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REVIEW

Distribution and abundance of the Southern Fulmar *Fulmarus glacialoides*

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Abstract We reviewed published and unpublished literature to establish the status of the breeding distribution and abundance of Southern Fulmars *Fulmarus glacialoides*. The species breeds widely throughout the Antarctic and on peri-Antarctic islands. From breeding population data collated from 73 of these localities, we estimated the minimum global population to be about 400,000 breeding pairs. After adjusting for seasonal variation in numbers of breeding pairs based on studies at Ardery Island, East Antarctica, the total global population is estimated to be at least one million breeding pairs. Of this, 72% nest on islands of the Scotia Sea arc and the South Atlantic Ocean. The precision of the estimate on the total number of breeding pairs is low, as several colony estimates were only available as orders of magnitude. Furthermore, different timing of the surveys and the difficulties of censusing colonial cliff-nesting birds reduced the count accuracy. Currently, there are no known threats to the global population, although the effects of fishery activities are not fully known.

Keywords Fulmarine petrels · Procellariiformes · Seabirds · Antarctica · Population estimation · Census methodology

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Introduction

Southern Fulmars (*Fulmarus glacialoides*) are found in great numbers in the Southern Ocean and they are an important consumer in the Southern Ocean ecosystem (Van Franeker et al. 2001). It has been estimated that 1.7 million individuals gather in the Prydz Bay area in East Antarctica (Cooper and Woehler 1994) during the summer months, and the breeding population of the Scotia Arc area and the Antarctic Peninsula has been estimated at 'several million' breeding pairs (Croxall et al. 1984). Southern Fulmars are known to disperse widely from Antarctica to subtropical waters, and they occasionally migrate along cool currents to tropical latitudes (Marchant and Higgins 1990). Many birds migrate north during the winter months when individuals have been recorded along the coasts of the Falkland Islands, South America, South Africa, Australia and New Zealand (Marchant and Higgins 1990).

Accurate knowledge of the breeding distribution and abundance of seabird populations is essential in order to assess population trends and to evaluate the potential impact of changes in the Antarctic ecosystem on seabirds. Consequently, the Group of Experts on Birds of the Scientific Committee on Antarctic Research (SCAR-GEB) is attempting to compile comprehensive syntheses of all Antarctic and sub-Antarctic breeding seabirds (Woehler

1993; Croxall et al. 1995; Van Franeker et al. 1999, and various others in preparation). Until the early 1980s, population estimates of Southern Fulmars were often derived from broad-scale surveys (Croxall et al. 1984), and many breeding localities had been rarely visited. Recently, new systematic censuses have been carried out in important breeding areas and new areas have been surveyed, enabling a more accurate appraisal of the current population and conservation status of the species.

The aim of this paper is to present a detailed review of published and unpublished information on the breeding distribution and abundance of Southern Fulmars. This is the first comprehensive estimate of the entire global breeding population of this species. We evaluated the accuracy of the population estimate by assessing the reliability of the range of different census methods employed.

Material and methods

Study species

Southern Fulmars are also known as Silver-grey/gray Petrel, Silver-grey/gray Fulmar and Antarctic Fulmar. In 1949, the species' scientific name *Procellaria glacialoides* was changed to *Fulmarus glacialoides*, thereby placing it in the same genus as its sibling species the Northern Fulmar *Fulmarus glacialis* (Voous 1949). This decision was recently justified by mitochondrial DNA research (Nunn and Stanley 1998).

Diet studies of Southern Fulmars indicate a great variability in prey species ingested. The main prey species are fish (*Pleuragramma antarcticum, Electrona antarctica*), Antarctic Krill (*Euphausia superba*) and various squid species (Bierman and Voous 1950; Ainley et al. 1984, 1991, 1992; Ridoux and Offredo 1989; Arnould and Whitehead 1991; Norman and Ward 1992; Hodum and Hobson 2000; Van Franeker et al. 2001). Southern Fulmars forage opportunistically and have been observed feeding at a sewage outfall (J.A. van Franeker, personal observation) or feeding on discards from fishing vessels (Watson 1975) and on whale and seal carrion (Gain 1914; Murphy 1936; Bierman and Voous 1950; Holdgate 1963).

