach Point on Thule Island, which were piloted from a vessel at sea within close proximity of the study site. The UAV was therefore controlled manually with the pilot configuring the camera settings to achieve consistent sets of imagery and estimating the level of overlap between images with attempts made to achieve at least 70% forward and lateral overlap. The majority of the surveys were flown at a horizontal speed of 5 m/s with the UAV set to capture a photograph every two seconds. An observer was present during flights to assist the pilot by keeping visual contact of the UAV and making observations of potential disturbance to wildlife (Dickens *et al.* 2021).

The UAV pilots underwent training prior to the study and gained a Remote Pilot Qualification – Small (RPQ-S) and a Civil Aviation Authority Permission for Commercial Operation (CAA PfCO). Flights were only conducted under suitable flying conditions and were made in accordance with the Air Navigation (Overseas Territories) Ordinance, following regulations set out by SGSSI under Regulated Activity Permits (Dickens *et al.* 2021).

For WNA, aerial surveys of all nine historical nesting islands within the Bay of Isles were conducted on the 20 November 2019. Flights were made from the deck of the MV *Pharos SG* which was positioned within close proximity to the islands. A constant altitude of 120 m Above Ground Level (AGL) was selected in order to efficiently cover the extent of the islands as well as to allow for the variability in topography, particularly when surveying Albatross Island which has an elevation of 80 m above sea level. A maximum altitude of 120 m AGL was in line with Air Navigation Ordinance regulations but was also at the limit of the utility of the spatial resolution provided by the UAV camera for identifying and counting the study species. As the surveys were conducted over large areas it was necessary to fly transects in order to cover the entirety of each island; this was done manually, with an estimated 70% overlap between flight paths (Dickens *et al.* 2021).

In most cases surveys were completed on a single battery charge however during surveys of larger areas, such as Albatross and Prion islands, it was necessary to retrieve the UAV part way through the survey, change the battery and return to complete the remainder of the survey (Dickens *et al.* 2021).

Orthoimages of islands within the Bay of Isles were mapped using QGIS (QGIS 2020). WNA chicks and adults were identified and recorded on each of the nine surveyed islands. Existing coordinates of the nests on Albatross and Prion islands, collected from ground-based surveys in January 2019, were overlayed and acted as reference points for identifying chicks as well as for estimating fledgling survival. The survival rate of the chicks on Prion Island was recorded during a ground-based survey of the population on 12 October 2019, a month prior to the aerial survey (Dickens *et al.* 2021).

The aerial surveys within the Bay of Isles resulted in a full census of fledgling and adult WNA across the nine islands, providing the first breeding success data for Albatross Island since 2002, information on fledgling dates for Prion Island, and giving the first records of fledglings on the seven smaller, less well studied islands, in recent years (Poncet *et al.* 2006, 2017; Dickens *et al.* 2021). The surveys were conducted later in the season than originally planned due to poor weather conditions (but typically of South Georgia) and by the time the surveys occurred the majority of fledglings had lost their white down, making them less conspicuous in the photographs than they would have been earlier in the season (Dickens *et al.* 2021).

Dickens *et al.* (2021) noted that while there was a size difference between WNA fledglings and giant petrels, in some cases their colouration made it challenging to distinguish between the two species, especially in areas with a lower spatial resolution as a result of flying at a constant height over variable terrain.

4.2.7 Autonomous Time-lapse Camera Systems

Autonomous time-lapse camera systems can be used for collecting phenological and reproductive data at some seabird colonies (e.g. Southwell *et al*. 2013; Lynch *et al*. 2015; Black *et al.* 2018; Hinke *et al.* 2018, in Dunn *et al.* 2021) but have too narrow a field of view to accurately monitor numbers except in very small colonies, making them more suitable for study of nesting phenology and success rather than census work (Black *et al.* 2018; Hinke *et al.* 2018, in Dunn *et al.* 2021). Arrival and departure movements and breeding timing have been recorded using these systems for Short-tailed Albatross (*Phoebastria albatrus*) (Otsubo & Higuchi 2022). In this study, the validity of information collected by time-lapse cameras was confirmed by comparing it with the results of previous field studies (Otsubo & Higuchi 2022). To obtain highly accurate data, the location of the time-lapse cameras is critical. Otsubo and Higuci (2022) concluded that the best location would be where the whole colony is seen from above so that the number of birds and their arrival/departure movements can be detected. Clifftops would be suitable, if found nearby. The installation of multiple cameras could make it easier to cover large colonies or separate breeding sites (Otsubo & Higuchi

2022). Ostubo and Higuchi (2022) collected data at 1-hour intervals for a period of nine months, which was long enough to cover the whole breeding season.

4.2.8 Aerial Photography

Aerial photography involves taking photographs from a fixed-wing aircraft or helicopter. There are no fixed-wing aircraft operating at South Georgia, and no airstrips, so the use of light fixed-wing aircraft for wildlife surveys is currently not possible. Similarly, current GSGSSI regulations regarding use of helicopters also precludes this option. This section is provided for completeness of the survey methods available, but it is acknowledged that they are not applicable to South Georgia at the current time.

Some early attempts made use of high altitude (4,156 m) vertical aerial photographs to estimate the size (area) of BBA colonies in the Falkland Islands, in combination with density estimates from direct ground counts in quadrats (Prince 1982; Thompson & Rothery 1991, in Wolfaardt & Phillips 2013). More recently aerial surveys have involved flying low altitude circuits over colonies and taking sequential overlapping photographs which are later stitched together using software to form photomontages, from which apparently occupied nests can be counted on-screen (e.g. Arata *et al.* 2003; Robertson *et al.* 2007; Strange 2008; Robertson *et al.* 2008; Baker *et al.* 2009, in Wolfaardt & Phillips 2013).

In Robertson *et al.* (2008) photographs of colonies of BBA at Ildefonso Archipelago, Chile, were taken between 14:00h and 15:00h to include the period of the day when the ratio of nesting birds to total birds was highest. Photographs were taken from an angle perpendicular to the land surface wherever possible.

Aerial photography is increasingly being used as the census method of choice for surface nesting seabirds, e.g. BBA and GHA in Chile (Arata *et al.* 2003; Lawton *et al.* 2003; Robertson *et al.* 2007; Robertson *et al.* 2008, in Wolfaardt & Phillips 2013), BBA in the Falkland Islands (Strange 2007, 2008, in Wolfaardt & Phillips 2013), and SGP in the Falkland Islands (Reid & Huin 2008, in Wolfaardt & Phillips 2013).

In a comparison of different techniques, Robertson *et al.* (2008) found that aerial photography identified more nesting BBA than other methods (yacht-based photography, ground counts, quadrat sampling and point-distance sampling), and that there was minimal variance (0.28%) between duplicate counts (Robertson *et al.* 2008, in Fretwell *et al.* 2017).

It is useful to combine aerial photography with some simultaneous ground-truthing to maximise accuracy, but this can be achieved by counting birds in a few study plots (Wolfaardt & Phillips 2013).

4.3 Methods for Burrow-Nesting Species

Population estimates of burrow nesting species are usually based on the number or density of nests in a particular area or habitat, the proportion of these nests that are considered to be occupied by breeding birds and the total area of the different habitats surveyed at the breeding site (if > 1 type of habitat was surveyed) (Wolfaardt & Phillips 2013). The density of nests will generally differ between habitat or vegetation type (e.g. Lawton *et al.* 2006) and burrow occupancy may vary spatially and temporally (Wolfaardt & Phillips 2013). As a result, it is necessary to derive habitat-specific density estimates (e.g. Berrow *et al.* 2000) to ensure that transects or quadrats are representative of the range of habitats at the breeding site, and to accurately estimate burrow occupancy levels and the occupied area of each habitat type or colony (Wolfaardt & Phillips 2013).

4.3.1 Traditional Methods

Methods for counting burrow-nesting species on South Georgia previously have involved straight-line transects across areas of suitable habitat and then quadrats of 3 m radius to examine burrows contained within that quadrat. Taped play-back has been used to determine whether a burrow was occupied or not. A sample of burrows from which no response was heard were then examined using an infra-red illuminated scope to check more accurately for occupancy (Berrow *et al.* 2000; Martin *et al.* 2009).

See Section 3.2.3 for a full description of methods for censusing burrow-nesting species on South Georgia (e.g. WCP).

