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Jeroen C. S. Creuwels · Jonathan S. Stark
Eric J. Woehler · Jan A. van Franeker
Christine A. Ribic

Monitoring of a Southern Giant Petrel *Macronectes giganteus* population on the Frazier Islands, Wilkes Land, Antarctica

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Abstract Since 1956, Southern Giant Petrels on the Frazier Islands, East Antarctica, have been counted with different census techniques, sometimes varying within seasons and among islands, which hindered analysis of the data. Protective measures for the islands from 1986 onwards have increased the need for reliable long-term census data, but reduced the ways to collect these data. Published and unpublished data were re-examined, and population trends were reconstructed based on two relatively standardised techniques: the number of active chicks (AC) and the number of apparently occupied nests (AON) around hatching. AC-values from Nelly Island from 1959 to 1998 indicate substantial periodic fluctuations, but no consistent long-term change. Since the late 1970s, AC-values on the other two islands and AON-values suggest that the breeding population may have grown by 35%. This recent growth, however, is within the extent of periodic fluctuations observed in Southern Giant Petrel population that is stable over the long term.

J. C. S. Creuwels (✉) · J. A. Franeker
Alterra-Texel, Marine and Coastal Zone Research, PO Box 167, 1790 AD, Den Burg, The Netherlands
E-mail: jeroen@creuwels.nl
Fax: +31-222-319235

J. C. S. Creuwels
Department of Marine Biology, University of Groningen, PO Box 14, 9750 AA, Haren, The Netherlands

J. S. Stark · E. J. Woehler
Australian Antarctic Division, Channel Highway, Kingston, TAS 7050, Australia

C. A. Ribic
USGS Wisconsin Cooperative Wildlife Research Unit, University of Wisconsin, 204 Russell Labs, Madison, WI 53706-1598, USA

Introduction

Southern Giant Petrels are considered a ‘vulnerable’ species according to IUCN guidelines (Birdlife 2000). The global population has probably decreased by 18% between the early 1980s and the late 1990s, although local population trends may have been positive (D.L. Patterson et al., in preparation). Human disturbance is often blamed for this global population decrease. Southern Giant Petrels are easily disturbed at their nest and readily leave their nest when humans approach at close distances (Warham 1962), which leads to decreases in reproductive success (Conroy 1972; Hunter 1984; Peter et al. 1991; Chupin 1997). Some colonies close to research stations have disappeared or decreased dramatically (Micol and Jouventin 2001; Nel et al. 2002).

Most Southern Giant Petrels breed on Sub-Antarctic islands and in the area around the Antarctic Peninsula (Hunter 1985; D.L. Patterson et al. in preparation). The Antarctic continental coast holds only about 1% of the global breeding population (Woehler et al. 2003). Here, along the southern limit of its habitat only four breeding localities in East Antarctica are known: Giganteus Island (67°35′S 62°30′E), Hawker Island (68°38′S 77°51′E), Frazier Islands (66°17′S 110°32′E) and Pointe Géologie (66°20′S 140°01′E). All these colonies are small and therefore probably vulnerable to catastrophic events or environmental variability (Shaffer 1987) including human disturbance. The largest of these four continental breeding populations exists on the Frazier Islands 17 km offshore of the Australian research station Casey. Here, Southern Giant Petrels have probably experienced relatively infrequent human disturbance because the islands are difficult to reach from the station. Since 1986, additional protective measures have been taken by banning helicopter flights and only allowing access by watercraft. The banding of Southern Giant Petrels has been discontinued, and only non-invasive observations from outside colony boundaries are currently permitted (Woehler et al. 2003). Earlier analyses suggested that the population on the Frazier Islands decreased till the 1980s and has been recovering after banding of chicks had stopped (Woehler et al. 1990; Woehler et al. 2003).

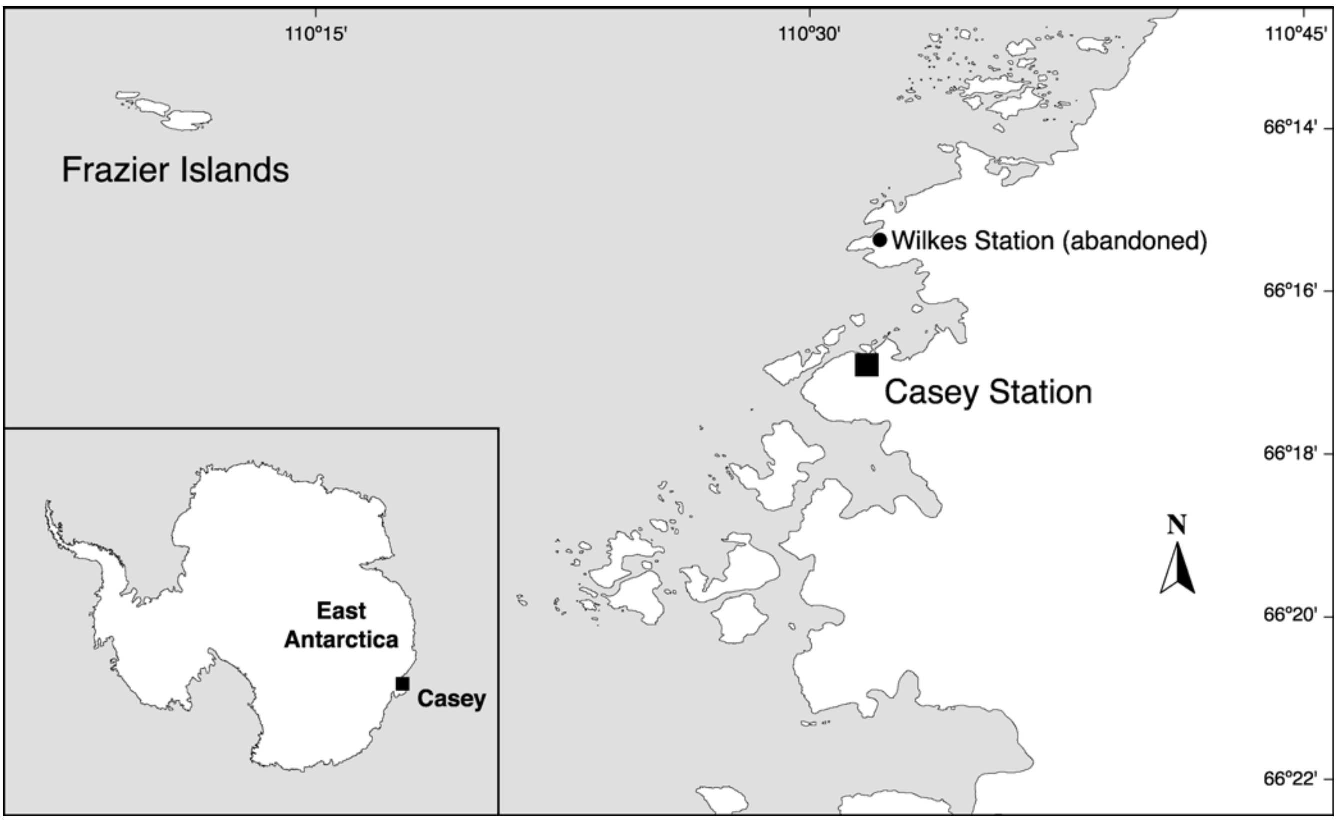
Detectability of long-term population change depends on the quality of census data. The accuracy of each census is influenced by the bias and precision of the counting technique (Verner 1985; Bibby et al. 2000). Especially in historical long-term datasets, biases may occur due to differences in study designs, aims, or techniques. On the Frazier Islands, until the mid 1980s the main purpose of many visits was to band chicks for the study of dispersal and longevity. Since then, the interest has shifted towards population monitoring for conservation purposes.