Studies conducted at breeding localities in East Antarctica (Hop Island, Haswell Island, Ardery Island, and Ile des Pétrels; see Table 1, Fig 1) indicate highly synchronised breeding. Birds return to colonies during the first half of October (Falla 1937; Prévost 1953; Mougin 1967; Pryor 1968; Luders 1977). The pre-laying exodus occurs during November and into the first week of December, but is less pronounced than in other petrel species (Luders 1977; Warham 1990; Brooke 2004). Egg-laying occurs between 3 and 23 December (mean approximately 11 December) and eggs are incubated for 45–47 days (Mougin 1967; Van Franeker et al. 1990; Hodum 2002; Creuwels and Van Franeker 2003). Incubation shifts are on average about 4 days, although the first few shifts are much longer and the last couple of shifts are shorter (Mougin 1967; Weimerskirch 1990). Hatching occurs between 20 January and 8 February (mean 25–27 January) (Hodum 2002; Creuwels and Van Franeker 2003). The duration of the chick guard period varies widely among colonies and seasons, averaging 14–24 days (Mougin 1967; Hodum 2002). Fledging occurs between 10 and 28 March (mean 15–20 March) (Prévost 1964; Mougin 1967; Hodum 2002; Creuwels and Van Franeker 2003). The chick-rearing period is 50–53 days, and chicks fledge on average 97–99 days after egg-laying (Mougin 1967, 1975; Hodum 2002; Creuwels and Van Franeker 2003). Anecdotal data on the breeding biology of Southern Fulmars seem to confirm that breeding seasons of Southern Fulmars advance with decreasing latitude. Hatching occurred between 20 January and 8 February January in East Antarctica (66–68°S) (Hodum 2002; J. Creuwels, unpublished data), between 15 and 24 January on Gibbs Island (61°S) (Furse 1977) and between 10 and 17 January on Bouvetøya (53°S) (O. Huyser, personal communication). Little is known of the breeding biology of Southern Fulmars in the Antarctic Peninsula and the Scotia Sea area.

Census methods

Historically, the accuracy of seabird census methods and census metrics have varied widely due to such factors as survey time constraints, topography of the breeding area and research objectives. Due to the inaccessibility of many Southern Fulmar breeding areas, nests and birds are typically surveyed from vessels or estimated from a vantage point located at some distance from the colony. In a few cases, especially where colonies were small, observers were able to enter the colony, and nests were counted individually and checked for eggs and chicks. Details on the precise census methodology employed are often lacking, but in most cases we were able to categorise studies according to the different census metric(s) used:

Unspecified number (Unspec.)

No information available on the type of count. In most cases, it is assumed to represent the number of *apparently occupied sites* (see below).

Total number (Total)

The total number of birds present in the colony, irrespective of their breeding status. This number may include birds sitting on a nest, birds sitting as a pair and birds not

Table 1 Overview of breeding localities and the estimated number of breeding pairs

	Locality	Latitude	Longitude	Census date	Season	Number of breeding pair				References
						Estimation		Min	Max	
I.	**Enderby Land**									
1	Proclamation Island	65°51′S	53°41′E	13 Jan 1930	1930	B	–			Falla (1937)
2	Aagaard Island	65°51′S	53°40′E	15 Dec 1996	1997	B	–			Gavrilo, unpublished report
II.	**Mac. Robertson Land**									
3	Kidson Island	67°12′S	61°11′E	24 Jan 1989	1989	2000	Unspec.			Robertson (1991)
4	Scullin Monolith	67°47′S	66°42′E	1–6 Feb 1987	1987	1350	Unspec.	1080	1620	Alonso et al. (1987)
5	Murray Monolith	67°47′S	66°53′E	17 Feb 1997	1997	30	Unspec.	10	50	Gavrilo, unpublished report
III.	**Princess Elizabeth Land**									
6	Svenner Islands	69°02′S	76°50′E		1981	2800	Unspec.			ANARE, unpublished report
7	Hop Island	68°50′S	77°42′E	2–3 Jan 1985	1985	2576	AN[a]			Green and Johnstone (1986)
8	McNab Island	68°49′S	77°40′E	2–3 Jan 1985	1985	320	AN[a]			Green and Johnstone (1986)
9	''Island A'' west of Hop Island	68°50′S	77°36′E	15 and 21 Dec 1981	1982	900	AOS			Green and Johnstone (1986)
10	''Island B'' west of Hop Island	68°50′S	77°36′E	15 and 21 Dec 1981	1982	150	AOS			Green and Johnstone (1986)
11	''Island C'' west of Hop Island	68°50′S	77°37′E	15 and 21 Dec 1981	1982	150	AOS			Green and Johnstone (1986)
12	''Island D'' west of Hop Island	68°50′S	77°37′E	15 and 21 Dec 1981	1982	950	AOS			Green and Johnstone (1986)
13	Buchan Island	68°47′S	77°46′E	10 Feb 1984	1984	2378	AN[a]			Green and Johnstone (1986)
14	Small island North of Buchan Island	68°47′S	77°46′E	15 and 21 Dec 1981	1982	400	AOS			Green and Johnstone (1986)
15	Filla Island	68°49′S	77°50′E	5–6 Jan 1985	1985	4007	AN[a]			Green and Johnstone (1986)
16	Islands North of Strelka Island	68°46′S	77°45′E	15 and 21 Dec 1981	1982	400	AOS			Green and Johnstone (1986)
17	Kryuchock Island	68°48′S	77°45′E	15 and 21 Dec 1981	1982	20	AOS			Green and Johnstone (1986)
18	''Northern Island'' NW of Forpost I.	68°51′S	77°33′E	15 and 21 Dec 1981	1982	730	AOS			Green and Johnstone (1986)
19	Forpost Island	68°52′S	77°35′E	15 and 21 Dec 1981	1982	750	AOS			Green and Johnstone (1986)
IV.	**Queen Mary Land**									
20	Haswell Island	66°31′S	93°00′E	20–24 Jan 1979	1979	3150	AOS	2950	3350	Starck (1980)
21	Fulmar Island	66°32′S	93°00′E		1963	1500	Unspec.	1300	1700	Pryor (1968)
V.	**Wilkes Land**									
22	Hudson Island	66°39′S	108°25′E	Mid Dec 1993	1994	200	Unspec.			Melick et al. (1996)
23	''Island A'' South of Hudson Island	66°40′S	108°25′E	Mid Dec 1993	1994	80	Unspec.			Melick et al. (1996)
24	Nelly Island	66°14′S	110°11′E		1962	500	Unspec.			Orton (1963)
25	Dewart Island	66°13′S	110°10′E		?	B	–			Murray and Luders (1990)
26	Ardery Island	66°22′S	110°30′E	20–31 Dec 1995	1996	3860	AOS			Barbraud and Baker (1998)
27	Odbert Island	66°22′S	110°33′E	Dec 1984	1985	2000	AOS			van Franeker et al. (1990)