The most widely used tools to determine burrow occupancy are the burrow-scope, call-playback response and feeling for an occupant by hand/with probe (Parker & Rexer-Huber 2020). Some studies use inspection hatches, and many use a combination of techniques. Most studies use direct inspection methods like these, which rely on detection of bird(s) in a burrow, but indirect methods (e.g. using activity sign at burrow entrances) are still occasionally combined with other methods (Parker & Rexer-Huber 2020). Responses to play-back are useful for some species like WCP, but response rate can vary within species, over a breeding period, and even within individuals. The probability of a bird responding is influenced by factors including breeding condition, sex of bird in burrow, time of day, and playback features like the range of calls used, duration and volume. However, even when playback reliably indicates occupancy, the presence of non-breeding birds can obscure true breeding numbers (Parker & Rexer-Huber 2020).

It is widely accepted that population estimates, usually expressed as numbers of breeding pairs, requires that counts of burrows be corrected by the proportion of burrows that contain a breeding pair (burrow occupancy rate). To reduce extrapolation errors, it is critical to test the assumption that every occupant will be found (occupant detection probability) and that breeders can be accurately distinguished from non-breeders (Parker & Rexer-Huber 2020).

A good pilot study that tests sampling techniques and determines minimum sample sizes can be a valuable tool for reducing the variance around population estimates, particularly if time is limited. A pilot study may also allow the main laying period to be estimated. Planning the timing of surveys so that fewest assumptions and corrections are needed can also reduce error. This is illustrated by burrow occupancy: studies are best timed for the period when most or all pairs have laid, but before many egg failures have occurred (Parker & Rexer-Huber 2020).

Ensuring that sampled habitat is representative of the occupied habitat while minimising variance is one of the key challenges when addressing availability biases in population estimates. Careful study design is the best tool to address this bias. Depending on the species and site, representative sampling may require random plots or transects throughout an area; random sampling within strata or subareas (stratified design, systematic sampling, or adaptive cluster sampling, to give a few examples). Habitat not available for sampling (cliffs, very fragile areas) introduces error if included in extrapolations, so there needs to be careful documentation of methods used to account for unsampled habitat types. Burrow detection probability, testing the assumption that every burrow in an area is found, can have a large impact on accuracy of population estimates (Parker & Rexer-Huber 2020).

The appropriate method to determine burrow detection is species- and site-dependent, but can involve simple repeat surveys or checking counts against other sampling methods. Alternatively, methods that explicitly take detection probability into account (e.g. variants of capture-mark-recapture or distance sampling) may be appropriate. Burrowing petrel estimates can also be influenced heavily by the area used for extrapolation. Seabird colonies with variable topography or elevation may require an area correction to ensure that available surface area is not underestimated (Parker & Rexer-Huber 2020).

4.3.2 Novel Methods – Bioacoustics

A recent study at Bird Island used recording devices (Song Metres SM4 Wildlife Acoustics Inc., Concord, MA) to collect acoustic data from two breeding areas for WCP at Bird Island in austral summer 2017/18 in order to measure colony attendance patterns (relative numbers of birds visiting at a given time). They assessed the distance at which WCP could be detected above background noise and the vocalisation rate of individuals, both of which could be used to calculate local densities of WCP in acoustic recordings (Linares *et al.* 2022). Using the recordings, they calculated the signal to noise ratio (SNR) at different distances (5 m intervals out to 100 m) using Raven Pro. Vocalisation rates were determined by a fieldworker on three dates at each site by counting the number of vocalisations produced in one minute by a focal WCP. The total sample size was 185 different individuals, of which 125 were in burrows, and 60 were on the surface. They then quantified vocal activity using Kaleidoscope Pro v5 classifiers (Wildlife Acoustics Inc.) and acoustic indices (Sueur *et al.* 2008; Buxton *et al.* 2018) for automatic quantification of vocal activity.

To estimate population density using the acoustic recorders, they determined the mean vocalisation rate of individuals (2.3 min^{-1}), mean call length (~15.3 sec), and detection distance (~15 m based on signal to noise ratios of playbacks). The study concluded that, if acoustic indices were linked to density, bioacoustic monitoring could be a viable and cost-effective method for censusing WCP and other burrow-nesting species (Linares *et al.* 2022).

4.4 Other Considerations

Given that a number of ACAP species breeding at South Georgia are classified as Vulnerable or Near Threatened, population monitoring is a key concern. Ideally, a population monitoring programme should include both intermittent large-scale censuses of the entire archipelago, together with more regular and intensive monitoring of population numbers, breeding success, and other parameters such as survival, such as that on-going at Bird Island (Wolfaardt & Phillips 2013).

The use of large-scale censuses alone to monitor population trends is problematic when considering factors such as high annual variability in breeding numbers of some species, especially biennial breeders (Croxall *et al.* 1998; Nel *et al.* 2002; Delord *et al.* 2008, in Wolfaardt & Phillips 2013). Rates of nest failure can be highly variable among years (e.g. Prince *et al.* 1994) so it is important this annual variation in breeding probability is accounted for when interpreting population trends from a limited number of data points (Wolfaardt & Phillips 2013).

4.5 Comparison of the Pros and Cons of Different Monitoring Techniques

The following table (Table 2) outlines a comparison of the differing pros and cons of using the various monitoring techniques covered throughout Section 4. It also provides an indicative estimate of associated costs with using a particular technique. It should be noted that these are just rough relative costs at this stage, as it was not possible to go undertake an in-depth quantitative cost-analysis as part of this project. Moreover, such an analysis is likely to require more information, and/or be examined on a case-by-case basis, as costs are inherently tied to the particular circumstances of a case-specific monitoring programme that may be planned (e.g. whether a vessel of opportunity may be available to land field workers on site, etc.).

Table 2. Comparison of the pros and cons of various monitoring techniques for ground-nesting ACAP species present at South Georgia.

Method	Pros	Cons	Costs	Which Species
Satellite	• Large coverage avoids stitching error; a known source of error in aerial photography mosaics • May be only appropriate for Wandering Albatross due to nesting terrain and large size of bird • No disturbance at colony • Suitable for automated counting using Deep Learning • Permanent archive	• Variance among counters higher than with aerial photography, but this may change as imagery improves • Has to be corrected for non-breeders to get a breeding pairs figure • Has the potential for automated counting through Deep Learning, but technique not fully refined yet • Cloud cover could affect quality of images • Processing and stitching can be time-consuming if not automated	Medium	Great Albatrosses
Yacht-based Counts	• Only viable method for inaccessible areas, where it is not possible to do ground counts • Beneficial for cliff nesting species, where nests cannot be recorded from the air or from land	• Yacht-based counts may often be less accurate than aerial photography. One study found that yacht-based counts underestimated counts by 55% compared to aerial photography (plane) • Expensive	Medium to high (if extensive field time required)	LMA Cliff-based BBA and GHA

Method	Pros	Cons	Costs	Which Species
Ground counts	• Allows for other types of monitoring data beyond census data (e.g. demographics) via ringing, nest monitoring, etc. • May be less costly than aerial photography by plane or where there is no suitable landing place • The only way to census giant petrels in dense tussac habitat, and the only way to ensure accurate counts of WNA on eggs or small chicks	• Ground counts often less accurate than aerial photography (plane). One study under-estimated counts by 13% compared to aerial photography (plane) methods • Can be expensive to install and operate field-teams and particularly to run long-term monitoring programmes	Medium to high (if extensive field time required)	Ground-nesting species, in small-medium colonies
Quadrat Sampling	• Good for very large colonies, where angles difficult for aerial photography • May sometimes be nearly as accurate as aerial photography	• Only ever an estimate, as based on extrapolation • Dependent on the ability to reasonably classify different habitat types for extrapolation of counts	High (if extensive field time required)	Large colonies
Point Distance Sampling	• Minimises disturbance as outside the colony • Similar rates of accuracy c.f. groundtruthed estimate of aerial photography (9%)	• Error may be introduced due to distance from colony	High (if extensive field time required)	

