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Recent trends in numbers of wandering (*Diomedea exulans*), black-browed (*Thalassarche melanophris*) and grey-headed (*T. chrysostoma*) albatrosses breeding at South Georgia

Sally Poncet[1,2] · Anton C. Wolfaardt[3] · Andy Black[1] · Sarah Browning[1] · Kieran Lawton[4] · Jennifer Lee[1] · Ken Passfield[1,2] · Georgina Strange[1] · Richard A. Phillips[5]

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Abstract South Georgia supports globally important populations of seabirds, including the wandering albatross *Diomedea exulans*, black-browed albatross *Thalassarche melanophris* and grey-headed albatross *T. chrysostoma*, currently classified by the world Conservation Union (IUCN) as vulnerable, near threatened and endangered, respectively. Surveys of these species at South Georgia were conducted during the incubation stage in November 2014 to January 2015, repeating previous surveys conducted in the 2003/2004 season. Numbers of wandering albatrosses breeding annually at South Georgia decreased by 18% (1.8% per year) from 1553 pairs in 2003/2004 to an estimated 1278 pairs in 2014/2015. Over the same period, black-browed and grey-headed albatrosses decreased by 19% (1.9% per year) and 43% (5% per year), respectively. These represent a continuation of negative trends at South Georgia since the 1970s and are in contrast to some populations elsewhere, which have shown signs of recent recovery. Given the importance of South Georgia for these species, the ongoing population declines, and in the case of grey-headed albatrosses, an acceleration of the decline is of major conservation concern. Incidental fisheries mortality (bycatch) is currently considered to be the main threat. Although seabird bycatch has been reduced to negligible levels in the fisheries operating around South Georgia, wider implementation of effective seabird bycatch mitigation measures is required to improve the conservation status of the South Georgia populations of wandering, black-browed and grey-headed albatrosses. In addition, more research is required to investigate the respective roles of bycatch and climate change in driving these population trends.

Keywords Conservation · Fisheries bycatch · Long-term monitoring · Climate change

✉ Anton C. Wolfaardt
acwolfaardt@gmail.com

[1] Government of South Georgia & the South Sandwich Islands, Government House, Stanley FIQQ 1ZZ, Falkland Islands

[2] South Georgia Surveys, P.O. Box 538, Stanley FIQQ 1ZZ, Falkland Islands

[3] P.O. Box 2276, Plettenberg Bay 6600, South Africa

[4] Skadia Pty Ltd, Horsham, VIC 3409, Australia

[5] British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

Introduction

South Georgia is a globally important breeding site for seabirds, including four albatross and three petrel species listed under the Agreement on the Conservation of Albatrosses and Petrels (Clarke et al. 2012). Most of these species are globally threatened or near threatened mainly as a result of incidental mortality, or bycatch, associated with commercial fisheries activities (Phillips et al. 2016). Long-term studies at Bird Island in the north-west of the archipelago indicate declines in numbers of wandering (*Diomedea exulans*), black-browed (*Thalassarche melanophris*) and grey-headed (*T. chrysostoma*) albatrosses since the 1970s (Prince et al. 1994; Croxall et al. 1998; Poncet et al. 2006; BAS unpublished data). Given the lack of evidence for any land-based threats (such as human disturbance and introduced predators) or disease, these declines have been attributed to factors affecting birds at sea, and in particular bycatch associated with commercial longline and trawl fishing operations (Croxall et al. 1998; Prince et al. 1998; Poncet et al. 2006).

Although the population sizes and demography of albatrosses at Bird Island are monitored annually, there have been few surveys of the remainder of the South Georgia archipelago. The first complete survey of wandering albatrosses was conducted in 1984, involving land-based counts of chicks (Clark 1984). The first archipelago-wide survey of black-browed and grey-headed albatross colonies took place in 1985/86, using yacht-based counts (Prince et al. 1994). All known colonies of these three species at South Georgia were surveyed again in 2003/2004, using yacht-based digital photography and ground counts (Poncet et al. 2006). In contrast to the earlier surveys, the 2003/2004 census accounted for errors associated with diurnal variation in adult attendance, and nest failure, and thus provided a more robust assessment of the status of the South Georgia populations. On the basis of the 2003/2004 surveys, the wandering albatross population was estimated to have declined by 30% between 1983/1984 and 2003/2004, with similar population decreases reported for black-browed and grey-headed albatrosses (Poncet et al. 2006).

In this paper, we report the results of a census of wandering, black-browed and grey-headed albatrosses breeding at South Georgia conducted in 2014/2015, 11 years after the previous census. Using the same methodology as in 2003/2004, including the application of correction factors, we also update information on the population status and trends of these species.

Materials and methods

South Georgia

The South Georgia archipelago consists of a main island and numerous offshore islands and islets. It lies between latitudes 53°S and 55°S and longitudes 34°W and 42°W, roughly 2000 km east of South America, and 350 km south of the Antarctic Polar Front in the south-west Atlantic Ocean (Fig. 1). The island is approximately 170 km long, 2–40 km wide and 3755 km^2 in area. Albatross colonies have been recorded at 56 locations along the vegetated coastal fringe of the main island and vegetated offshore islands. The entire 200-nautical mile Maritime Zone around South Georgia is included in the South Georgia and the South Sandwich Islands Marine Protected Area, which was formally declared in 2012 (Government of South Georgia and the South Sandwich Islands 2013).