Table 1 continued

	Locality	Latitude	Longitude	Census date	Season	Number of breeding pair				References
						Estimation		Min	Max	
28	Holl Island	66°25′S	110°25′E	Dec 1977–Jan 1978	1978	400	Unspec.			Cowan (1979)
29	Lewis Island	66°06′S	134°22′E	18 Jan 1960	1960	86	AOS			Law (1962)
VI.	**Terre Adélie**									
30	Ile des Petrels, Pointe Géologie	66°39′S	140°01′E	*c.*20 Dec 1962–2001	1963–2002	53	AN[b]			Jenouvrier et al. (2003)
VII.	**King George V Land**									
31	Cape Pigeon Rocks	66°59′S	143°47′E	Dec 1997–Jan 1998	1998	501	AOS	476	526	Barbraud et al. (1999)
32	Four Islets	66°56′S	143°54′E	Dec 1997–Jan 1998	1998	65	AOS	62	68	Barbraud et al. (1999)
33	''Island D''	66°58′S	143°54′E	Dec 1997–Jan 1998	1998	1015	AOS	964	1066	Barbraud et al. (1999)
34	''Island C''	66°57′S	143°55′E	Dec 1997–Jan 1998	1998	708	AOS	673	743	Barbraud et al. (1999)
35	''Island B''	66°56′S	143°57′E	Dec 1997–Jan 1998	1998	920	AOS	874	966	Barbraud et al. (1999)
36	''Island A''	66°58′S	143°57′E	Dec 1997–Jan 1998	1998	1497	AOS	1422	1572	Barbraud et al. (1999)
37	Stillwell Island	66°55′S	143°48′E	Dec 1997–Jan 1998	1998	2155	AOS	2047	2263	Barbraud et al. (1999)
38	Penguin Point	67°39′S	146°12′E	31 Dec 1912	1913	24	AOS			McLean *in* Falla (1937)
VIII.	**Ross sea sector**									
	Balleny Islands (39–42)									
39	Young Island	66°25′S	162°24′E		1964; 1965	B	–			Robertson et al. (1980)
40	Row Island	66°31′S	162°38′E	10–18 Feb 1965	1965	5500	Unspec.	5000	6000	Robertson et al. (1980)
41	Borradaile Island	66°35′S	162°45′E		1964; 1965	PB	–			Robertson et al. (1980)
42	Sturge Island	67°28′S	164°38′E	27–31 Jan 1965	1965	15,000	AOS	10,000	20,000	Robertson et al. (1980)
43	Scott Island	67°24′S	179°55′W	7 Jan 1982	1982	PB	–			Wilson and Harper (1996)
IX.	**Bellinghausen Sea**									
44	Peter I Øy	68°47′S	90°35′W	19 Jan 1997	1997	10,000	Unspec.	5000	15,000	Gavrilo (1997)
X.	**Antarctic Peninsula**									
45	Pourquoi Pas Island	67°41′S	67°28′W	27 Feb 1986	1986	7500	AOS	5000	10,000	Poncet and Poncet, unpublished data
46	Anvers Island, NW coast	64°32′S	62°53′W	30 Jan 1987	1987	5000	AOS	1000	10,000	Poncet and Poncet, unpublished data
47	Brabant Island	64°15′S	62°20′W	2 Feb 1987	1987	1000	AOS	300	1500	Poncet and Poncet, unpublished data
48	Davis Island	64°06′S	62°04′W	2 Feb 1987	1987	5000	AOS	1000	10,000	Poncet and Poncet, unpublished data
49	Trinity Island	63°48′S	60°45′W	21 Jan 1987	1987	10,000	AOS	2000	20,000	Poncet and Poncet, unpublished data
50	Tower Island	63°35′S	59°49′W	21 Jan 1987	1987	75	AOS	50	100	Poncet and Poncet, unpublished data
51	Cape Kjellman	63°44′S	59°24′W	31 Jan 1990	1990	B	–			Poncet and Poncet, unpublished data
52	Otter Rock	63°38′S	59°12′W	1 Feb 1990	1990	5000	AOS	1000	10,000	Poncet and Poncet, unpublished data
53	Cape Roquemaurel	63°33′S	58°57′W	18 Jan 1987	1987	2000	AOS	1000	5000	Poncet and Poncet, unpublished data