Method	Pros	Cons	Costs	Which Species
Aerial Photography (UAV)	• UAV photography can observe nests that may be hidden from ground counts by rugged terrain • No disturbance at colony (if flown high enough and if the drone can be flown from the ship) • Provides permanent archive record • Suitable for automated counting using Deep Learning (within 5% of manual counts from imagery)	• Impeded by poor weather conditions, which can be typical in South Georgia. The method works best if combined with ground counts (and oblique photography for BBA and GHA) from a vessel, done on no flying days • Potential for equipment failure and limited battery life • Processing and stitching of photos time consuming and costly. It can take months to get images stitched, processed, birds counted, etc. While yacht-based counts and ground counts are instantaneous • Can be difficult to distinguish between some species (e.g. WNA chicks and giant petrels)	High	Proven for BBA and WNA. As well as King Penguins and Elephant Seals at South Georgia
Time-lapse Cameras	• Can collect phenology and reproductive data remotely • Requires fewer visits to colony • Provides permanent archive record	• Not viable to collect census data with this method • Still requires colony visit to install cameras • Substantial effort required for image processing, although there is the possibility for autonomous methods of image processing in the future • Potential for equipment failure	High (if extensive field time required)	Small colonies

Method	Pros	Cons	Costs	Which Species
Aerial Photography (Plane)	• Identified highest number of individuals compared with other methods • Minimal variance in duplicate counts • Good for counting large numbers of birds • Good for colonies on relatively open ground • Can be timed to optimal period (soon after egg laying) as less time consuming than ground counts • No disturbance at colony (if flown high enough) • Provide permanent archive record	• Not good for cliff nesting species where it is not possible to get a perpendicular angle for photographs • Not good for species nesting in dense cover • Processing and stitching of photos time consuming and costly • Expensive • Require runways or ships with helidecks to operate in remote locations and South Georgia has no runway allowing deployment from land nor are helicopters permitted • Impeded by poor weather conditions	High	Large colony species on open ground (e.g. BBA)

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6 Appendix 1 – Existing Maps of Species Colony Locations

As detailed in earlier sections of the report, a number of key whole island surveys of ACAP species on South Georgia occurred in the last decades. In this section, maps from relevant surveys are presented to show the current known location of the seven ACAP species which breed on the South Georgia archipelago. Note, multiple maps are provided if different locations were surveyed in different years, thereby ensuring that all information on all known locations is provided.

6.1 Northern Giant Petrel and Southern Giant Petrel

6.1.1 Northern Giant Petrel & Southern Giant Petrel – Whole-Archipelago Survey (2005/07)

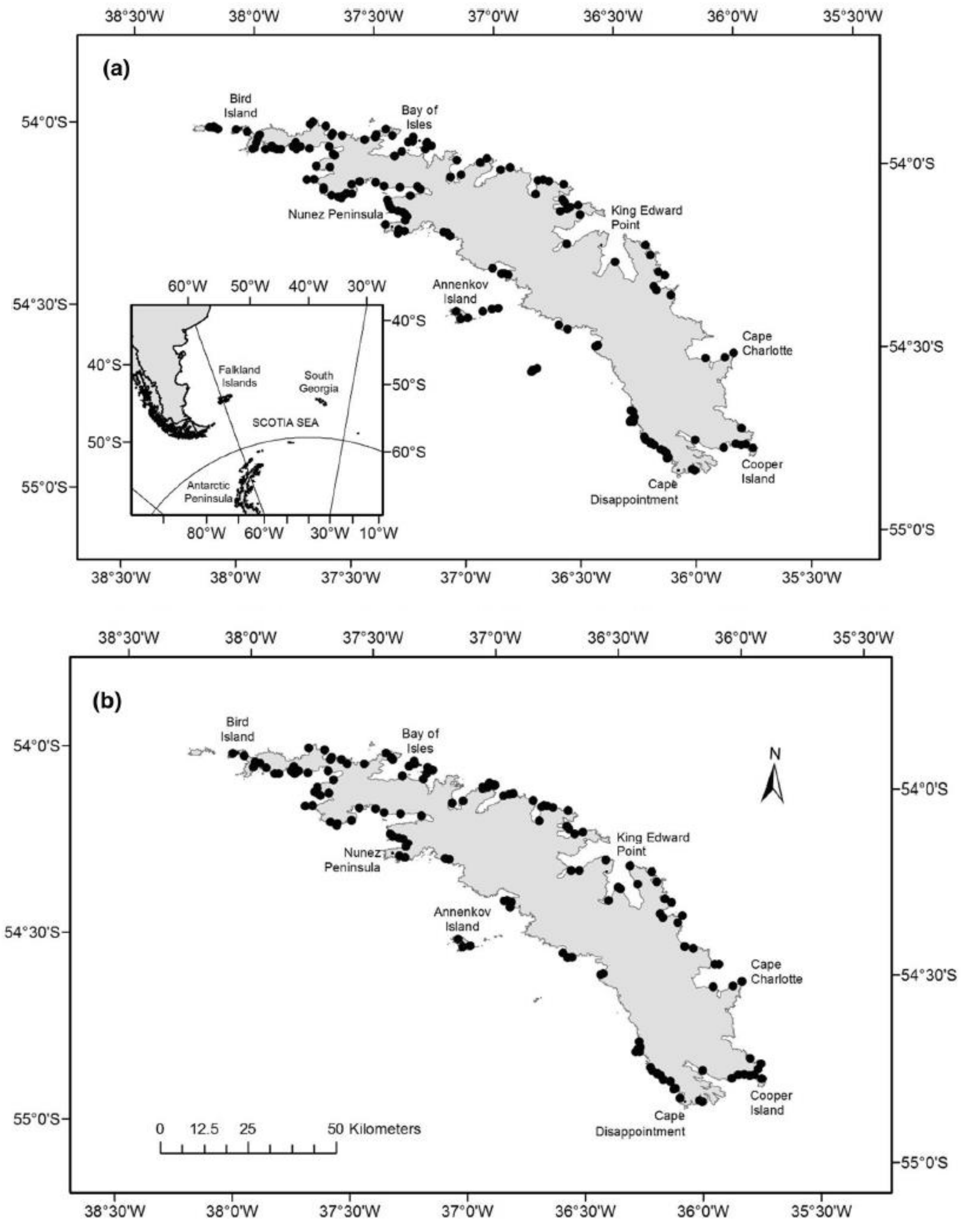

Figure 1. Breeding locations of: (a) Northern Giant Petrel; and (b) Southern Giant Petrel at South Georgia, 2005/06 to 2006/07 whole-archipelago survey. Figure from Poncet *et al*. (2020).

Table 3. The ten breeding locations with the largest numbers of Northern Giant Petrel and Southern Giant Petrel nests at South Georgia, 2005/06 to 2006/07. (Adapted from Poncet *et al*. 2020).

Northern Giant Petrels

ID	Breeding Location	Corrected Nest Count
1	Bird Island	2,272
2	Hope Valley	1,291
3	Annenkov Island 1	919[a]
4	Granat Point	880
5	Cape Rosa	667
6	Kade Point	576
7	Saddle Island	520
8	Paryadin Peninsula North	479
9	Annenkov Island 2	463
10	Annenkov Island 3	421

[a] Includes 396 nests estimated using surface area/density estimates.

Southern Giant Petrels

ID	Breeding Location	Corrected Nest Count
1	Cape Charlotte	706
2	Bird Island	604
3	Köppen Point	543
4	Albatross Island	516
5	Hope Valley	332
6	Cape Vahsel	308
7	Paryadin Peninsula North	218
8	Annenkov Island 2	210
9	Harcourt Island	197
10	Doris Bay	176