Wandering albatross census

Wandering albatrosses were recorded breeding at 30 locations around South Georgia during the 2003/2004 survey (Poncet et al. 2006). Small numbers of birds have subsequently been recorded at four additional locations. The majority of the population is located in the north-west of the archipelago and on Annenkov Island, with a handful of sites supporting small numbers at the south-west tip of the archipelago (Fig. 1). In total, 28 of the 34 known breeding locations were surveyed from 1 to 31 January 2015, which coincides with the early to mid-incubation period and is consistent with the 2003/2004 survey dates (30 December 2003 to 31 January 2004).

The census of wandering albatrosses breeding at Albatross Island was conducted from a field camp during 1–10 January 2015. The majority of the remaining locations were surveyed by shore parties deployed from the vessel *MV Hans Hansson* between 9 and 20 January. Survey methods and corrections for previous breeding failure 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 geographical positioning system (GPS) unit.

Rough sea conditions prevented landings at six locations: at Chaplin Head and Ranvik where no birds were observed during the 2004 survey (Poncet et al. 2006); at Nilse Hullet and Trollhul North where four nests and one nest, respectively, were reported in 2007; at Aucellina Point where two nests were reported in 2013 (D. Poncet, personal communication); 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 other logistical constraints, Annenkov Island was not surveyed in 2014/15. In 2004, the estimate for Annenkov Island (193 pairs) represented 12% of the total South Georgia breeding population.

As part of a long-term annual monitoring programme at Bird Island, all breeding attempts and failures were recorded in daily visits during the laying period, and at least weekly visits during the rest of incubation at the Wanderer Ridge study colony ($n = 120$ nests; or c. 16% of the Bird Island breeding population). All remaining nests on Bird Island were marked during early to mid-incubation, following which a count of all active nests was conducted on 31 January 2015. The proportion of nests at Wanderer Ridge that had failed by that date was then used as a correction factor to estimate the original number of pairs that attempted to breed at Bird Island, and all other breeding locations surveyed in 2014/2015.

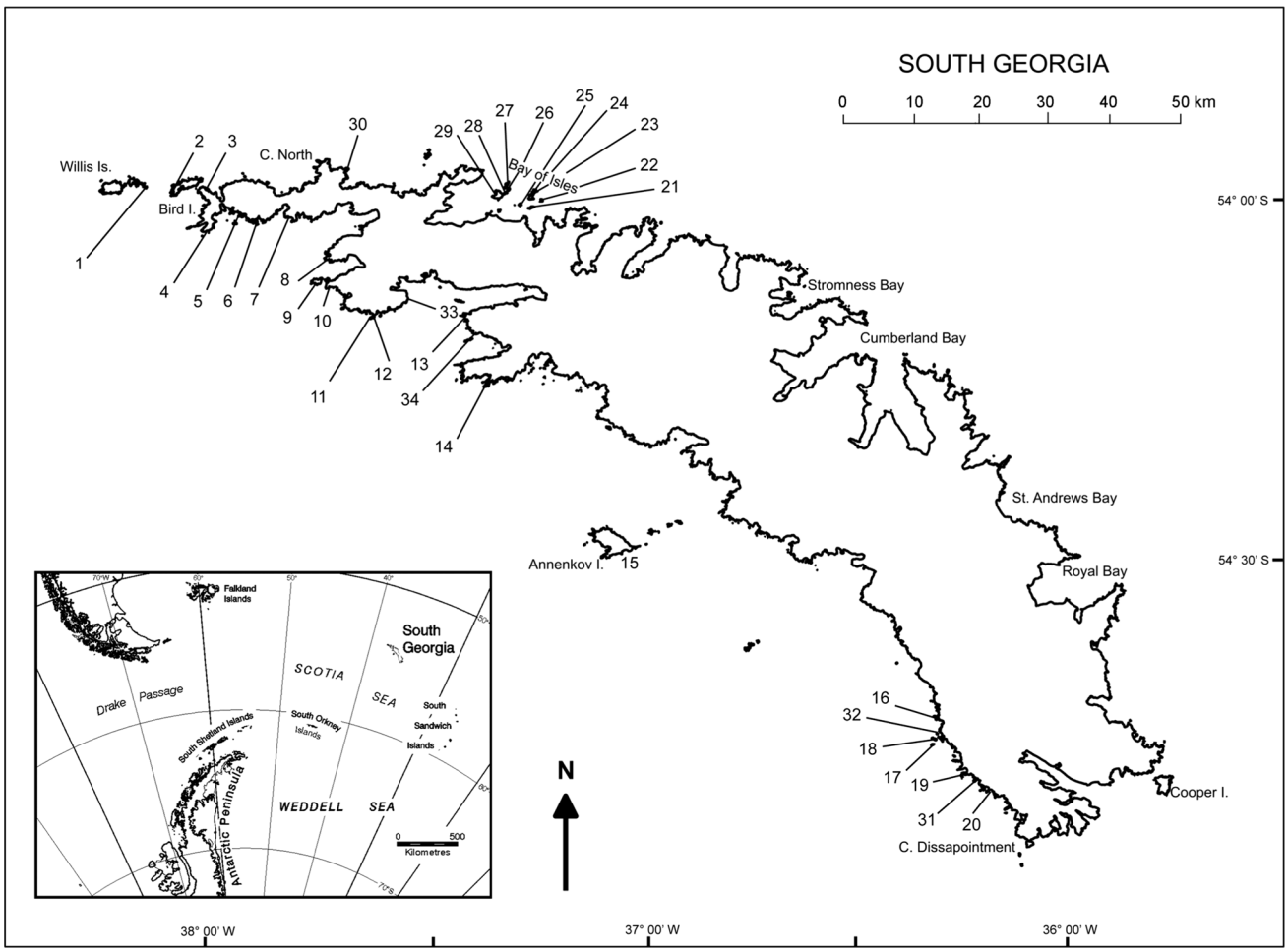

Fig. 1 Breeding locations of wandering albatross at South Georgia with *inset* map showing location of South Georgia and the Scotia Sea. *Numbers* refer to the locations listed in Table 1

On the basis of the breeding failure data from the Wanderer Ridge study colony in 2014/2015, counts of active nests at sites on 1–13 January, 14–17 January and 18–20 January were inflated by 2.56, 3.49 and 4.35%, respectively.