Table 1 continued

	Locality	Latitude	Longitude	Census date	Season	Number of breeding pair				References
						Estimation		Min	Max	
54	Young Point	63°36′S	58°57′W	21 Jan 1987	1987	PB	–			Poncet and Poncet, unpublished data
55	Astrolabe Island	63°17′S	58°40′W	18 Jan 1987	1987	5000	AOS	1000	10,000	Poncet and Poncet, unpublished data
XI.	**South Shetland Islands**									
56	Greenwich Island	62°34′S	59°34′W		2000	PB	–			Naveen (2003)
57	Bridgeman Island	62°03′S	56°45′W		1977	100	Unspec.			Furse (1978)
58	O'Brien Island	61°30′S	55°58′W		1977	7880	Unspec.			Furse (1978)
59	Eadie Island	61°28′S	55°57′W		1977	8500	Unspec.			Furse (1978)
60	Aspland Island	61°28′S	55°55′W		1977	9800	Unspec.			Furse (1978)
61	Gibbs Island	61°28′S	55°34′W		1977	18,830	Unspec.			Furse (1978)
62	Rowett Island	61°17′S	55°31′W	Dec 1970–Mar 1971	1971	40	Unspec.			Furse and Bruce (1975)
63	Cornwallis Island	61°04′S	54°28′W		1977	550	Unspec.			Furse (1978)
64	Clarence Island	61°12′S	54°05′W		1977	25,475	Unspec.			Furse (1978)
XII.	**South Orkney Islands**									
65	Inaccessible Islands	60°35′S	46°40′W	31 Dec 1986	1987	50,000	AOS	10,000	100,000	Poncet and Poncet, unpublished
66	Monroe Island	60°36′S	46°01′W	6 Jan 1984	1984	7500	AOS	5000	10,000	Poncet and Poncet, unpublished
67	Coronation Island, Sandefjord Bay	60°38′S	46°00′W	6 Jan 1984	1984	15,000	AOS	10,000	20,000	Poncet and Poncet, unpublished
68	Coronation Island, East Cape	60°39′S	45°16′W	24 Nov 1956	1957	3000	Unspec.			Hall (1957)
69	Powell Island	60°41′S	45°03′W	31 Dec 1983	1984	3500	AOS	1200	7000	Poncet and Poncet, unpublished
XIII.	**South Sandwich Islands**									
70	Zavodovski Island	56°18′S	27°35′W	30 Jan 97; Feb 98	1997; 1998	B	–			Poncet (1997); Convey et al. (1999)
71	Visokoi Island	56°42′S	27°09′W	30 Jan 1997	1997	26,000	AOS	15,600	36,400	Poncet (1997); Convey et al. (1999)
72	Candlemas Island	57°04′S	26°41′W	29–30 Jan 1997	1997	500	AOS	450	550	Poncet (1997); Convey et al. (1999)
73	Vindication Island	57°06′S	26°46′W	29 Jan 1997	1997	2200	AOS	1320	3080	Poncet (1997); Convey et al. (1999)
74	Saunders Island	57°47′S	26°27′W	29 Jan 1997	1997	10	AOS	9	11	Poncet (1997); Convey et al. (1999)
75	Montagu Island	58°25′S	26°20′W	28 Jan 1997	1997	20,000	AOS	12,000	28,000	Poncet (1997); Convey et al. (1999)
	Bristol Island and environs (76–79)									
76	Bristol Island	59°02′S	26°37′W	27–28 Jan 1997	1997	7000	AOS	4200	9800	Poncet (1997); Convey et al. (1999)
77	Freezland Rock	59°03′S	26°37′W	27 Jan 1997	1997	1300	AOS	780	1820	Poncet (1997)
78	Wilson Rocks	59°02′S	26°38′W	27 Jan 1997	1997	7000	AOS	4200	9800	Poncet (1997)
79	Grindle Rock	59°02′S	26°38′W	27 Jan 1997	1997	5000	AOS	3000	7000	Poncet (1997)
80	Thule Island	59°27′S	27°22′W	25–26 Jan 1997	1997	3500	AOS	2100	4900	Poncet (1997); Convey et al. (1999)
81	Cook Island	59°28′S	27°12′W	26–27 Jan 1997	1997	14,000	AOS	8400	19,600	Poncet (1997); Convey et al. (1999)

Table 1 continued

	Locality	Latitude	Longitude	Census date	Season	Number of breeding pair				References
						Estimation		Min	Max	
XIV.	**South Atlantic Islands**									
	Bouvetøya and environs (82–83)									
82	Bouvetøya	54°26′S	03°24′E	Jan–Feb 1997,1999	1997; 1999	50,000	Unspec.	20,000	100,000	K. Isaksen, personalcommunication
83	Larsøya	54°28′S	03°24′E	17–21 Dec 1928	1929	B	–			Olstad (1929)
	All breeding localities				Total	396,385				

Only the latest, reliable records are given. *B* denotes confirmed breeding locality, but no numbers given. *PB* denotes possible breeding locality. In table census units are given as follows: *Unspec.* unspecified method, *AOS* apparently occupied sites and *AN* active nests

[a] Estimated number of currently breeding pairs, based on the proportion 'active nests (AN)/apparently occupied nests (AOS)' in a few reference areas

[b] Maximum number of active nests (AN), no data available on number of apparently occupied nests (AOS)

attached to a nest site. In general, the total number of individuals has been rarely recorded in seabird colony surveys.