6.2 White-chinned Petrel

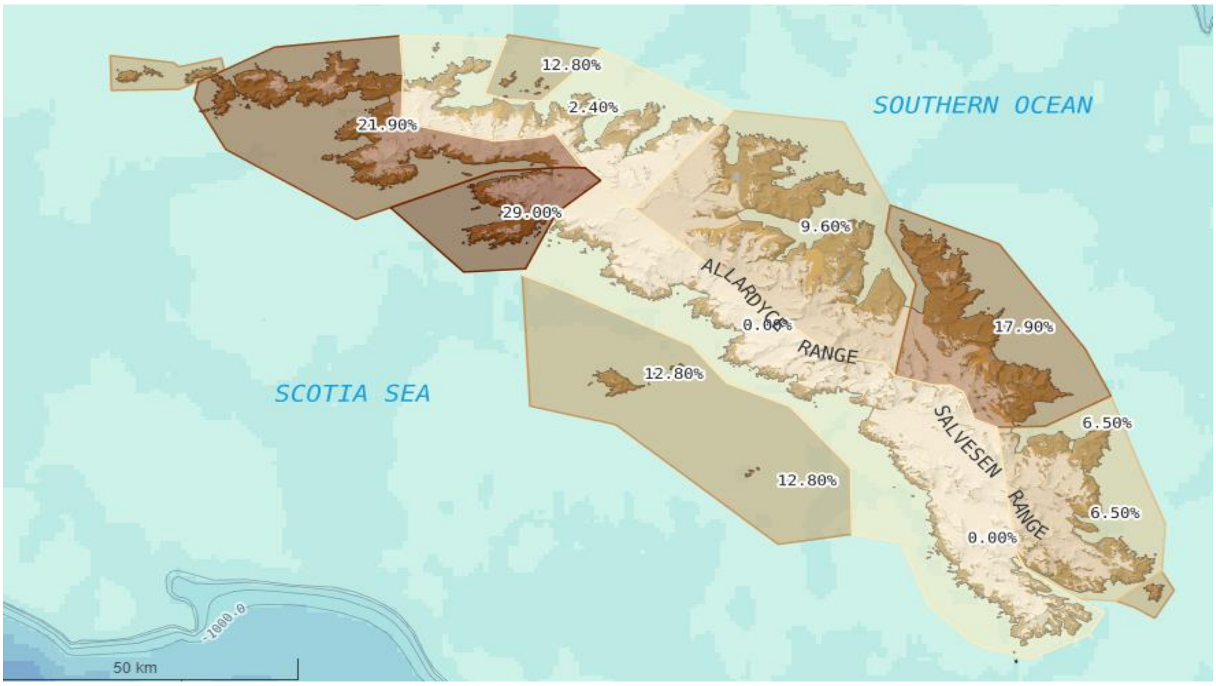

Figure 2. White-chinned petrel colony locations by eight eco-geographic zones within which the numbers of nesting WCPs were calculated independently. The map is based on a whole island survey by Martin *et al*. (2009), where transect plots were counted and then extrapolated up to a whole island estimate adjusted to the eight identified eco-geographic zones. See Section 3.2.3 for more details on survey methods for this count. Figure from https://www.sggis.gov.gs/ MPA Portal 07/03/22.

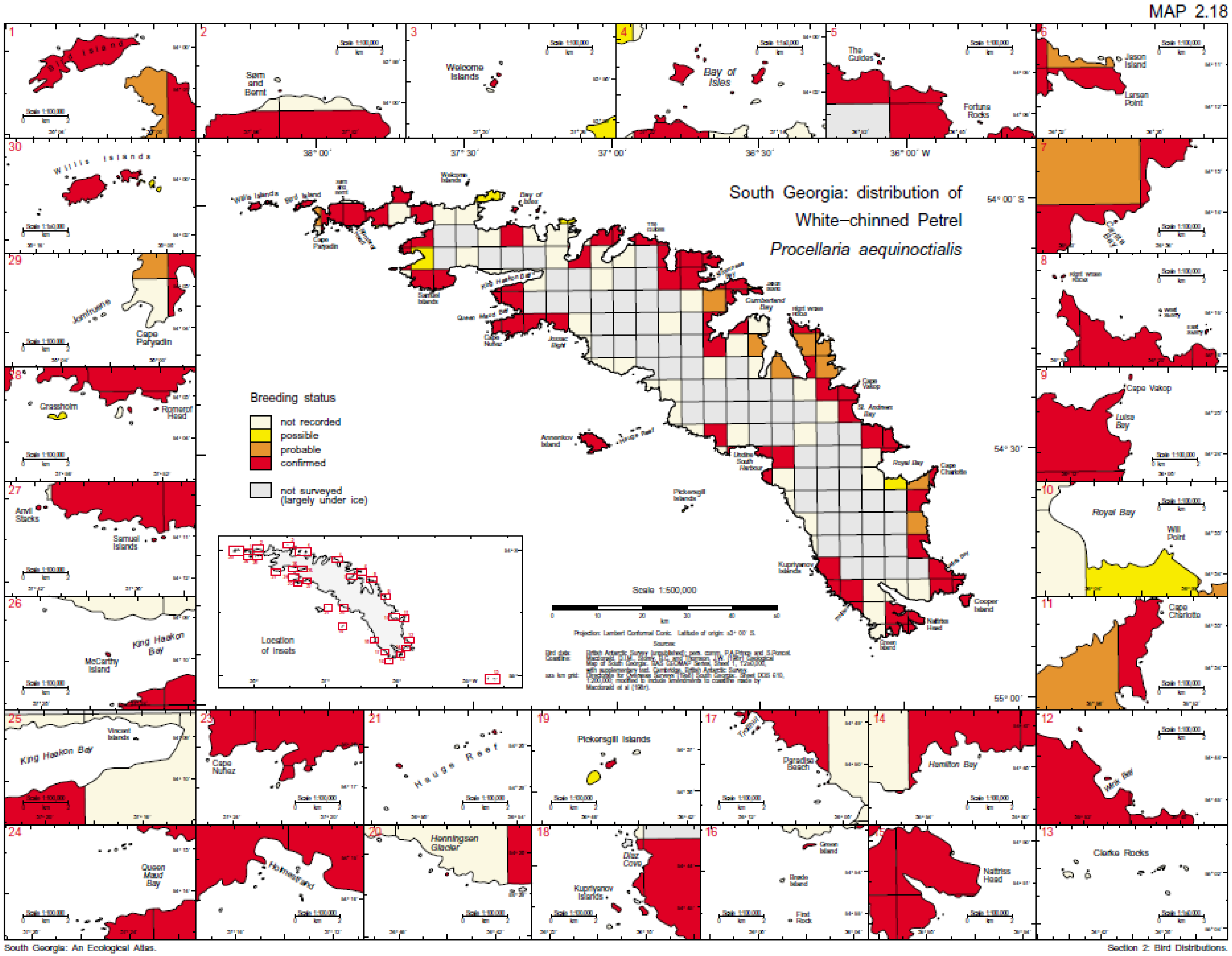

Figure 3. Breeding distribution of White-chinned petrel (*Procellaria aequinoctialis*) at South Georgia. Figure taken Prince & Poncet (1996).

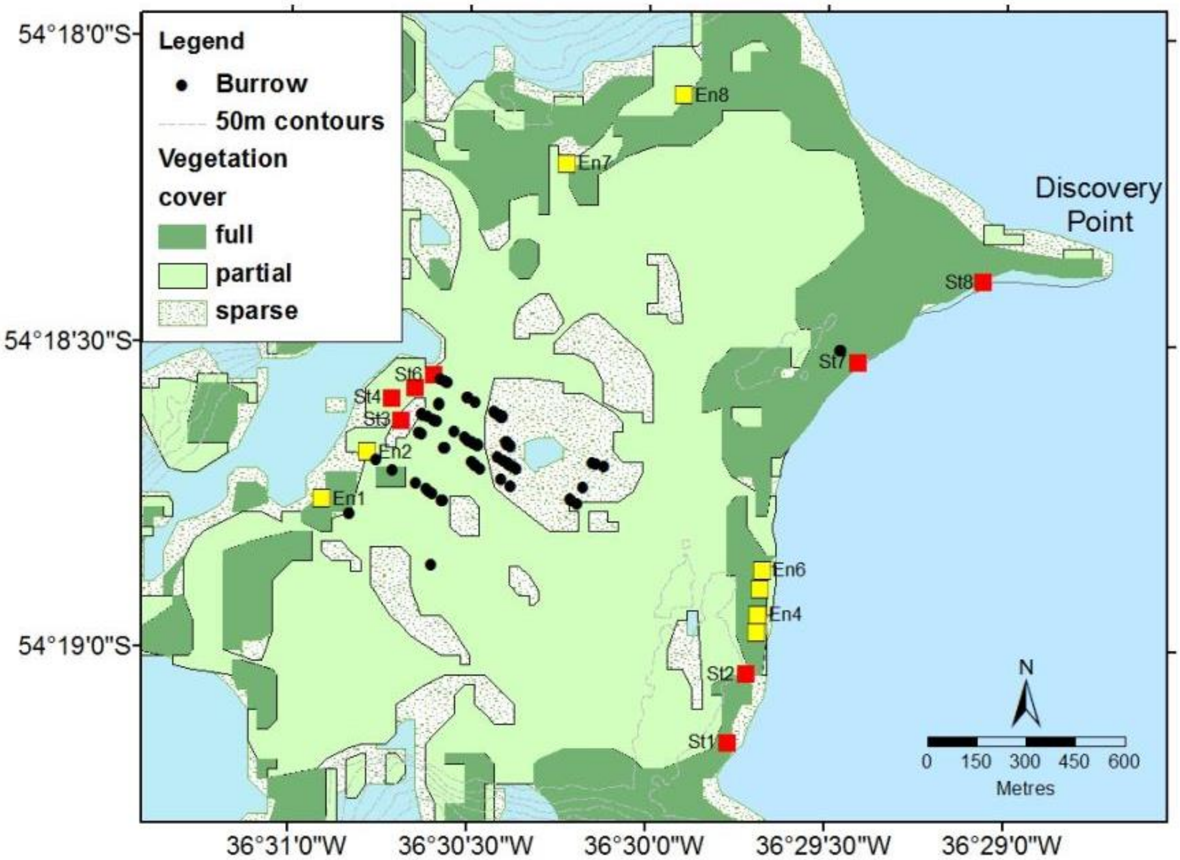

Figure 4. The location of burrowing petrel (including White-chinned Petrels) transects and the burrows recorded at Hestesletten, Thatcher Peninsula as part of post-rat eradication monitoring study from 2012 onwards (GSGSSI unpublished data).