The first census of the Southern Giant Petrel population on the Frazier Islands was carried out in 1955. Since then, at irregular intervals, data have been collected by different and sometimes poorly described census techniques. Methods varied from superficial aerial surveys to exact chick counts by banding. In some years, multiple visits to the islands allowed estimates on breeding performance. Annual reproductive success, together with the number of breeding pairs, will determine future population trends and is thus an important parameter for long-term monitoring (Croxall and Rothery 1991). Comparisons with less marginal populations living under more moderate climatic conditions might reveal how well the Frazier Islands population is performing. Breeding performance might also differ among colonies, due to differences in breeding habitat quality (cf. Patterson et al. 2003) such as snow deposition, elevation for fly-off possibilities, or distance to a main feeding source consisting of Adélie Penguins *Pygoscelis adeliae*.

From the start of the breeding season onwards, Southern Giant Petrels experience an accumulating number of breeding failures (Hunter 1984). This will result in a decreasing number of active nests (AN) over the season. In earlier analyses of the Frazier Islands population (Woehler et al. 2001, 2003), however, this date effect was not taken into account due to the low number of censuses. In this study, more census data were available because data were analysed for each island separately instead of only total numbers of breeding pairs on the Frazier Islands.

The purpose of the present paper was to review and re-examine all available census data, checking both published and unpublished information sources in order to select reliable time series based on comparable methods, locations and accuracy. Monitoring seabird populations is usually done by counting 'breeding pairs' although the meaning of this definition varied between researchers and studies. Thus for a reconstruction of the population trend of Southern Giant Petrels on the Frazier Islands it was necessary to establish what had actually been counted, and also how it was counted. Such a classification of census methods and census units will help to standardise future monitoring of this population and possibly of other seabird populations as well.

Fig. 1 Situation map of Frazier Islands, situated in relation to Casey Station and to the Antarctic continent



Material and methods

Study area

The Frazier Islands (66°23′S, 110°17′E) are situated in Vincennes Bay, Wilkes Land, East Antarctica, approximately 17 km WNW of the Australian base Casey. The island group consists of Nelly Island, Dewart Island and Charlton Island, which are separated from each other by 50–100 m wide sea channels (Figs. 1 and 2). The three islands have a similar topography with ridges running NW to SE at the northern and southern parts of the islands. The northern ridges have steep slopes to the North and Northwest. The southern ridges are lower, except on Nelly Island, where the southern peak is 70 m high and very steep (Fig. 2). Colonies are found on higher and lower ridges, which were classified ('high' or 'low') as to their position relative to their surroundings.

Mapping of colonies

Colonies were defined as an aggregation of nests of a single species (either Southern Giant Petrel or Adélie Penguin) less than 15 m apart. Locations of colonies were mapped during a census on 26 December 1998. Boundaries of the colonies were recorded by walking slowly 15 m from the most peripheral nests of each colony with a mobile Trimble GPS Pathfinder system and locations were retrieved every 10 s. Coordinates were differentially corrected afterwards with a reference base station at Casey, resulting in a position determination accurate to a couple of decimetres. Solitary nests (more than 15 m away from a colony) were also mapped as stationary positions. Colony area was computed with ArcView software. The density of each colony was calculated by dividing the number of AN by colony area. Distances between the centre of each Southern Giant Petrel colony to the centre of the nearest Southern Giant Petrel colony, as well as to the edge of the closest Adélie Penguin colony were determined using ArcView.