Apparently occupied sites (AOS)

The number of individuals or pairs sitting tightly on an area that seems suitable (relatively horizontal and large enough to hold an egg) for successful breeding (Walsh et al. 1995; CCAMLR 1997; Bibby et al. 2000). AOS are normally counted from a distance, and therefore no distinction can be made between active and failed nests. In many studies, AOS-counts have also been reported as 'breeding pairs', or 'nesting pairs'.

Active nests (AN)

The number of nests containing an egg or chick, present on the day of census. AN are counted any time after egg-laying when all nests may be approached on foot and their contents individually checked.

Active chicks (AC)

The number of nests containing a chick on the day of census. AC can be counted individually by checking nest content, or by counting from a distance (distance-count) later in the season when chicks no longer brooded and therefore visible. Very late in the season when most chicks are unattended and often difficult to distinguish from adults, these distance-counts are less reliable.

The most commonly used metric for measuring the size of a breeding population is 'breeding pair'. The total number of breeding pairs in a colony may be defined as the total number of pairs that laid an egg during the season. However, this number is difficult to determine for Southern Fulmars for a number of reasons: occasionally another breeding pair may lay an egg in an abandoned nest during the same breeding season, eggs may roll into adjacent nests, un-paired females may lay an egg and even an incubating trio was observed. In order to record the actual number of eggs laid in one season, birds have to be individually marked and nests monitored at least twice daily, particularly since birds may also abandon the nest site within 24 h after losing their egg (Prévost 1953; J. Creuwels and J. van Franeker, unpublished data).

A Southern Fulmar colony or 'breeding locality' is defined here as the smallest geographically distinct area for which we have some data on the number of breeding birds. Due to the typical loosely scattered distribution pattern of Southern Fulmar nest sites along a coastline, colony boundaries are often difficult to identify. In this review, most estimates were of populations of entire islands (in some cases: archipelagos) rather than specific colonies.