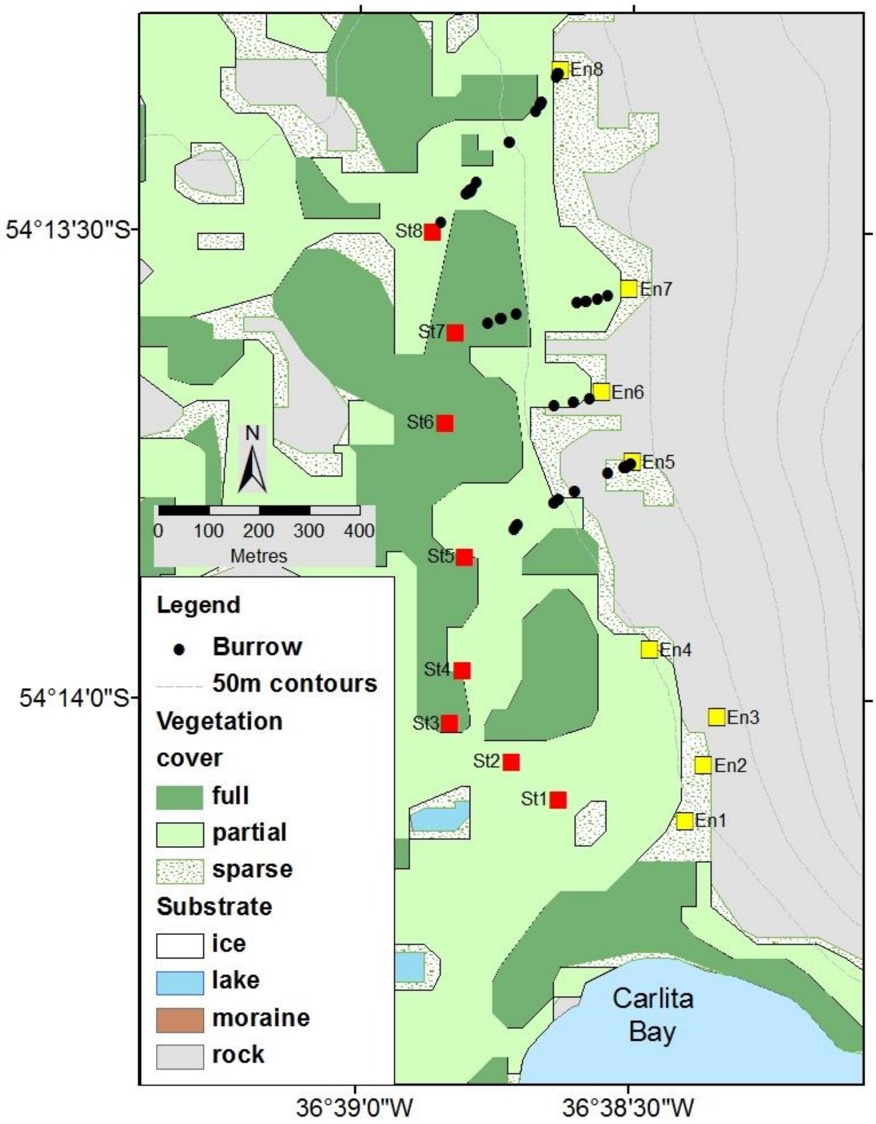

Figure 5. Location of burrowing petrel (including White-chinned Petrels) transects and the burrows recorded in the Olsen Valley, Busen Peninsula as part of post-rat eradication monitoring study from 2012 onwards (GSGSSI unpublished data).

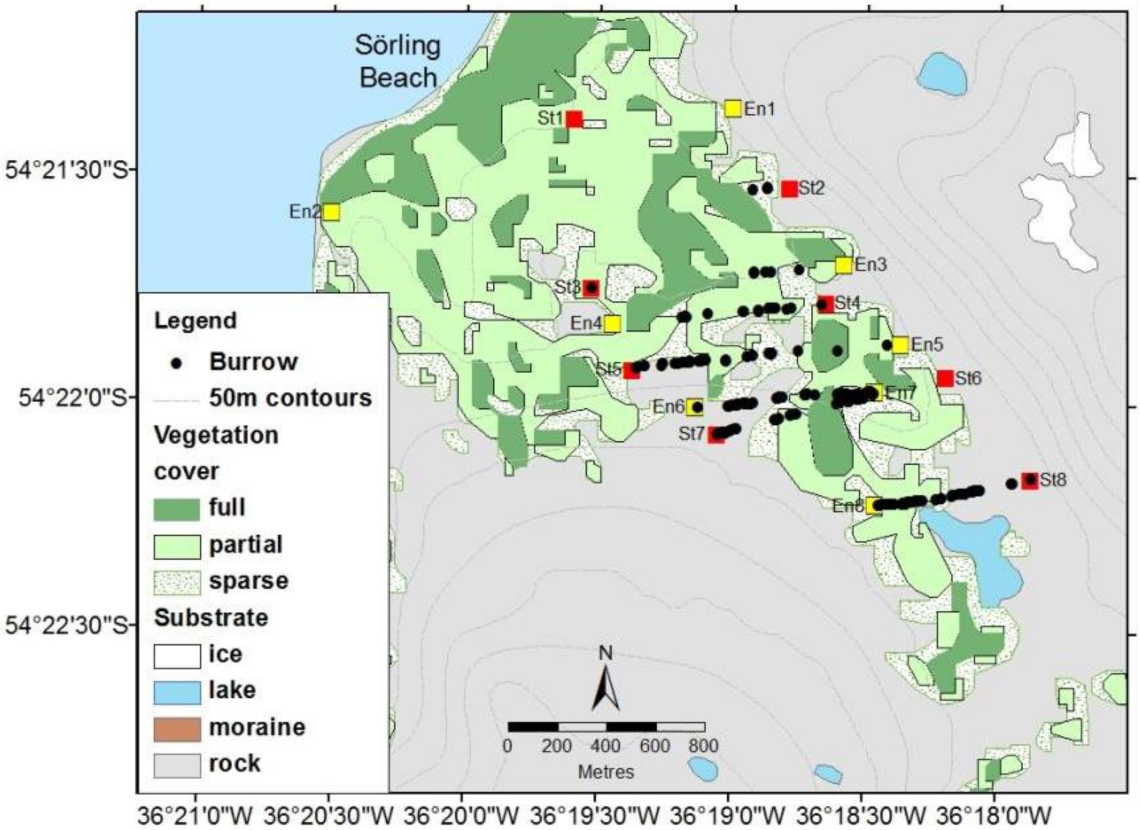

Figure 6. Location of burrowing petrel (including White-chinned Petrels) transects and the burrows recorded in Sörling Valley, Barff Peninsula as part of post-rat eradication monitoring study from 2012 onwards (GSGSSI unpublished data).