Census

Data in this study come from censuses on the Frazier Islands conducted since the 1955 season. All authors, except the last author of this paper have been personally involved in censuses since 1984 and their data were supplemented with information from published sources and unpublished information in files of the Australian Antarctic Division and Australian Bird and Bat Banding

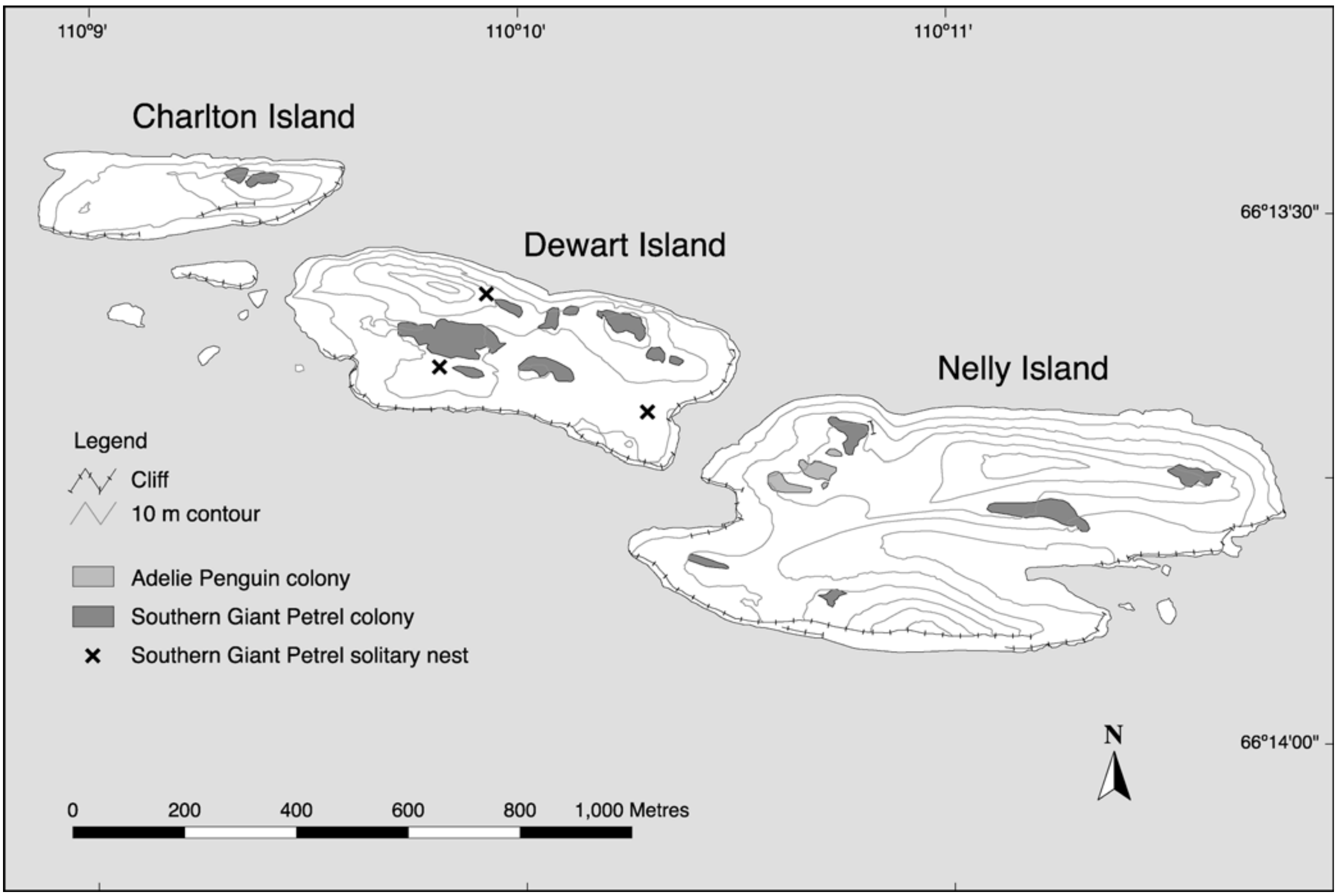


Fig. 2 Locations of Southern Giant Petrel and Adélie Penguin colonies on the Frazier Islands