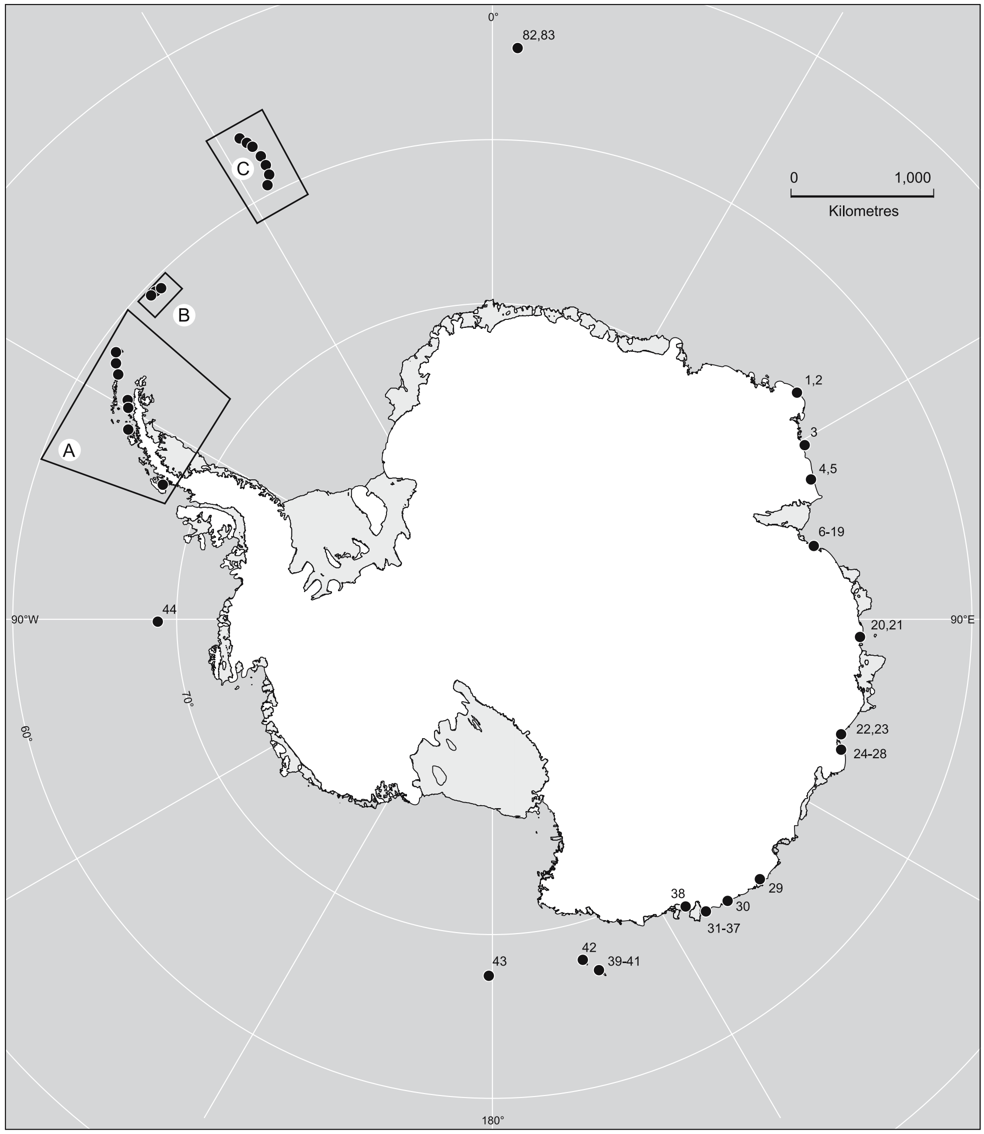

Fig. 1 Distribution of breeding localities of Southern Fulmars. Area A (Antarctic Peninsula and environs) is given in detail in Fig. 2, area B (South Orkney Islands) in Fig. 3, area C (South Sandwich Islands) in Fig. 4. *Numbers near the dots* correspond with numbers in Table 1

Where surveys were very approximate, population size estimates were often recorded as a range rather than a precise figure, and in these cases, the mean of the upper and lower data is presented as the population estimate. Where no estimates of the number of breeding birds were available, the breeding location was recorded as 'breed'. Those sites that were listed as possible or probable but where breeding was unconfirmed were recorded as 'possibly breed'. The 'census season' is the year during which the breeding season ended (i.e. the 1998/1999 season is given as 1999), following the CCAMLR convention (Woehler et al. 2001).

A full overview containing all census data including many historical surveys and additional notes will be made available through the SCAR-GEB website (http://www.birds.scar.org). Latitudes and longitudes of the breeding localities were obtained from the SCAR Composite Gazetteer of Antarctica (http://www.scar.org/information).

Intra-seasonal variation in colony attendance

One of the important factors that influence the outcome of censuses is how bird numbers in a colony vary over the season. The intra-seasonal variation in numbers of breeding pairs and birds attending the colony was investigated in a study area on Ardery Island, Wilkes Land, East Antarctica, during three consecutive seasons (1997–1999) from the spring arrival of birds through to fledging. Southern Fulmars were counted on an almost daily basis, first by distance-counts and subsequently by individual nest checks (active nests) in the colony. The distance-counts of apparently occupied sites and total numbers of birds present were conducted from a viewpoint about 30–60 m away from the boundaries of the colony.

Results

Distribution and abundance

An overview of the most recent and reliable census data for all breeding localities of Southern Fulmars is presented in Table 1. In total, 80 confirmed and three possible breeding localities have been recorded and the global breeding population estimated at a minimum of 400,000 breeding pairs. Census data are lacking for seven of 80 breeding localities, but descriptive notes (Falla 1937; Robertson et al. 1980; Convey et al. 1999) suggest that their total breeding population probably comprises less than 1% of the estimated global breeding population. The current population estimate of 400,000 breeding pairs, based on the most recent and reliable counts (Table 1), should be interpreted as a *minimum estimate*. Below we discuss the historic population estimates for 14 areas around the Antarctic (Fig. 1) and island archipelagos in the Southern Ocean, and compare these with this study's estimates in Table 1.

Areas I–VIII: East Antarctica and adjacent islands

East-Antarctica (Fig. 1) has previously not been reviewed as a whole, although three separate reviews have been compiled for this area: Robertson et al. (1980) estimated 15,000–20,000 breeding pairs for the Balleny Islands in the Ross Sea sector; Jouventin et al. (1984) mentioned about 50 breeding pairs on Ile des Pétrels in Terre Adélie; and Woehler and Johnstone (1991) estimated 29,000 breeding pairs for the Australian Antarctic Territory.

Estimates from more recent surveys (see Table 1) indicate no significant change in population size. A recent survey of part of King George V Land (area VII), revealed many new breeding localities with almost 7,000 previously unrecorded breeding pairs (Barbraud et al. 1999). In total, we estimate that 59,000 breeding pairs or 15% of the estimated global breeding population breed in East Antarctica.

Area IX: West Antarctica (excluding Antarctic Peninsula)

Only one breeding locality is known from West Antarctica, located on Peter 1 Øy (Fig. 1). Southern Fulmars were recorded by the first expedition to land on the island in 1929 (Olstad 1929; Holgersen 1945). In 1948, Holgersen (1951, 1957) estimated a minimum of 3,500 'nesting pairs'. During a recent circumpolar survey, Gavrilo (1997) estimated that thousands of breeding pairs were present on the island. We estimate that 10,000 breeding pairs or 3% of the estimated global population breed on Peter 1 Øy.

Area X: Antarctic Peninsula

Southern Fulmars were first recorded to breed on the Antarctic Peninsula (Fig. 2) in 1902 (Anderson 1905) when Nordenskjöld explored this area. The first review of breeding population data included three breeding localities with a total of 100 to 1,000 breeding pairs (Croxall et al. 1984).