6.3 Wandering Albatross

6.3.1 Wandering Albatross – Whole-Archipelago Survey 2003/04

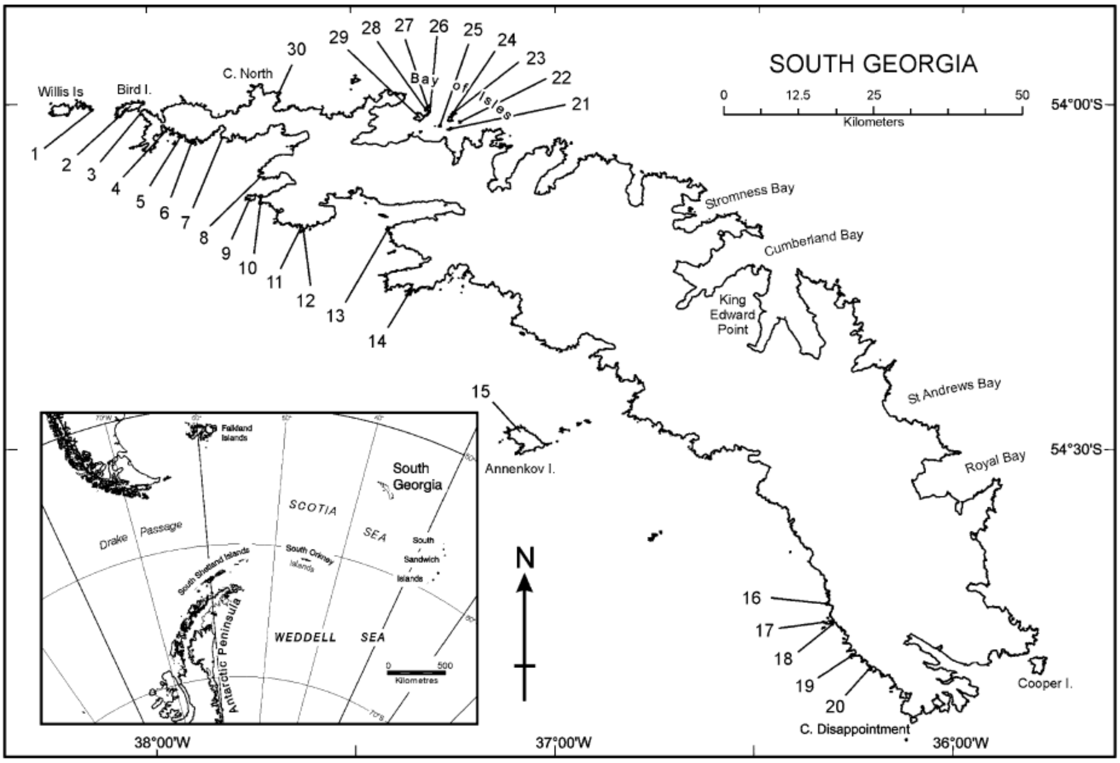

Figure 7. Breeding locations (30) of wandering albatross at South Georgia based on 2003-04 whole-archipelago survey. Figure from Poncet *et al.* (2006). Numbers refer to the locations listed in Table 4.

Table 4. Locations of wandering albatross colonies to correspond with location numbers in Figure 7, based on 2003/04 whole-archipelago survey (adapted from Poncet *et al.* 2006).

ID	Location	Breeding Pairs
1	Proud Island	Y
2	Bird Island	Y
3	Cape Alexandra	Y
4	Coal Harbour	Y
5	Frida Hole	Y
6	Chaplin Head	N
7	Weddell Point	Y
8	Kade Point	Y
9	Saddle Island	Y
10	Cape Demidov Isthmus	Y
11	Bomford Peninsula (Granat Point)	Y
12	Samuel Island (Tidespring Island)	Y
13	Cape Rosa	Y
14	Nunez Peninsula	Y
15	Annenkov Island	Y
16	Diaz Cove north	N
17	Kupriyanov Island outer	Y
18	Kupriyanov Island inner (Poncet Island)	N
19	Ranvik	N
20	Trollhul	Y
21	Inner Lee	Y
22	Outer Lee	Y
23	Skua Island	N
24	Prion Island	Y
25	Petrel Island	Y
26	Invisible Island	Y
27	Mollyhawk Island	Y
28	Crescent Island	Y
29	Albatross Island	Y
30	Nameless Point	Y

6.3.2 Wandering Albatross – Whole-Archipelago Survey 2014/15

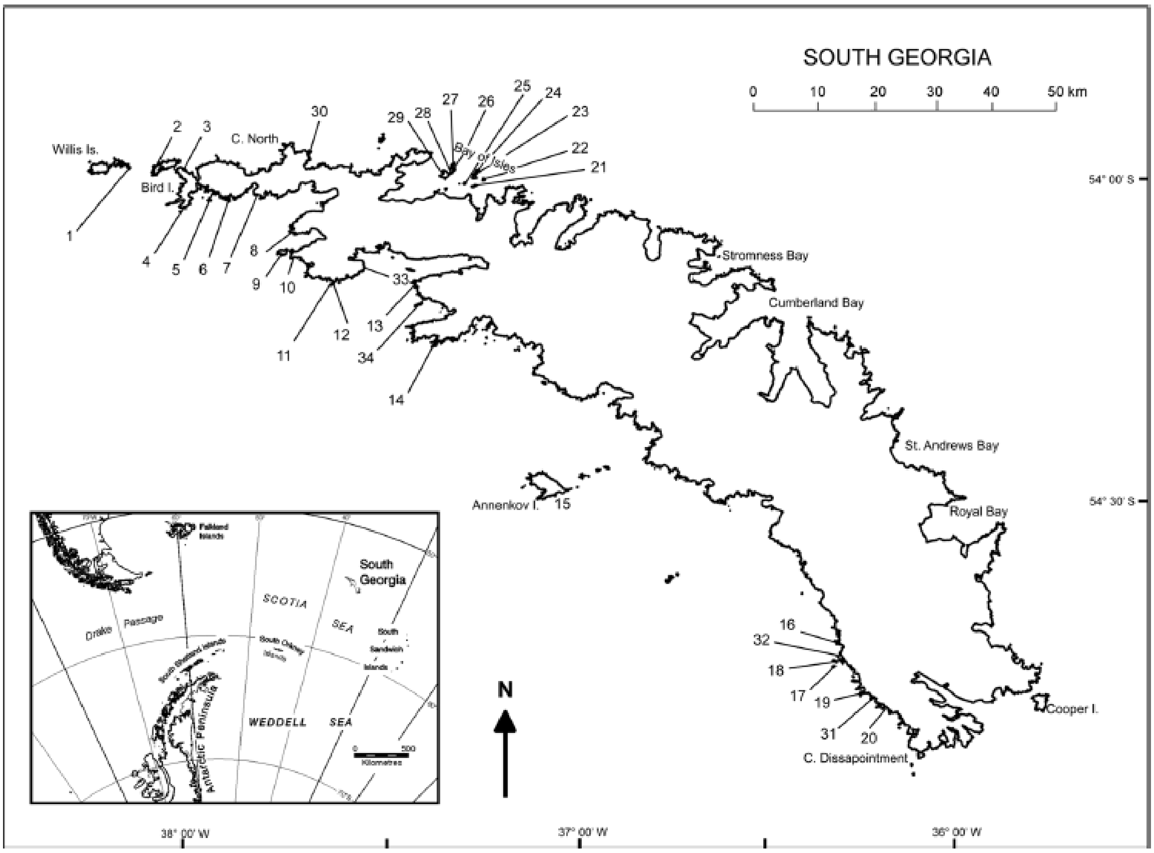

Figure 8. Breeding locations (34) of wandering albatross at South Georgia, based on 2014/15 whole-island survey. Figure from Poncet *et al.* (2017). Numbers refer to the locations listed in Table 5.

Table 5. Locations of wandering albatross colonies to correspond with location numbers in Figure 8, based on 2014/15 whole-archipelago survey (adapted from Poncet *et al.* 2017). Entries with a dash (-) indicate not surveyed in 2014/15 season.