Black-browed and grey-headed albatross surveys

Black-browed and grey-headed albatrosses are known to breed at 22 locations on the mainland and offshore islands of South Georgia (Fig. 2). Each of these breeding locations comprises one or more colonies, including some mixed colonies in which both species breed. Colonies are typically located on steep coastal headlands and cliffs covered in tussac grass (*Poa flabellata*), which are often difficult to access for ground counts. A subset (13) of the 22 breeding locations surveyed in 2003 (Poncet et al. 2006) were resurveyed in 2014 using the same methodology; these held c. 30% and c. 70%, respectively, of total numbers of black-browed and grey-headed albatrosses in the archipelago in 2003. The 2014 surveys took place from 24 November to 6 December 2014, which matches closely with the timing of the previous surveys (23 November to 7 December 2003). At Bird Island, a subset of 7 black-browed and 11 grey-headed albatross colonies were counted (on the ground) in 2014 as part of the annual monitoring programme and compared to the ground counts of the same study colonies in 2003. On the basis of the 2003/2004 all-island census, these study colonies represent approximately 39 and 62%, respectively, of the total black-browed and grey-headed breeding populations at Bird Island. The ground counts at Bird Island in 2003 and 2014 were adjusted for previous breeding failure based on data collected from study colonies that were visited daily during the laying period, and at least weekly thereafter, in each of the study years. Five of the colonies at Bird Island for which ground counts were conducted were also photograph-surveyed in 2014 to estimate the error associated with the photographic survey methodology (see below). The colonies at the other 12 breeding locations surveyed in