Table 1 Overview of Southern Giant Petrel censuses on the Frazier Islands

Season	Date	Day nr[a]	Islands			Census[b]		References
			Nelly	Dewart	Chariton	Method	Unit	
1955	21, 22 Jan 1956	94	250			AIR?	*Unspec.*	Woehler et al. (1990) and Ingham (1959)
1958	27 Jan 1959	99	80–100	20+		LAND	*Unspec.*	Woehler et al. (1990) and Murray and Luders (1990)
1959	15 Dec 1959	56	60			LAND	AN[c]	Woehler et al. (1990) and R.L. Penney (unpublished data)
1959	12 Feb 1960	115	**46**			LAND	AC	Woehler et al. (1990), Murray and Luders (1990) and R.L. Penney (unpublished data)
1960	21, 22 Mar 1961	153	**34**	10+		LAND	AC	Woehler et al. (1990) and Murray and Luders (1990)
1963	21 Jan 1964	93	10+			*Unknown*	AC	Woehler et al. (1990)
1967	07 Mar 1968	139	**72**			LAND	AC	Woehler et al. (1990), Murray and Luders (1990) and Shaughnessy (1971)
1971	20, 21 Jan 1972	93	**52**	53+[d]		LAND	AC	[Woehler et al. (1990)], [Murray and Luders (1990)] and Murray (1972)
1971	20, 21 Jan 1972	93			10–20	AIR	*Unspec.*	[Woehler et al. (1990)], [Murray and Luders (1990)] and Murray (1972)
1973	31 Jan 1974	103	76+[e]			*Unknown*	*Unspec.*	Woehler et al. (1990) and Murray and Luders (1990)
1974	29 Jan 1975	101		29[f]		LAND?	*Unspec.*	Woehler et al. (1990), [Murray and Luders (1990)] and Australian Antarctic Data Center
1976	13 and 17 Feb 1977	118	27+	**43**		LAND	AC	[Woehler et al. (1990)], [Murray and Luders (1990)] and Cowan (1979)
1977	24 Jan 1978	96	**48**	**48**	**6**	LAND	AC	Woehler et al. (1990), Murray and Luders (1990) and Cowan 1979
1978	30 Jan and 2 Feb 1979	103	**37**	**46**	**5**	LAND	AC	Woehler et al. (1990), [Murray and Luders (1990)] and Australian Antarctic Data Center
1979	20, 21 Jan 1980	93	**44**	**55**		LAND	AC	Woehler et al. (1990) and Australian Antarctic Data Center
1982	18 Jan 1983	90	**43**	[10][g]	[0][g]	LAND	AC	Woehler et al. (1990) and Australian Antarctic Data Center
1983	28, 29 Nov 1983	40	63	68	9	LAND	AN	Woehler et al. (1990) and Australian Antarctic Data Center
1983	28, 29 Nov 1983	40	69[h]	68+	9+	LAND	AON	Woehler et al. (1990) and Australian Antarctic Data Center
1983	25, 26 Jan 1984	98	**52**			LAND	AC	Woehler et al. (1990)
1984	3 and 6 Mar 1985	135	**64**	**69**		LAND	AC	Woehler et al. (1990) and J.A. van Franeker (unpublished data)
1985	14 Feb 1986	117	**59**[i]	**50**[i]	**9**	LAND	AC	[Woehler et al. (1990)] and [Australian Antarctic Data Center]
1989	23 Dec 1989	64	**73**	**106**	**14**	LAND	AON	Woehler et al. (1990)
1996	18 Feb 1996	121	**11**			LAND	AC	J.C.S. Creuwels (unpublished data)
1997	23 Dec 1997	64	**96**	**104**	**21**	LAND	AON	J.C.S. Creuwels (unpublished data)
1998	26 Dec 1998	67	**95**	**103**	**17**	LAND	AON	J.C.S. Creuwels (unpublished data)
1998	14 Mar 1999	145	**66**	**82**	**11**	LAND	AC	J.C.S. Creuwels (unpublished data)
2001	26 Dec 2001	67	**93**	**135**	**20**	LAND	AON	E.J. Woehler and F. Olivier (unpublished data)

Data in bold are used for population trend analyses in this article (Figs. 3a–c), census values followed by a '+' are minimum estimates, data between brackets are not used in this article, and references between brackets mention different values than in this table

[a]Daynumber is (an average of) the number of days after 20 October (estimated mean laying period)

[b]see Material and methods for description of census methods and units

[c]Penney (unpublished field notes) mentioned "approximately 60 nellies incubating eggs"

[d]Birds in one colony could not be banded. Murray (1972) estimated ca. 20 another chicks in this colony

[e]No details known; in this season only 27 chicks banded

[f]Data uncertain: Murray and Luders 1990 give 26++; Woehler et al. 1990 give 29; ABBBS give 12 chicks banded

[g]Census data from Dewart Island and Charlton Island are confused with number of banded chicks

[h]63 AN and six occupied nests with empty nest content is mentioned (Woehler et al. 1990), but it is not fully sure if a number of 69 is a minimum estimate, or a total number of AON

[i]Data from banding records ABBBS are used and differ slightly from earlier published values: Nelly Island: 55 chicks and Dewart Island 54 chicks

Schemes. When confusion existed on the actual numbers (see Table 1), data were taken, if possible, from field notes or from published data by the surveyor who did the census. Numbers based on extrapolations or estimations were not used for analysing population trends. Breeding seasons are named after the year when the eggs were laid. For example, the 1959 season started in October 1959 and lasted till May 1960.

Over the years, different census methods and census units have been used to estimate the breeding population, unfortunately often poorly documented. Census methods have been classified as follows:

Unknown No details on the census method are given. Data were not used for analyses.

Air Counting birds from air. Numbers represent only crude estimates of the population, and were not used for analyses.

Land Counting birds while walking on the island. Unfortunately this category could not be subdivided by censuses from close distance (unaided eye) and those from a viewpoint (use of binoculars), because this was often not documented. Furthermore, both techniques are probably used within one census between different colonies on the island (e.g. from close distance for small colonies and from viewpoint for large colonies).

Census units represent what was actually counted such as nests, chicks, or adults. The census units have been classified in four categories:

Unspecified census units (unspec.) Number of birds counted without attention to breeding status or where no details on the census method were given. In this census method it is likely that non-breeding birds are included in the number of counted birds. Aerial censuses were included in this category.

Apparently occupied nests (AON) Number of well-constructed nests occupied by at least one, apparently breeding, bird. Non- or failed breeders normally occupy a proportion of the AON; thus AON will include a certain proportion of failed or non-breeding nest-sites. AON censuses are possible during the egg and early chick phases without causing disturbance (see Walsh et al. 1995; Bibby et al. 2000).

Active nests (AN) Number of nests observed to contain an egg or chick. The method implies checking all nests with apparently breeding birds for the presence of an egg or chick, to determine the actual number of breeding sites at the date of the count. Because of the disturbanceinvolved with AN-censuses, the method was abandoned after 1983.

Active chicks (AC) Number of chicks after the initial chick phase, when most chicks are not brooded or guarded anymore by their parents. AC-censuses are possible without disturbance, however till 1986 they often coincided with chick banding.

Within a particular season, census methods often differed for the separate islands. Therefore, when analysing population trends the islands had to be treated separately. Breeding Southern Giant Petrels have a very high fidelity to their nesting colony (Ingham 1959; Warham 1962; Conroy 1972; Voisin 1988) making exchange of individuals among the islands unlikely.