ID	Location	Breeding Pairs
1	Proud Island	Y
2	Bird Island	Y
3	Cape Alexandra	Y
4	Coal Harbour	Y
5	Frida Hole	Y
6	Chaplin Head	-
7	Weddell Point	Y
8	Kade Point	Y
9	Saddle Island	Y
10	Cape Demidov Isthmus	Y
11	Bomford Peninsula (Granat Point)	Y
12	Samuel Island (Tidespring Island)	Y
13	Cape Rosa	Y
14	Nunez Peninsula	Y
15	Annenkov Island	-
16	Diaz Cove north	N
17	Kupriyanov Island outer	Y
18	Kupriyanov Island inner (Poncet Island)	N
19	Ranvik	-
20	Trollhul	Y
21	Inner Lee	Y
22	Outer Lee	Y
23	Skua Island	N
24	Prion Island	Y
25	Petrel Island	N
26	Invisible Island	Y
27	Mollyhawk Island	Y
28	Crescent Island	Y
29	Albatross Island	Y
30	Nameless Point	N
31	Trollul north	-
32	Kupriyanov islet	N
33	Nilse Hullet	-
34	Aucellina Point	-

6.4 Black-browed and Grey-headed Albatross

6.4.1 Black-browed and Grey-headed Albatrosses – Whole-Archipelago Survey 2003/04

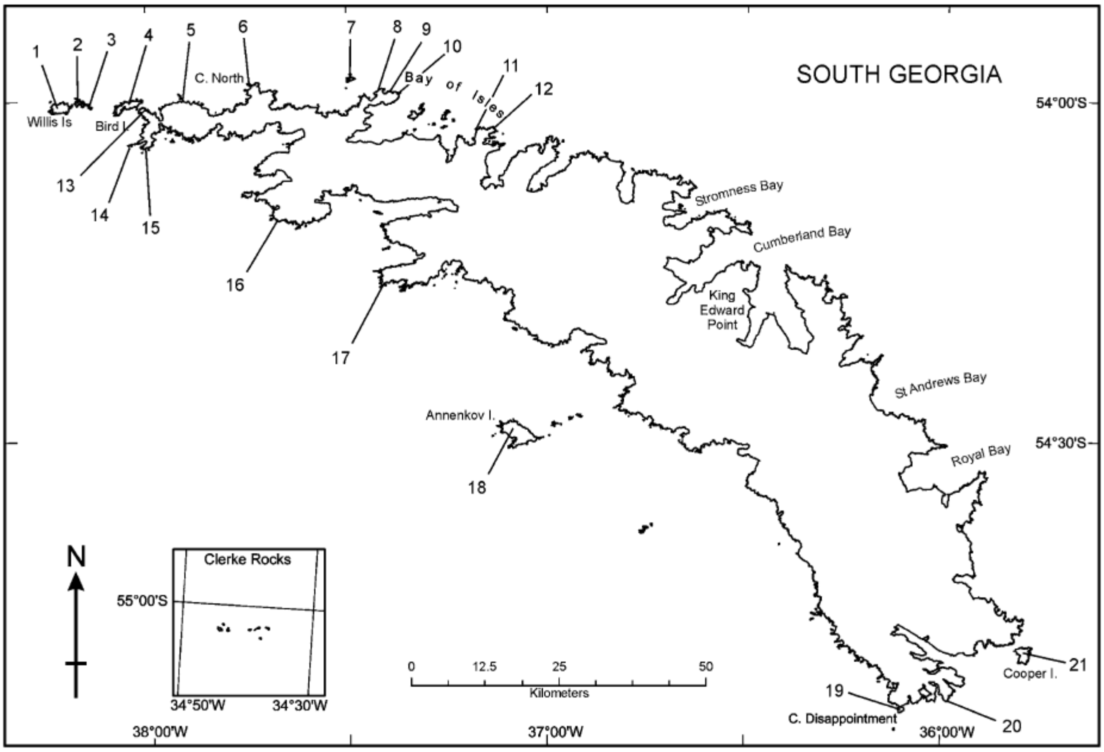

Figure 9. Breeding locations (22) of black-browed and grey-headed albatrosses (9) at South Georgia, based on 2003/04 whole-archipelago survey. Numbers refer to the locations listed in Table 6. (Figure from Poncet *et al*. 2006).

Table 6. Locations of black-browed and grey-headed colonies to correspond with location numbers in Figure 9, based on 2003/04 whole-archipelago survey (adapted from Poncet *et al.* 2006).

ID	Location	BBA	GHA
1	Main Island, Willis Islands	Y	Y
2	Trinity Island, Willis Islands	Y	Y
3	Hall Island, Willis Islands	N	Y
4	Bird Island	Y	Y
5	Sorn & Bernt coast	Y	Y
6	Cape North	Y	Y
7	Welcome Islets	Y	N
8	Sheathbill Bay	Y	N
9	Sitka Bay	Y	N
10	Cape Buller	Y	N
11	Cape Wilson	Y	N
12	Cape Crewe	Y	N
13	Paryadin Peninsula north	Y	Y
14	Jomfruene	N	Y
15	Paryadin Peninsula south	Y	Y
16	Klutschak Point	Y	N
17	Cape Nunez	Y	N
18	Annenkov Island	Y	N
19	Green Island	Y	N
20	Rumbolds Point	Y	N
21	Cooper Island	Y	N
22	Clerke Rocks	Y	N

6.4.2 Black-browed and Grey-headed Albatrosses – Whole-Archipelago Survey 2014/15

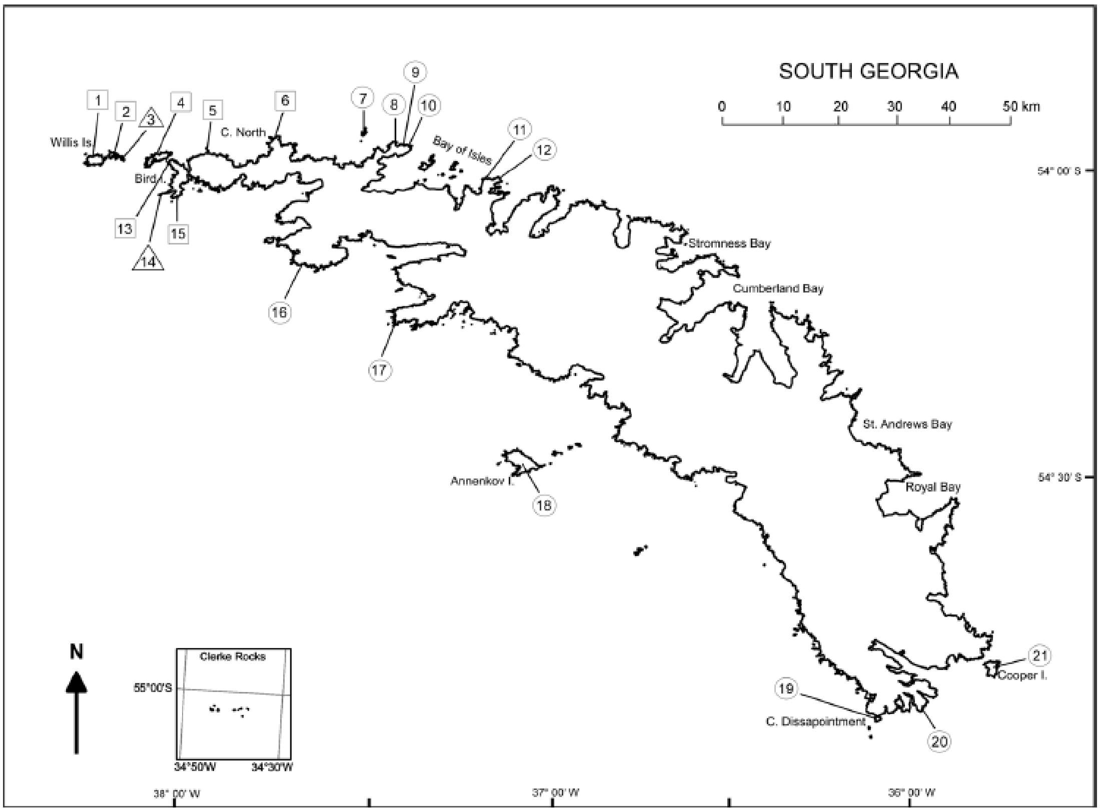

Figure 10. Breeding locations of black-browed albatross and grey-headed albatross at South Georgia, based on 2014/15 whole-island survey. Numbers refer to the locations listed in Table 7. Locations at which both species breed (*squares*) are distinguished from those at which only one species breed: grey-headed albatrosses (*triangles*) and black-browed albatrosses (*circles*). Figure from Poncet *et al.* (2017).

Table 7. Locations of black-browed and grey-headed colonies to correspond with location numbers in Figure 10, based on 2014/15 whole-island survey (adapted from Poncet *et al.* 2017). Entries with a dash (-) indicate not surveyed in 2014/15 season.