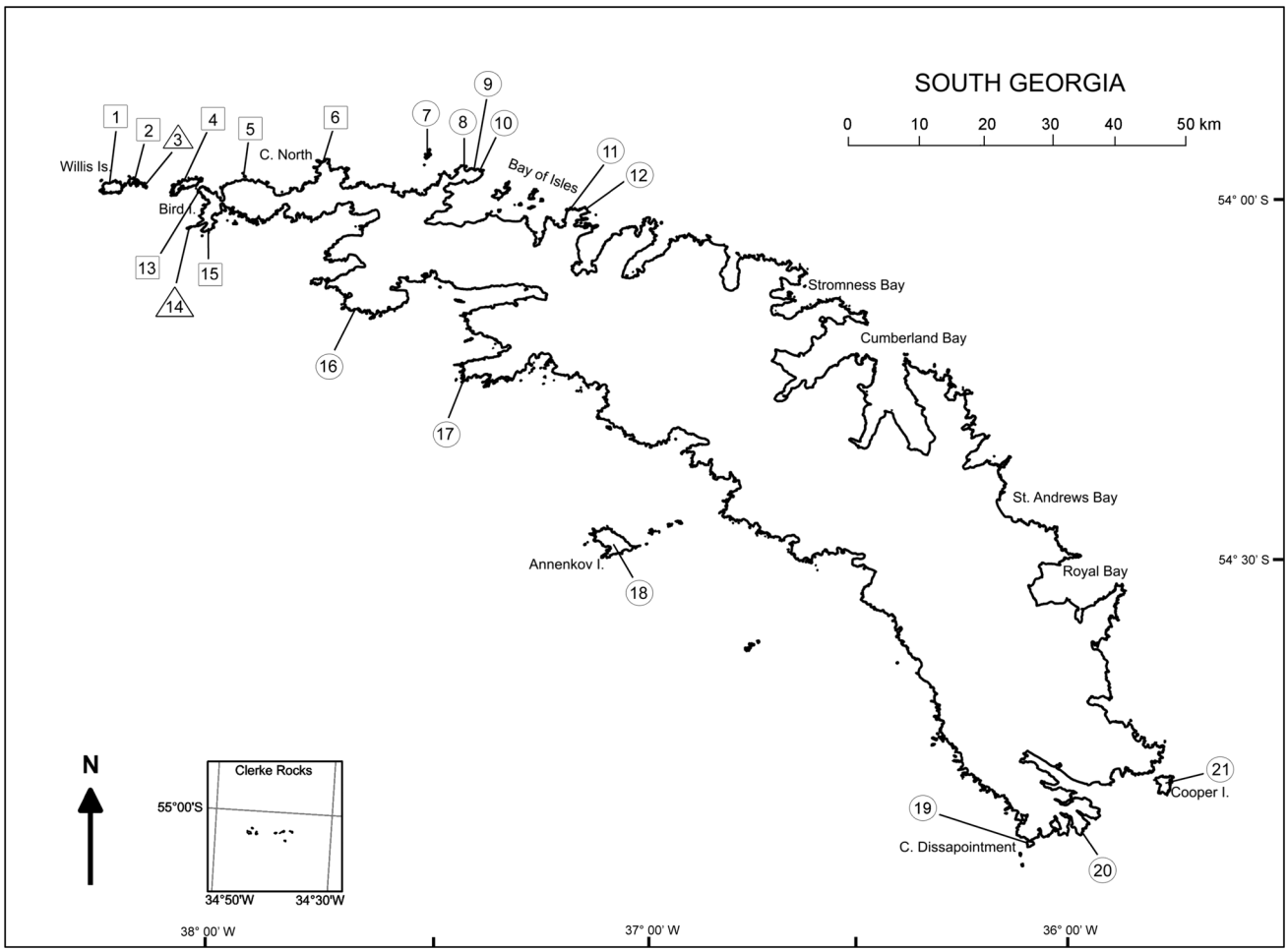

Fig. 2 Breeding locations of black-browed and grey-headed albatrosses at South Georgia. *Numbers* refer to the locations listed in Table 2. Locations at which both species breed (*squares*) are distinguished from those at which only one of these species breed: grey-headed albatrosses (*triangles*) and black-browed albatrosses (*circles*)

2014 were photographed from a rigid hull inflatable boat (RHIB), supported by the Government of South Georgia and the South Sandwich Islands' fisheries patrol vessel, *MV Pharos SG*, and were later counted in their entirety. Colony positions within the breeding locations were already well documented from previous censuses (Prince et al. 1994; Poncet et al. 2006).

All photographs were taken with a Canon EOS 5D MKIII Digital Single Lens Reflex camera and a 24–105 mm image stabilizer lens in both JPEG Fine and RAW image formats. RAW files were subsequently converted into high-resolution TIFF files. The photographic protocols were the same as used in 2003. Colonies were generally photographed from a distance of 100–200 m, the exact distance and angle varying according to the topography, and the prevailing wind and sea conditions. 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. This was achieved during the survey by aligning reference photographs and annotated marine charts from the 2003 census with the colonies being photographed in 2014. The coordinates of all these positions were recorded with a GPS unit, to serve as a reference for future surveys. Colony areas were initially photographed at the wide-angle end of the focal range to provide perspective photographs in which to locate the specific colonies. Thereafter, the telephoto end of the focal range was used to take close-up photographs of the colonies for subsequent counting. Fast shutter speeds (1/1000 s or faster) were used to minimise camera shake.

Once downloaded to a computer, and using the wide-angle photographs as a guide, photographic montages of overlapping photographs were constructed using GNU image manipulation program (GIMP) and Adobe Photoshop. In cases where colonies lacked distinct boundaries, counting 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

Table 1 Counts and estimates of the number of pairs of wandering albatross breeding at South Georgia and the percentage change in the number of breeding pairs between 2003/2004 and 2014/2015

Location no.	Location	No. of breeding pairs 2003/2004		No. of breeding pairs 2014/2015		Change (%)
		Count	Estimate	Count	Estimate	
1	Proud Island	6	6	3	3	−50
2	Bird Island	920	948	723	772	−18.6
3	Cape Alexandra	39	40	34	35	−12.5
4	Coal Harbour	16	16	18	18	12.5
5	Frida Hole	6	6	3	3	−50
6	*Chaplin Head*	[*0*	*0*			]
7	Weddell Point	10	10	10	10	0
8	Kade Point	22	23	10	10	−56.5
9	Saddle Island	39	40	31	32	−20
10	Demidov isthmus	2	2	1	1	−50
11	Granat Point[a]	15	15	7	7	−53.3
12	Tidespring Island[b]	1	1	5	5	400
13	Cape Rosa	4	4	4	4	0
14	Nunez Peninsula	3	3	1	1	−66.7
15	*Annenkov Island*[d]	[*187*	*193*			]
16	Diaz Cove North	0	0	0	0	
17	Kupriyanov Island outer	5	5	9	9	80
18	Poncet Island[c]	0	0	0	0	
19	*Ranvik*	[*0*	*0*			]
20	Trollhul	3	3	2	2	−3.6
21	Inner Lee	9	9	15	15	66.7
22	Outer Lee	9	9	3	3	−66.7
23	Skua Island	0	0	0	0	
24	Prion Island	42	43	36	37	−13.9
25	Petrel Island	1	1	0	0	−100
26	Invisible Island	1	1	1	1	0
27	Mollyhawk Island	3	3	1	1	−66.7
28	Crescent Island	15	15	11	11	−26.7
29	Albatross Island	151	155	136	139	−10.3
30	Nameless Point	2	2	0	0	−100
31	*Trollhul north*[e]	[				]
32	Kupriyanov islet[e]			0	0	
33	*Nilse Hullet*[e]	[				]
34	*Aucellina Point*[e]	[				]
Total for South Georgia, excluding Annenkov Island[f]		1324	1360	1064	1119	−17.7
Total for South Georgia, including Annenkov Island[g]			1553		1278	

Nest failure data from the Wanderer Ridge study colony at Bird Island were used as correction factors to estimate the original number of pairs that attempted to breed at each location (see text for further details)

Location numbers are the same as used in Poncet et al. (2006), with a few exceptions listed below, and are mapped in Fig. 1. The calendar year provided is the one in which chicks hatched

Locations that were not surveyed in 2014/2015 are italicised and enclosed in square brackets

[a] Location 11 (Granat Point) was called Bomford Peninsula in Poncet et al. (2006)

[b] Location 12 (Tidespring Island) was called Samuel Island in Poncet et al. (2006)

[c] Location 18 (Poncet Island) was called Kupriyanov Island inner in Poncet et al. (2006)