Evaluation of AON type counts

During the 1997 and 1998 seasons, after counting the number of AON in a colony during a short time period (5–10 min), observations were continued for prolonged periods in order to assess the actual breeding status for as many nests as possible in each colony. It was recorded whether the nest content became visible, and if so, whether it contained an egg, chick, or nothing. It was assumed that in continued observations, birds sitting on failed or non-breeding sites would stand up or move around in such a way that nest contents would become visible. If large pieces of eggshells were observed just out of the nest, it was judged to be successful and counted as having a hatched chick. For all AON it was also noted whether the attending adults were singles or pairs. If a second adult was sitting or standing near the nest, within the reach of the bird sitting on the nest, it was counted as a 'pair'.

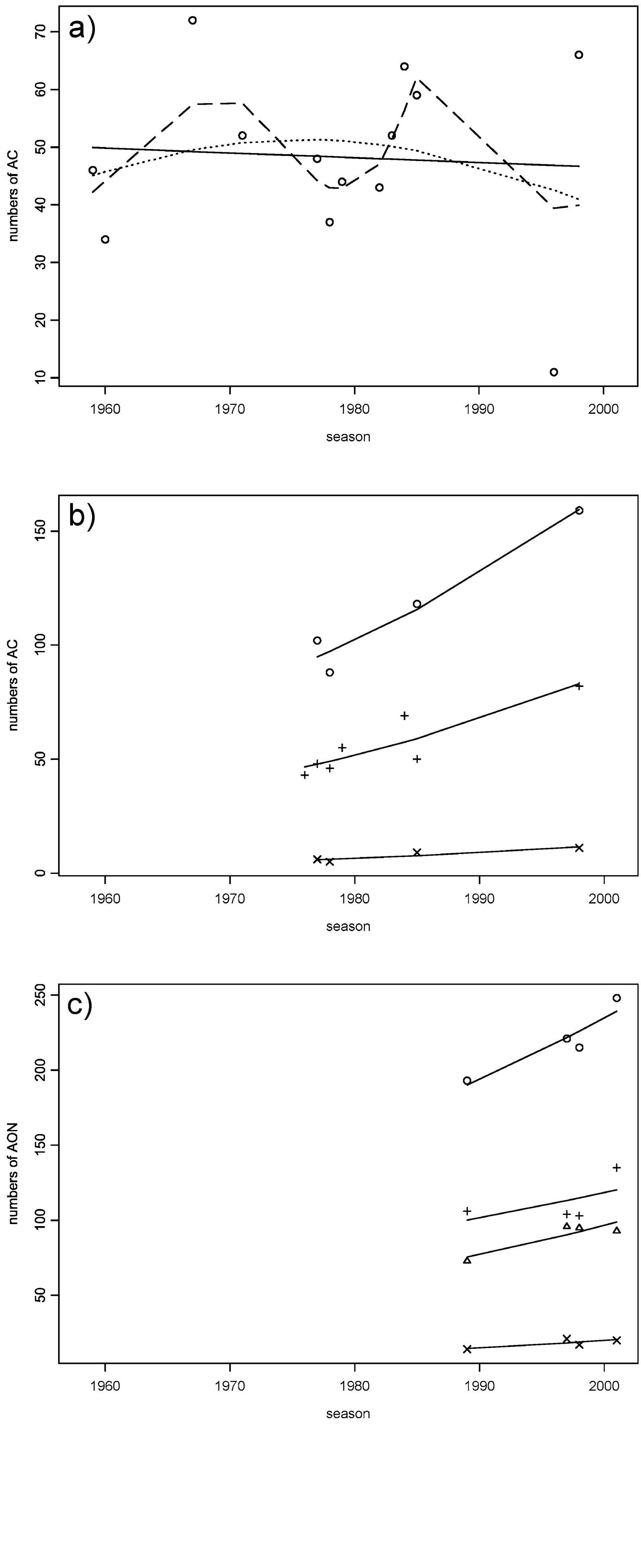
Breeding performance

Breeding performance was defined as the number of AC (in the chick period) in proportion to the number of AN (before or around hatching) in the same season. These data were only available for two early seasons (1959 and 1983). For the 1998 season, we estimated the number of AN by subtracting the number of occupied nests that were observed to have no egg or chick from the number of AON.

Statistical analysis

Since the census data are counts, a Poisson regression framework was used to investigate population trends. Residual analysis was used to identify influential points

Fig. 3 Population trends on the Frazier Islands. *Graphs* show the number of AC and fitted models for **a** Nelly Island and for **b** Dewart Island, Charlton Island as well as Totals for all Frazier Islands together. Furthermore is shown **c** the number of AON and fitted models. Used symbols are: *triangles* for Nelly Island, *x-es* for Dewart Island, *crosses* for Charlton Island, and *circles* for Totals of the Frazier Islands together. Fitted models are: *solid lines* for LR-models, *dotted lines* for PR-models, and *dashed lines* for GAM-models (for details, see text)



(Cook and Weisberg 1999). For data sets with fewer than ten points only linear regression (LR) models were used, otherwise also generalised additive models (GAM) and polynomial regression (PR) models were used (see Woehler et al. 2003). The percentage of variance explained (%VE) was calculated using [(residual deviance/null deviance)×100]. Dates of AC-censuses varied widely; thus it was tested whether a date effect existed. Comparisons between proportions (such as breeding performance or nest content) were tested using log-likelihood tests (G-statistics, see Sokal and Rohlf 1995). Seasons were separately analysed if proportions differed significantly among the seasons. Correlations between breeding performance and environmental variables were tested with Pearson product-moment coefficients. Differential population trends among colonies on the Frazier Islands (e.g. as result of differences in size, or in exposure to snow and wind) could not be established because the number of accurate datapoints was too low for statistical analyses. Statistical analysis was done using S + 2000 and SPSS 10.0. All statistical tests were two-tailed and significance level was set at $\alpha = 0.05$.