Between 1986 and 1989, S. Poncet and J. Poncet (unpublished data) undertook detailed seabird distribution and abundance surveys of the Antarctic Peninsula and recorded over 40,000 breeding pairs of Southern Fulmars. We estimate that 41,000 breeding pairs or 10% of the estimated global breeding population breed on the Antarctic Peninsula.

Area XI: South Shetland Islands

The South Shetland Islands (Fig. 2) consists of two main island groups. The southern group lies relatively close the Antarctic Peninsula and includes Deception Island, which was mentioned historically as a possible breeding locality (Anderson 1905; Gain 1914). Increased numbers at sea probably occurred due to whaling activities around Deception Island (Gain 1914; Murphy 1936), but we found no evidence that breeding may have occurred here. Croxall et al. (1984) mentioned no confirmed breeding here. Recently, Naveen (2003) suggested Greenwich Island as a possible breeding locality.

The northern group, also called the Gibbs and Elephant Island Group, appears to be an important breeding area. Detailed surveys in the 1970s showed that many birds breed here, especially on Gibbs and Clarence Islands (Furse and Bruce 1975; Furse 1978). In total, 71,000 breeding pairs are estimated (Croxall et al. 1984), this being 18% of the estimated global breeding population.

Area XII: South Orkney Islands

The South Orkney Islands (Fig. 3) were first surveyed in the early 1930s (Ardley 1936), when more than 500,000 breeding pairs were estimated to nest on the Inaccessible Islands and 25,000 breeding pairs on Coronation Island. Croxall et al. (1984) estimated 100,000–one million breeding pairs for the South Orkney Islands.

J. Poncet and S. Poncet (unpublished data) censused about 25,000 breeding pairs on three islands of the South

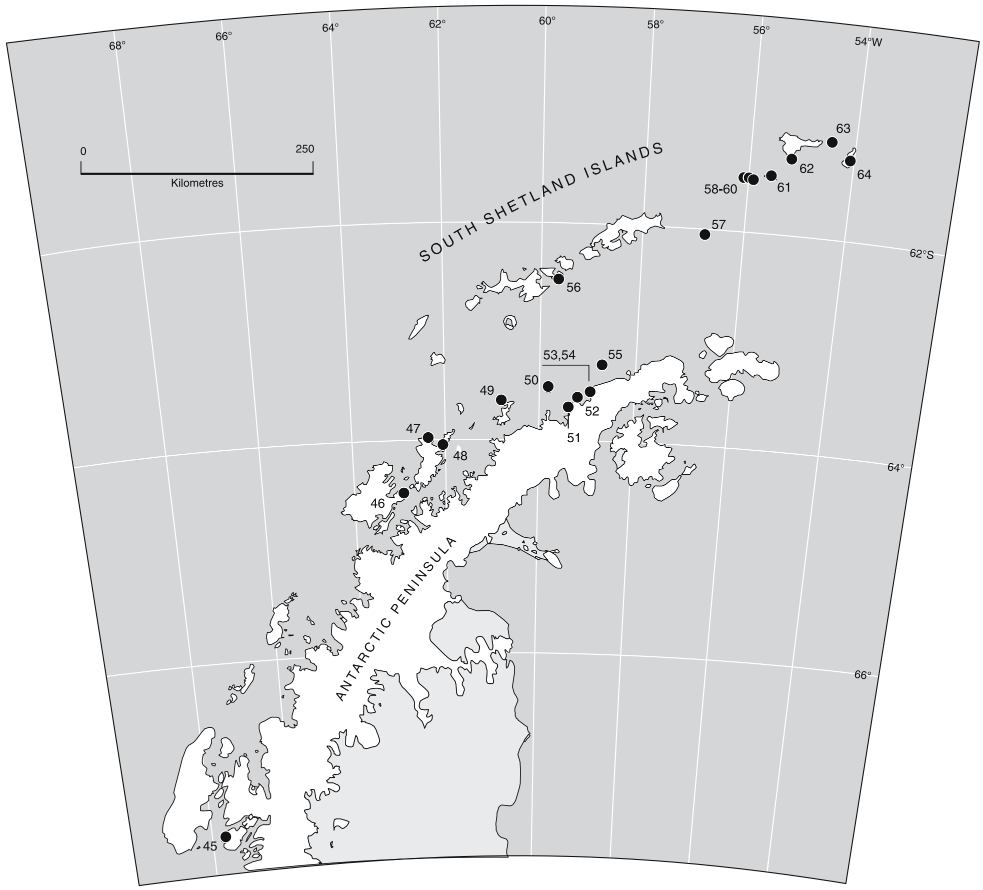

Fig. 2 Distribution of breeding localities of Southern Fulmars on the Antarctic Peninsula and Shetland Islands. *Numbers near the dots* correspond with numbers in Table 1

Orkneys in 1984 and a further 50,000 breeding pairs on Inaccessible Islands in 1986 (Table 1). No recent estimates are available for the east coast of Coronation Island, last surveyed in 1957 (Hall 1957). On the basis of these data, we estimate the current population of this area to be about 80,000 breeding pairs, representing 20% of the estimated global breeding population.