[d] Annenkov Island was not surveyed in 2015

[e] Locations 31, 32 and 33 were first documented as wandering albatross breeding locations in 2007 and Location 34 in 2013

[f] These are the total counts and estimates for all locations surveyed in 2014/2015, and so exclude Annenkov Island

[g] These totals represent the total estimates for South Georgia. We have imputed the 2014/2015 estimate for Annenkov Island using the overall rate of decline between 2003/2004 and 2014/2015 (17.7%)

Table 2 Number of breeding pairs of black-browed and grey-headed albatrosses at South Georgia in 2003/2004 and 2014/2015

Location no.	Location	Number of breeding pairs					
		Black-browed albatross			Grey-headed albatross		
		2003/2004	2014/2015	Change (%)	2003/2004	2014/2015	Change (%)
1	*Main Island, Willis Island*	[*14,559*			*5177*		]
2	*Trinity Island, Willis Island*	[*13,960*			*3309*		]
3	*Hall Island, Willis Islands*	[*0*			*2686*		]
4	Bird Island[a]	(3192)	(2714)	−15.0	(3189)	(2248)	−29.5
5	Sorn & Bern Coast	74	60	−18.9	1625	616	−62.1
6	Cape North	1546	1642	−5.4	488	324	−33.6
7	Welcome Islets	188	152	−19.1	0	0	
8	Sheathbill Bay	481	345	−28.3	0	0	
9	Sitka Bay	816	588	−27.9	0	0	
10	Cape Buller	177	93	−47.5	0	0	
11	Cape Wilson	205	200	−2.4	0	0	
12	Cape Crewe	42	31	−26.2	0	0	
13	Paryadin Peninsula North	1428	1079	−24.4	6721	3740	−44.4
14	Jomfruene	0	0		490	389	−20.6
15	Paryadin Peninsula South	3789	2802	−26.0	22,058	12,251	−44.5
16	*Klutschak Point*	[*784*			*0*		]
17	*Cape Nunez*	[*981*			*0*		]
18	*Annenkov Island*	[*9398*			*0*		]
19	*Green Island*	[*3404*			*0*		]
20	*Rumbolds Point*	[*2340*			*0*		]
21	Cooper Island	10,606	8772	−17.3	0		
22	*Clerke Rocks*	[*1254*			*0*		]
	Total for South Georgia, excluding locations not counted in 2014	22,544[b]	18,298	−18.8	34,571[b]	19,568	−43.4

Figures for Bird Island are direct ground counts that have been adjusted for breeding failure using data from study colonies that were visited daily during laying and weekly thereafter. Figures for all other colonies are from photographic counts corrected for diurnal variation and breeding failure (see text and Table 3 for further details)

Location numbers are the same as used in Poncet et al. (2006) and are mapped in Fig. 2. The calendar year provided is the one in which chicks hatched

Locations that were not surveyed in 2014/2015 are italicised and enclosed in square brackets

[a] In both 2003/2004 and 2014/2015, the figures provided for Bird Island are for the subset of colonies counted in both years and do not represent the totals for this breeding location. These figures are therefore presented in round brackets

[b] The totals for 2003/2004 exclude the figures from locations not surveyed in 2014/2015, even though these are listed in the table in italics and within square brackets

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 (K. Lawton) had overall responsibility for the on-screen counts in the 2003 survey. To determine potential observer bias, albatrosses from a subset of 12 colonies (10 black-browed albatross and 2 grey-headed albatross 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 lead to inflated estimates of breeding pairs if a substantial number of 'loafing' birds (mates of birds on nests, failed breeders or non-breeders) were in the colony at the time of the survey. To account for diurnal variation in attendance of non-breeding birds (Poncet et al. 2006), photographic counts of a black-browed albatross colony at Bird Island (colony F1, comprising 101 breeding pairs) were conducted at two-hourly intervals from 10h00 to 20h00 during the survey period, except for 2 days of poor weather. As in the 2003/2004 survey, the diurnal

Table 3 Comparison of estimates from vessel-based photographic counts (corrected for diurnal variation and breeding failure) and ground counts (corrected for breeding failure) from selected study colonies at Bird Island in 2014

Colony	Date	Time GMT	Near time	*a* Photographic counts	*b* Diurnal adjustment	*c* Diurnally corrected photographic counts ($a \times 1/b$)	*d* Overall correction of photographic counts ($c \times 0.864$)	*e* Corrected ground counts	*f* Difference (%) (d vs e) ($(d - e)/e \times 100$)
Black-browed albatross									
F1	29 Nov 2014	9.22	10.00	115	0.9802	117	101	99	2.0
H	29 Nov 2014	9.34	10.00	38	0.9802	39	33	33	0
I	02 Dec 2014	15.55	16.00	831	0.9875	842	727	695	4.6
K	02 Dec 2014	15.30	16.00	195	0.9875	197	171	246	−30.5
Total							1032	1073	−3.8
Grey-headed albatross									
D	02 Dec 2014	15.30	16.00	301	0.9875	305	263	101	160.4
K	02 Dec 2014	15.30	16.00	1044	0.9875	1057	913	1197	−23.7
Total							1176	1298	−9.4