Results

Locations of Southern Giant Petrel colonies

Colonies were located on snow-free areas on the northern and southern ridges as well on low snow-free ridges in the valleys (Fig. 2). The colonies on high ridges have steep slopes with easy fly-off points in northerly or northeasterly directions. The GPS-locations of colonies were compared with older maps. Location of most colonies matched well with those observed in December 1989 (Woehler et al. 1990), apart from a few minor topographical differences likely due to less accurate mapping techniques in the past.

Trends in numbers of breeding Southern Giant Petrels

From all standardised censuses on the Frazier Islands, only counts of AC and AON had been done frequently enough to allow analysis of long-term trends in the breeding population of Southern Giant Petrels (Table 1).

On Nelly Island, the number of AC was counted during 13 seasons. This constitutes our longest data-series available for this population, as AC counts for the other islands were available only for a reduced number of more recent years. The number of AC on Nelly Island fluctuated strongly between an unusual minimum of 11 chicks in 1996 and a maximum of 72 chicks in 1967 (Fig. 3a). Linear and PR models indicated no significant trend in the population over the full time period (LR model: 0.3% VE, $P = 0.624$; PR model: 4.3% VE, $P = 0.207$). However, a GAM model demonstrated that values around the long-term average are not random, but show significant periodic fluctuations (29.0% VE, $P < 0.001$) (Fig. 3). The 1996 census on Nelly Island was identified as a potential influential point (residual value of −6.3) with a number of surviving chicks that was depressed to around 10–20% of the expected value. Removal of this point improved fit of linear and polynomial models (LR model: 15.7% VE, $P = 0.031$; PR model: 17.6% VE, $P = 0.073$). However, from a biological viewpoint the 1996 datapoint should not be removed since there is no doubt that the observation is fully reliable. The Nelly Island data series was also checked for a date effect, as the dates of census varied between 18 January and 22 March (see Table 1). No significant relationship between census date and number of AC existed (LR model: 3.8% VE, $P = 0.092$; PR model: 3.9% VE, $P = 0.239$).

On Dewart Island an AC census was conducted seven times (Fig. 3b), the first complete one being in the 1976 season with 43 chicks. The numbers increased to 82 chicks in the 2001 season, which was highly significant (LR model: 77.9% VE, $P < 0.001$). On Charlton Island an AC census was conducted only four times, starting with six chicks in 1977 and ending with 11 chicks in 1998 (Fig. 3b). This increase was not significant due to the low sample size (LR model: 84.0% VE, $P = 0.116$). However, totals of all islands together over the time period 1976–1998 increased 35% though there were only four datapoints (Fig. 3b; LR model: 93.7% VE, $P = 0.001$). Data for 1996 were lacking for both Dewart and Charlton Island.

Data of the type ‘AON’ were collected for the first time in the 1989 season. In 1989, 193 AON were found on the Frazier Islands, which increased to 248 AON in the 2001 season (Fig. 3a). Increases for separate islands were 27.4% on Nelly Island, 27.4% on Dewart Island and 42.9% on Charlton Island but none of these changes was significant (LR-models with only four censuses for all islands; Nelly Island: 79.5% VE, $P = 0.07$; Dewart Island: 32.5% VE, $P = 0.159$; Charlton Island: 65.0% VE, $P = 0.292$). When all islands were taken together, however, the trend was significant (87.2% VE, $P = 0.014$).

Breeding performance

For Nelly Island, there are three seasons for which there exists the combination of a census conducted just before or around hatching plus a later AC, allowing an estimate for breeding performance (Table 2). On the other two islands such comparative censuses were performed only in the 1998 season. Despite a variable interval and different timing of the censuses, no differences in the breeding performance were found. Breeding performance between the late egg/early chick phase and the later chick phase averaged 80.4% ($G = 1.27$, $P = 0.530$). In the 1998 season the breeding performance on the three Frazier Islands averaged 81.1% with no

Table 2 Breeding performance of Southern Giant Petrels during three seasons

Season	Island	First census		Second census		Breeding performance	Time between censuses
		Date	AN	Date	AC		
1959	Nelly Island	15 Dec 1959	60[a]	12 Feb 1960	46	83.6%[b]	59 days
1983	Nelly Island	28,29 Nov 1983	63	23/28 Jan 1984	52	82.5%	58 days
1998	Nelly Island	26 Dec 1998	86[c]	14 Mar 1999	66	76.7%	78 days
1998	Dewart Island	26 Dec 1998	95[c]	14 Mar 1999	82	86.3%	78 days
1998	Charlton Island	26 Dec 1998	15[c]	14 Mar 1999	11	73.3%	78 days

[a]Penney (unpublished field notes) wrote ‘approximately 60 nellies were incubating eggs and there were at least 20 more which were associated with nests but which took off when we neared’

[b]in December 1959 5 eggs were taken for albumin sampling, therefore breeding performance calculated from 55 AN

[c]see Material and Methods for estimation of AN

significant differences among the islands ($G=3.37$, $P=0.185$).

Geographic data on the colonies were used to explain the differences in reproductive success among colonies in the 1998 season. The breeding performance of lower elevation colonies (82.2%) was similar to higher elevation colonies (80.7%; $G=0.08$, $P=0.780$). No correlations were found between the breeding performance and colony size by number of AON ($r^2=0.11$, $P=0.258$), by colony area ($r^2=0.13$, $P=0.298$), or by nest-density (AON/area; $r^2=0.06$, $P=0.499$). Neither was breeding performance affected by distances to nearest penguin colony ($r^2=0.03$, $P=0.660$), nor to the nearest Southern Giant Petrel colony ($r^2=0.02$, $P=0.714$).