ID	Location	BBA	GHA
1	Main Island, Willis Islands	-	-
2	Trinity Island, Willis Islands	-	-
3	Hall Island, Willis Islands	-	-
4	Bird Island	Y	Y
5	Sorn & Bernt coast	Y	Y
6	Cape North	Y	Y
7	Welcome Islets	Y	N
8	Sheathbill Bay	Y	N
9	Sitka Bay	Y	N
10	Cape Buller	Y	N
11	Cape Wilson	Y	N
12	Cape Crewe	Y	N
13	Paryadin Peninsula north	Y	Y
14	Jomfruene	N	Y
15	Paryadin Peninsula south	Y	Y
16	Klutschak Point	-	-
17	Cape Nunez	-	-
18	Annenkov Island	-	-
19	Green Island	-	-
20	Rumbolds Point	-	-
21	Cooper Island	Y	N
22	Clerke Rocks	-	-

6.5 Light-mantled Albatross

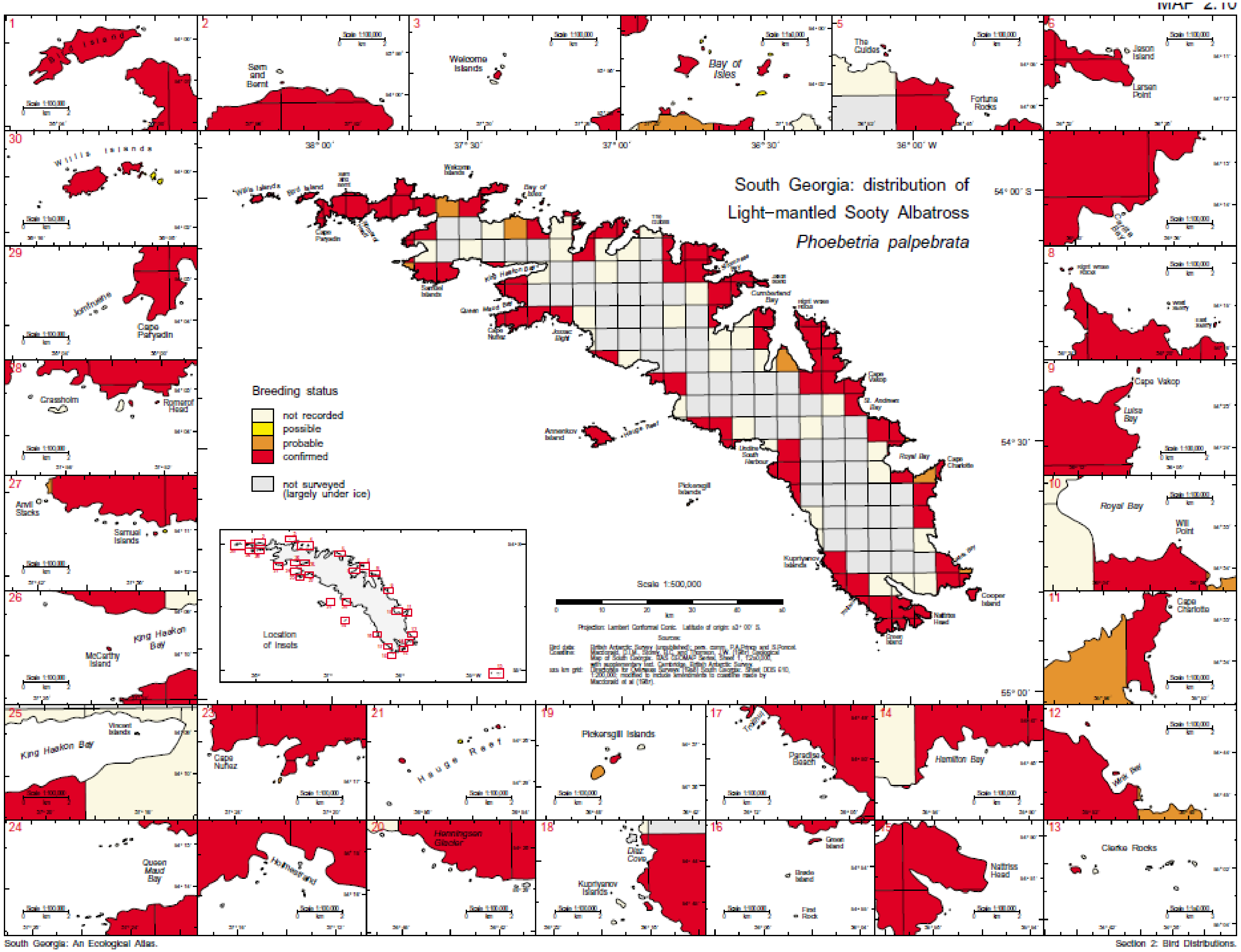

Figure 11. Breeding distribution of Light-mantled albatross (*Phoebetria palpebrata*) at South Georgia. Figure from Prince & Poncet (1996).

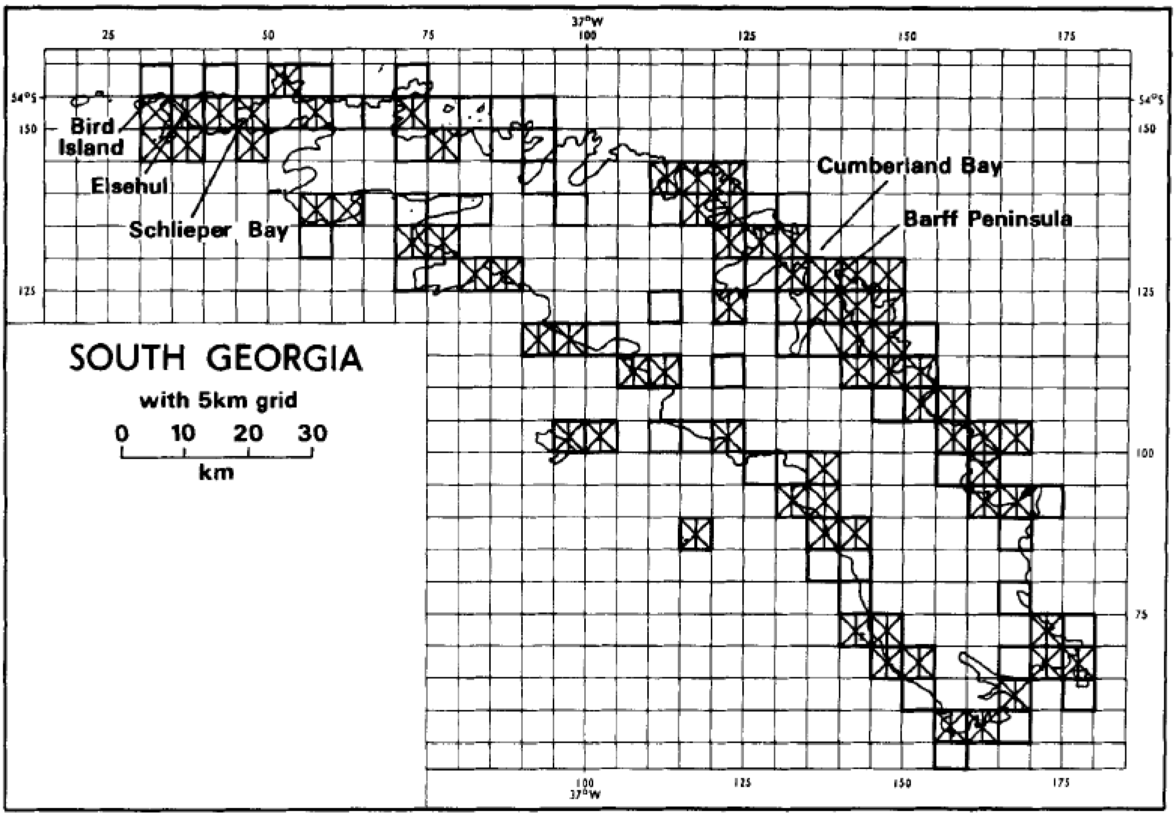

Figure 12. Breeding distribution of the Light-mantled albatross at South Georgia. Map based on data collected by British Antarctic Survey field parties, 1971-1981. All outlined *5* km squares were surveyed; LMA breeds in all those marked with a cross. Place names are those mentioned in the text (Section 3.5.3). Figure from Thomas *et al.* (1983).