Colonies F1, H and I are single-species (black-browed albatross) colonies. Colonies D and K are mixed colonies, but the latter is made up predominantly (91%) of grey-headed albatrosses. Albatrosses that could not be identified to species level in the photographic counts were apportioned based on the ratio of identified black-browed and grey-headed albatrosses in mixed colonies, and for single-species colonies, were assumed to be of that species

attendance pattern was broadly consistent across the study period, with a gradual increase in the number of birds from 10h00 to a maximum at 14h00 (solar noon c. 14h20), followed by a decline until 20h00 hours. Although the patterns of diurnal attendance were similar in 2003 and 2014, with peak attendance around solar noon, the magnitude of the diurnal variation was slightly less pronounced in 2014. On average over the survey period, the number of birds present in colony F1 at 10h00, 12h00, 16h00 and 18h00 represented 0.9802, 0.9846, 0.9875 and 0.9694, respectively, of those present at 14h00. To account for diurnal variation, counts at colonies were standardised to represent the number of birds likely to be present at 14h00, by multiplying the photographic count by the reciprocal of these proportions. For example, if a count from a photograph taken at 16h00 was 554 birds, the expected number at 14h00 would be $554 \times (1/0.9875) = 561$ birds.

Photographic counts of colonies in 2014 were corrected simultaneously for breeding failure and the presence of loafers following the approach of Poncet et al. (2006). On the basis of the 2003/2004 survey data and analyses, Poncet et al. (2006) reported a highly significant functional relationship between the original nest estimate and the diurnally corrected photographic counts, as follows: *Original nest estimate* = *0.864* (*SE* ± *0.017*) × *diurnally corrected photographic count*. This functional equation accounts for the presence of loafers, nest failure and time of day in one integrated step and, given the absence of species effects, was used to correct photographic counts for both black-browed and grey-headed albatrosses in the 2003/2004 survey (Poncet et al. 2006). During the 2014/2015 survey, it was not possible to quantify the daily failure rates for the Bird Island colony (F1) photographed to determine the diurnal pattern of attendance of non-breeders (see above). Consequently, estimates of the original number of breeding pairs from the photographic counts in 2014 were calculated using the equation from the 2003/2004 study (Poncet et al. 2006): *original number of breeding pairs* = *0.864* (*SE* ± *0.017*) × *diurnally corrected photographic count*, where 0.864 is derived from the 2003/2004 survey and accounts for both the presence of loafers and previous nest failure, and where the diurnal correction factor has been updated based on the two-hourly photographic surveys conducted in 2014. It is therefore assumed that the proportion of loafers present and nests that failed were similar during the 2014/2015 and 2003/2004 surveys. As in 2003, this correction factor was applied to both black-browed and grey-headed albatrosses. 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 black-browed albatross colonies (comprising a total of 1073 breeding pairs) and two grey-headed albatross colonies (comprising 1298 breeding pairs) at Bird Island.

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 the black-browed and grey-headed albatrosses that were identified.

Of the 71 colonies photographed at two locations, Paryadin North and Paryadin South, 10 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 imputed using the mean change in the number of breeding pairs from 2003/2004 to 2014/2015 at the remaining colonies within the Paryadin North and South locations that were counted in both years. The imputed figures for these 10 colonies amounted to 153 black-browed and 931 grey-headed albatrosses, representing 3.9 and 5.8%, respectively, of the combined estimate for these two locations in 2014.

Results

Wandering albatross

Between 2004 and 2015, numbers of wandering albatrosses estimated to breed annually at South Georgia decreased by 17.7%, or 1.8% per annum (Table 1). This rate of decline excludes Annenkov Island and three other locations that collectively represented approximately 12% of the total South Georgia population in 2004. Using this overall rate of decline to impute the estimate for Annenkov Island, the total breeding population of wandering albatrosses at South Georgia in 2014/2015 is estimated to be 1278 pairs (Table 1). Decreases were recorded at 18 of the 28 surveyed locations, ranging from 10.3 to 56.5% for those that supported at least 25 pairs in 2004 (Table 1). The largest declines were recorded at Kade Point, where the number of breeding pairs decreased from 23 in 2004 to 10 in 2015, and at Granat Point (15 vs 7). The number of breeding pairs at Bird Island, which supports the majority (c. 60%) of the total South Georgia population, was 18.6% lower in 2015 than in 2004, a reduction of 1.9% per annum. This is not statistically different from the overall decline at all other sites surveyed in 2015 of 15.8%, or 1.6% per annum (Z-score = 1.24, $P = 0.21$). There were no active nests in 2015 at two locations where wandering albatrosses were recorded breeding in 2004: Nameless Point (formerly 2 nests) and Petrel Island (formerly 1 nest). In addition, locations where wandering albatrosses were recorded breeding prior to, but not during, the 2003/2004 survey and where no birds were recorded breeding in 2015 include Chaplin Head, Kupriyanov islet, Ranvik, Diaz Cove north, Skua Island and Poncet Island. There were seven locations at which numbers remained stable or increased between 2004 and 2015, all of which held <20 pairs: Invisible Island, Cape Rosa, Weddell Point, Coal Harbour, Kupriyanov Islands outer island, Inner Lee and Tidespring Island (Table 1).

Black-browed and grey-headed albatrosses

Between 2003 and 2014, the number of black-browed and grey-headed albatrosses breeding in the 18 study colonies monitored annually at Bird Island declined by 15% (1.5% per annum) and 30% (3.1% per annum), respectively (Table 2). Decreases in individual colonies at Bird Island ranged from 3 to 43% for black-browed albatrosses, and 7 to 50% for grey-headed albatrosses.