Evaluation of AON type of counts in the 1997 and 1998 seasons

Detailed observations on the nest contents after the AON-census revealed the breeding status for almost half of the nests in our censuses. In the 1997 season, nest contents became more often visible (55.7%) than in the 1998 season (37.7%; $G=14.24$, $P<0.001$; Table 3). Despite the difference in the proportions of revealed/unrevealed nests, the proportion of AON found to contain no egg or chick stayed equal in both seasons (9.4% of all AON; $G<0.01$, $P=0.943$). Where the nest contents became visible, 20.1% of the nests were empty and 79.9% nests were successful (11.3% with egg and 68.6% with chick), which was consistent over the two seasons ($G=2.15$, $P=0.142$).

Table 3 Additional observations on nest contents of AON sites, obtained during outside-colony censuses

Single/pair	Nest content revealed			Unrevealed
	Empty	Egg	Chick	
1997 season (221 AON)				
Single	16	13	85	95
Pair	5	0	4	3
Total	21 (9.5%)	13 (5.9%)	89 (40.3%)	98 (44.3%)
1998 season (215 AON)				
Single	13	7	50	126
Pair	7	3	1	8
Total	20 (9.3%)	10 (4.7%)	51 (23.7%)	134 (62.3%)

Pairs did not reveal their breeding status more frequently than single birds, despite substantial differences in both seasons (Table 3). In the 1997 season 25.0% of the pairs and 45.5% of the singles did not show their nest content ($G=2.04$, $P=0.154$) and in the 1998 season this was 42.1% of the pairs and 64.3% of the singles ($G=3.50$, $P=0.061$). AON sites attended by pairs were more likely to contain no egg or chick (no egg or chick in 38.7% of all sites attended by pair and 7.2% of all sites with a single bird; $G=22.30$, $P<0.001$), which was consistent between the seasons ($G=0.62$, $P=0.431$). Consequently, pairs had relatively fewer chicks (16.1%) than single birds (33.3%; $G=4.38$, $P<0.036$), which was consistent between the seasons ($G=0.66$, $P=0.416$).

Discussion

Census techniques

In published reviews on Antarctic birds it is often not fully clear which census methods or which census units were used to estimate the number of ‘breeding pairs’ (e.g. Woehler and Croxall 1997; Woehler et al. 2001). The number of breeding pairs can be derived from counts or estimates of the number of (apparently occupied) nests in different breeding phases, of counts of AC. These options can give quite different results. The purpose of the study will usually determine the choice of a census method, but there might be constrains due to logistic, financial, and time limitations. The aim of the Frazier Islands censuses is to establish a long-term population trend of Southern Giant Petrels. For such purpose, consistency in the monitoring procedure (the combination of census method, census unit, timing, and effort) is of greater importance than the actual values.

At the Frazier Islands, two relatively standardised methods were recognised to allow trend analysis: AC- and AON censuses. Counts of AC have the advantage of being relatively easy and accurate, but are conducted late in the season and thus may suffer from strong variability in breeding success among seasons. Counts of AON are conducted earlier in the season, but are less accurate because a proportion of the nests counted will have no egg or chick. Since mid-1980s, protective measures for the Frazier Islands (e.g. no more chick banding) have resulted in a shift from AC- towards AON censuses. Furthermore, restriction of access to small boat transport will usually allow annual mid-summer visits (AON censuses around hatching) but late AC censuses will be often impossible due to sea ice conditions.

During a workshop on the statistical assessment of population trends of Antarctic seabirds it was concluded that developing standardised population surveys should get high priority (Woehler et al. 2001). For a few species selected for the CCAMLR Environmental Monitoring Program (CEMP) detailed methods for the collection of population data are available (http://www.ccamlr.org/pu/E/pubs/std-meth04.pdf). Most species, however, like the Southern Giant Petrel, still lack an appropriate census protocol. The analysis of a historical long-term population dataset, as well as indicating where problems arise during data collection, is a first step in developing standardised census procedures for this species, and possibly for other seabird species as well.

Population trends

Earlier analyses of the Frazier Island data (Woehler et al. 2001, 2003) suggested that the local Southern Giant Petrel population was declining from 1955 until the early 1980s due to human disturbance and recovery was the result of protective measures since the mid-1980s. In re-examining the dataset and the sources of the data, some of this population trend could be attributed to inconsistency of census methods. Firstly, the highly influential census in 1955 was probably performed from the air (helicopter). Such a census is very inaccurate and likely to include many non-breeding birds, and therefore removed from the analysis. Secondly, different census methods were used. Before starting with AON censuses in 1989, most data came from AN- and AC censuses, which will be lower than from AON censuses because of the proportion of unsuccessful but attended nests. Thirdly, some surveys were incomplete and had to be excluded. Some colonies had been overlooked, because detailed colony maps were lacking in past. For example, Cowan (1979) noted a colony on Nelly Island that he apparently had missed in the previous season.

A critical review of all available census data led to the data selection shown in Table 1 and Fig. 3, which suggests a basically stable long term population with some periodic fluctuations over the period 1959–1998 (Fig. 3a). As in the earlier analysis by Woehler et al. (2001, 2003) a dip in the population is seen in the 1970s. The second fluctuation in the 1990s could be not detected in earlier analyses, because the 1996 datapoint, which concerned only Nelly Island, was not selected for the Woehler et al. (2001, 2003) dataset. Datasets on AC- as well as AON censuses for the other islands, and for all the islands combined are limited to a more recent time period (Figs. 3b, c). All trends suggested an increasing population since the late 1970s, but only three out of eight were significant. More censuses, and preferably over a longer time span, are needed to infer real population trends. Trends derived from such small datasets should be treated cautiously because removing or adding one or two data points might lead to different conclusions.

In the 1996 season all surface-breeding petrel species in the Windmill Island area performed very badly due to extreme snowfall (Van Franeker et al. 2001; J.C.S. Creuwels and J.A. van Franeker, unpublished data). Unfortunately, only Nelly Island was visited in this season, but trends for Dewart and Charlton Island would have been quite different, if census numbers had been available for this season. We noted that snow cover had decreased in consecutive seasons, and observed that birds in the valleys ('low colonies') started to breed in recently uncovered areas just outside the former colony boundaries. High annual variation in numbers of fledged chicks or numbers of 'breeding pairs' is also known from other continental Antarctic colonies of Southern Giant Petrels (Woehler et al. 2001; Micol and Jouventin 2001). Seasons with infrequent and irregular mass mortality of eggs or chicks could represent 10% or more of the reproductive life of most seabird species (Wooller et al. 1992).

Breeding performance and number of non-breeders

Breeding failures of Southern Giant Petrels are most frequent shortly after egg-laying and around hatching (Mougin 1968; Conroy 1972; Hunter 1984). Thus after the egg-laying period, any census method based on active nests (AN- or AC censuses) will always give an underestimate of the actual number of breeding efforts. On the Frazier Islands averaged over three widely spaced seasons (1959, 1983 and 1998), about 20% of Southern Giant Petrel nests had failed between the first AN census around hatching and the second late-AC census. Similarly, Hunter (1984) recorded on South Georgia that two thirds of the losses (almost 20% of all breeding attempts) occurred in this period (from 1 week before until 4 weeks after the mean hatching date). At localities with more moderate climatic conditions most chick mortality occurs in this period (Hunter 1984; Cooper et al. 2001). At the Frazier Islands, however, it was found that at least in one season 10% of chicks died just before they were ready to fledge (Cowan 1979). Within one season a similar breeding performance was found between the colonies differing in their geographic position, colony size and distance to the Adélie Penguin colony.

In order to establish the proportion non-breeders in AON censuses, extensive observations were made in 1997 and 1998 following the initial AON counts (Table 3). In both seasons, censuses were conducted somewhat after the median hatching peak, as seen in the high proportion of chicks recorded. Eggs recorded in these censuses might also include failed eggs, which are sometimes incubated unsuccessfully for long periods. All observed chicks were very young. At the end of December, 9.4% of the AON did not contain an egg or chick, which is close to 8.7% at end November 1983 and ca.10% at end December 1989 (Woehler et al. 1990). The proportion of nests with no chick or no egg, expressed as a percentage of only those nests of which contents were revealed, was 20.1%. This percentage is probably an overestimate because the persistent incubation behaviour at nests where contents remained invisible suggests the presence of egg or chick. Birds without an egg or chick are much more likely to stand up or move around, and thus revealing their nest contents. Interestingly, the proportion of empty nests was equal in both seasons, in spite of the fact that the proportion of unrevealed nests was much higher in the 1998 season.

Unfortunately, there are no data for the Frazier Islands to estimate loss rates of eggs prior to the AN-censuses around hatching. If Southern Giant Petrels experience similar losses in the early incubation period as other surface-nesting fulmarine petrels, which breed one to two months later in the season, then 30% of early breeding failures could be expected (Creuwels and Van Franeker 2003). This figure is much higher than the 10% losses observed under more temperate climatic conditions at South Georgia (Hunter 1984). Thus, at this stage we cannot reliably estimate the actual number of breeding pairs, although population trends can well be monitored with AON- and AC censuses.

Disturbance

Giant Petrels are highly sensitive to human presence, and leave their nest much faster than other procellariiforms (Warham 1962; Chupin 1997). Their uncovered eggs and small chicks are vulnerable to predation by skuas *Catharacta spp*. (Warham 1962; Conroy 1972; Hunter 1984; Peter et al. 1991), thus repeated human visits to colonies may cause low reproductive success (Prévost 1958; Conroy 1972; Peter et al. 1991; Chupin 1997). Chronic human disturbance, such as aircraft flights, presence of nearby research stations, and continuous research activities in the colony can cause population declines (Croxall 1984; Rootes 1988; Peter et al. 1991; Micol and Jouventin 2001; Woehler et al. 2003). Difficult access to the Frazier Islands, however, has caused relatively low and infrequent human disturbance levels. Some disturbance certainly came from visits of ornithologists for censuses or to band birds, although we did not detect any negative effects of increased banding efforts. During 11 seasons from 1971 through 1986, chicks were banded on the Frazier Islands, and personnel were transported to the islands mostly by helicopter (Murray and Luders 1990). In this period the number of AC increased on both Nelly Island and Dewart Island. The possibility cannot be excluded that this increase would have been higher without disturbance, but it is more likely that one or two visits per year fall within the range of each individual to deal with stress. For another Antarctic seabird, the Adélie Penguin, Fraser and Patterson (1997) argued that although short-term studies often found negative effects of human disturbance, this was rarely found in studies with long-term demographic datasets (but see Woehler et al. 1994). Recent work by Patterson et al. (2003) confirmed that at this stage no significant detectable human impact could be shown for the Adélie penguin population decline at Palmer Station.

Conclusions and recommendations

This study detected no negative effects of human disturbance on the Southern Giant Petrel population on the Frazier Islands. The global vulnerable status of this species, however, justifies a precautionary approach as taken since 1986. Since transport to Frazier Islands is limited to small boats, research access is limited to good weather and ice conditions, which mostly occur during the mid-summer period. For long-term monitoring of the Southern Giant Petrels we suggest continuation of AON censuses at a standardised date (on Frazier Islands: around hatching). Due to the extreme variability in breeding performance and/or breeding efforts, monitoring is best attempted at annual rather than at multi-year intervals. Our analysis reveals no objections to opportunistic study visits, such as chick banding or an additional AC census late in the nestling period. A late AC census makes an estimation possible of the reproductive output and would improve comparisons with historical AC-values. Generally, to improve data quality of bird censuses it is recommended to specify census methods, census units, viewing positions, distances to the colony, and if binoculars are used. Furthermore, specifying numbers for separate colonies and using accurate maps would further increase accuracy and makes analysis possible at colony level.

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