The corrected vessel-based photographic counts of the four black-browed albatross colonies on Bird Island yielded 1032 breeding pairs, compared to 1073 pairs for the corrected ground counts, a difference of 41 pairs (Table 3). For grey-headed albatrosses, the difference between the vessel-based estimates (1176 pairs) and corrected ground counts (1298) was 122 pairs. The photographic counts therefore underestimated the number of breeding pairs by 3.8% for black-browed albatrosses and 9.4% for grey-headed albatrosses, but there was considerable variation between colonies (Table 3). The differences between the two counters of the photographic counts for the 12 colonies double-counted averaged 0.8% (range 0–8.1%; Kruskal–Wallis ANOVA: $H_{(1)} = 0.013$; $P = 0.91$; n.s.), with an overall difference for all colonies of 2% (total birds counted 2284 vs 2329).

Estimates based on corrected photographic counts indicated decreases in both species between 2003 and 2014 at all locations surveyed in 2014 (Table 2). The declines ranged from 2% (Cape Wilson) to 48% (Cape Buller) for black-browed albatrosses and 21% (Jomfruene) to 62% (Sorn and Bern Coast) for grey-headed albatrosses. Including Bird Island, the overall decline of black-browed albatrosses at South Georgia was 19% (1.9% per annum) and of grey-headed albatrosses was 43% (5% per annum) from 2003 to 2014; there was no obvious spatial pattern in the rates of decline at different sites (Table 2). The total number of birds breeding in mixed colonies (both species combined) declined by 41% between 2003 and 2014, corresponding to 4.7% per annum. Overall, grey-headed and black-browed albatrosses comprised 81 and 19% of the birds in mixed colonies, respectively.

Discussion

The number of wandering albatrosses breeding at South Georgia decreased by over 17% between 2004 and 2015, at a similar annual rate of decline (1.9%) to that recorded from 1984 to 2004 (1.8% per annum, Poncet et al. 2006). The few sites at which numbers remained stable or increased slightly in recent years held few (<20) pairs. The rate of decline at Bird Island, which held 70% of the South Georgia population in 2004, is similar to that recorded for all sites elsewhere in the archipelago. Consistent methods were used in 2004 and 2015, so there should be no methodological biases. Moreover, for all three species surveyed, data from the intensively studied colonies at Bird Island show that 2014/15 was not an anomalous year (BAS unpublished data), so the rates of decline calculated from 2003 to 2014 are considered to be representative of the long-term trend. However, it is acknowledged that caution is required when interpreting population trends derived from censuses conducted some years apart. This is especially the case for species such as the wandering and grey-headed albatross that breed biennially and for which the proportion of deferring breeders each year may vary (Dillingham and Fletcher 2011; Bonnevie et al. 2012). Notwithstanding this caveat, and despite some variability between locations, it is clear that long-term decreases (over 30 years) of wandering albatrosses have occurred throughout the archipelago, presumably influenced by wide-scale, rather than local-scale drivers. The decline between 1984 and 2004 was ascribed primarily to incidental mortality associated with commercial fisheries operations (Poncet et al. 2006); the continuation of this decline suggests that bycatch remains a major threat.

Following the introduction of a suite of bycatch mitigation measures, including a time–area closure of the local fishery for Patagonian toothfish (*Dissostichus eleginoides*), historically high levels of seabird bycatch have been reduced to negligible levels in fisheries operating around South Georgia (Croxall 2008; Varty et al. 2008). The main threats are therefore considered to be from more distant fisheries, particularly during the non-breeding period when birds range more widely (Wolfaardt and Christie 2010). Wandering albatrosses overlap, and potentially interact, with multiple fisheries across ocean basins (Prince et al. 1998). Although levels of observer coverage and the availability of bycatch data remain poor for many fleets, several studies have concluded that bycatch, particularly by pelagic longline fishing vessels in the south-west Atlantic, is sufficient to account for the decline in the wandering albatross at South Georgia (Tuck et al. 2011; Jiménez et al. 2012, 2014). In contrast, wandering albatrosses breeding at the Prince Edward and Crozet islands in the Indian Ocean (the largest and second largest populations, respectively) (Agreement on the Conservation of Albatrosses 2009) have shown signs of recent recovery (Weimerskirch et al. 1997; Nel et al. 2002a; Delord et al. 2008; Ryan et al. 2009). These contrasting trends presumably reflect, at least in part, differences in the relative overlap with different fleets, and in the adoption in recent decades of seabird bycatch mitigation, as birds from the Indian Ocean spend much more time in that region and off Australia, and rarely visit the Atlantic Ocean even during the non-breeding season (Weimerskirch 1998; Nel et al. 2002b; Weimerskirch et al. 2015).

Between 2003 and 2014, both black-browed and grey-headed albatrosses declined at all locations surveyed in 2014. The annual rates of decline were 1.9% for black-browed albatrosses and 5% for grey-headed albatrosses (19% and 43%, respectively, over the 11-year period, 2003–2014), which are both greater than the rates recorded at the subset of colonies counted in 1985/1986 and 2003 (1.1% for single-species colonies of both black-browed and grey-headed albatrosses and 2.2% for mixed colonies; Poncet et al. 2006). Between 2003 and 2014, the overall rate of decline of birds in mixed- colonies (40.8%) was similar to that recorded for grey-headed albatrosses (43.4%) and generally reflected the ratio of grey-headed (81%) and black-browed (19%) albatrosses within these colonies. Comparisons between counts in 2003 and the mid-1980s were interpreted cautiously because of differences in survey methodologies (Poncet et al. 2006). In contrast, the 2014 photographic survey, which included approximately 30 and 70%, respectively, of the total South Georgia populations of black-browed and grey-headed albatrosses, followed directly the methods used in the 2003/2004 census, and so the trend is considerably more robust. However, it is important to recognise the residual error associated with the estimates. The colonies at Bird Island are surveyed annually by direct ground counts, and numbers adjusted for breeding failure using data from study colonies visited daily during laying, and weekly thereafter. The error is therefore expected to be very low. Comparing these estimates with those obtained from photograph surveys at Bird Island suggests that the latter underestimate breeding pairs of black-browed and grey-headed albatrosses by 3.8 and 9.4%, respectively. Nevertheless, our study confirms that numbers of both species at South Georgia have continued to decrease since the 1970s and that the rates, particularly for grey-headed albatrosses, appear to have accelerated over the last 11 years.

Black-browed albatrosses have been recorded as bycatch in a range of southern hemisphere longline and trawl fisheries and are often the species caught in greatest numbers (e.g. Moreno et al. 2006; Sullivan et al. 2006;

Otley et al. 2007; Bugoni et al. 2008; Watkins et al. 2008; Jiménez et al. 2010; Maree et al. 2014). Fisheries mortality was considered to be the main driver of the decline in black-browed albatrosses at South Georgia between the mid-1980s and 2003 (Phillips et al. 2005; Arnold et al. 2006; Poncet et al. 2006). On the basis of the projected global population decline, the IUCN Red List threat status was changed in 2003 from vulnerable to endangered (BirdLife International 2016b). However, given increases recorded subsequently at the Falkland Islands, which hosts approximately 70% of the global population (Catry et al. 2011; Wolfaardt 2013), the species was down-listed in 2013 to near threatened (BirdLife International 2016b). This improved conservation status is further supported by increases reported recently for black-browed albatrosses at the Diego Ramirez and Ildefonso archipelagos in southern Chile between 2002 and 2014 (Robertson et al. 2014, 2016). This has been attributed to changes in the configuration of fishing gear used by the Chilean industrial longline fleet for Patagonian toothfish, which have led to a significant reduction in seabird mortality (Moreno et al. 2008; Robertson et al. 2014, 2016). The increase at the Falkland Islands has been associated with favourable environmental conditions and efforts to reduce seabird bycatch in both longline and trawl fisheries (Otley et al. 2007; Catry et al. 2011; Snell et al. 2012; Wolfaardt 2013).

That the black-browed albatross population at South Georgia continues to decline suggests that at least some of the fisheries they encounter remain a threat or that other factors are affecting the population. While breeding, black-browed albatrosses from South Georgia remain largely within the waters managed by the local government and the Commission for the Conservation of Antarctic Marine Living Resources (Phillips et al. 2004; Varty et al. 2008), where seabird bycatch has been reduced to negligible levels (Croxall 2008). In contrast, most (>90%) of the South Georgia population spend the non-breeding period in the Benguela upwelling region off south-west Africa (Phillips et al. 2005), where they are particularly vulnerable to bycatch (Petersen et al. 2008; Watkins et al. 2008). Following the introduction of mitigation measures in 2006, significant reductions in seabird bycatch, including of black-browed albatrosses, have recently been recorded for some of those fisheries (e.g. Maree et al. 2014). Whether this will lead to a change in the trend of the South Georgia population in the future remains to be seen.

The marked decline of grey-headed albatrosses at South Georgia is also in contrast with some populations elsewhere. Between 2002 and 2011, numbers breeding at Diego Ramirez remained stable (Robertson et al. 2014). From 2001 to 2008, numbers of grey-headed albatrosses at Marion Island also changed little, but appear to have decreased at neighbouring Prince Edward Island, possibly due to higher temperatures and consequent heat stress, as the latter site is at the northern extent of the breeding range (Ryan et al. 2009). Their decrease at South Georgia (which supports approximately 50% of the global population) of about 5% per year from 2003 to 2014 underscores the up-listing by IUCN of the grey-headed albatross in 2013 from Vulnerable to Endangered (BirdLife International 2016a). As with black-browed albatrosses, the vulnerability of the South Georgia population of grey-headed albatrosses to bycatch is greatest during the non-breeding period. Their circumpolar distribution (Croxall et al. 2005) and propensity to forage at oceanic frontal zones bring grey-headed albatrosses into potential conflict with pelagic longline fisheries targeting tuna and similar species in international waters. Although seabird bycatch mitigation has recently been adopted by all five Regional Fisheries Management Organisations responsible for managing tuna fisheries on the high seas, the extent of use and effectiveness of these measures has yet to be assessed (ACAP Intersessional Group 2014). Contrasting population trends suggest that grey-headed albatrosses from South Georgia face greater at-sea threats than birds from the Prince Edward Islands and southern Chile. Grey-headed albatrosses from Campbell Island exhibited a decline from the 1940s to 1997, attributed to rising sea-surface temperatures and associated impacts on feeding conditions (Waugh et al. 1999; Moore 2004). However, this decline appears to have ceased, with estimated numbers at Campbell Island showing a non-significant increase from the 1990s to 2006–2012 (Sagar 2014).

An increasing number of studies have documented combined impacts of both fisheries mortality and climate on albatross populations (e.g. Rolland et al. 2008, 2010; Barbraud et al. 2012). While it is clear that fisheries impacts are an important contributing factor, further investigations should also consider the role of environmental change in driving the demography of wandering, black-browed and grey-headed albatrosses breeding at South Georgia. Critically, a concerted international effort is required to reduce bycatch of these and other seabirds to negligible levels through the widespread use of effective bycatch mitigation measures (Phillips et al. 2016).

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