Area XIII: South Sandwich Islands

The South Sandwich Islands (Fig. 4) have been rarely visited (e.g. Larsen 1908; Wilkinson 1956, 1957) and only anecdotal information was available until recently. Kemp and Nelson (1932) and Holdgate and Baker (1979) gave detailed descriptions of each island's topography, geology and biology, but did not attempt to estimate the breeding population of birds. From these reports, it appeared that Southern Fulmars nested here in high numbers. Croxall et al. (1984) mentioned roughly one million breeding pairs.

Detailed systematic surveys have been undertaken recently (Poncet 1997; Convey et al. 1999), confirming the importance of this island group for the global population. Many islands contained numerous breeding pairs, notably Visokoi Island, Montagu Island, Bristol Island (including Wilson, Grindle, and Freezland Rocks) and Cook Island. These recent population estimates total about 90,000 breeding pairs, this being 22% of the estimated global population.

Area XIV: South Atlantic Islands

In the South Atlantic Ocean, only Bouvetøya and adjacent rocks and islets (Fig. 1) are known to contain breeding pairs of Southern Fulmars. Based on high numbers of Southern Fulmars observed at-sea near Bouvetøya, it has been suggested that this species may breed on the island (e.g. Bierman and Voous 1950; Holgersen 1951), although no systematic survey has been conducted.

K. Isaksen (personal communication) estimated between 20,000 and 100,000 breeding pairs in 1996–1998, based on rough extrapolations. In contrast to colonies in East Antarctica where birds disperse after each breeding season, high numbers of Southern Fulmars (50,000 individuals) are seen around Bouvetøya during the winter months (Augstein 1987). We have assumed that 50,000 pairs may nest here, or 13% of the estimated global population.

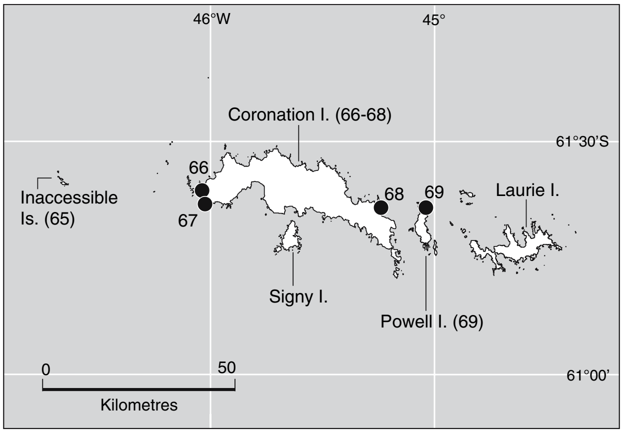

Fig. 3 Distribution of breeding localities of Southern Fulmars on the South Orkney Islands. *Numbers near the dots* correspond with numbers in Table 1

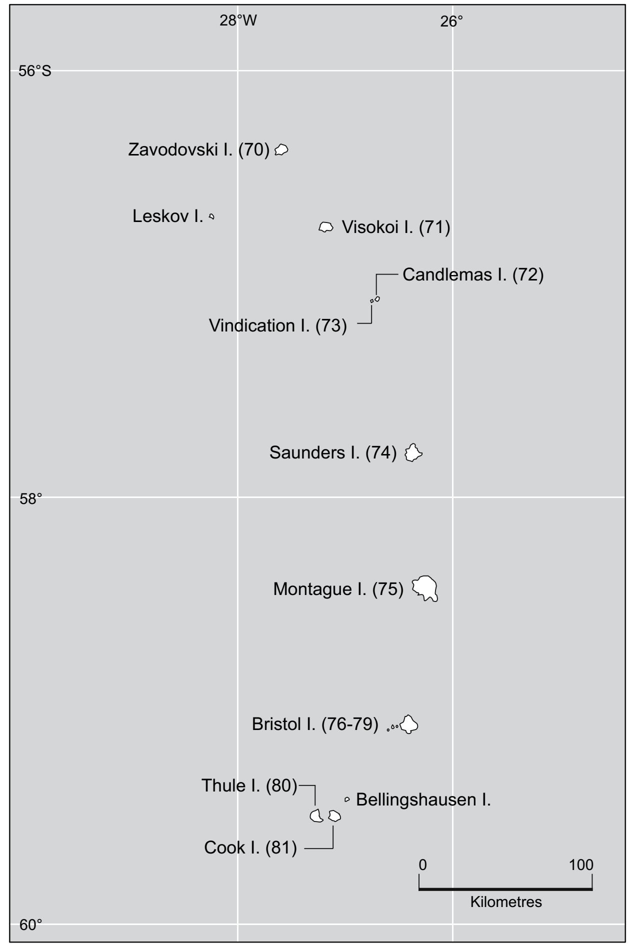

Fig. 4 Distribution of breeding localities of Southern Fulmars on the South Sandwich Islands. *Numbers* behind the islands' name indicate that breeding occurs on the island, and correspond with numbers in Table 1

Intra-seasonal variation in the Ardery Island study colony

During three consecutive seasons (1997–1999), the intra-seasonal variation in breeding population numbers was investigated on Ardery Island, East Antarctica. On average, the number of eggs laid (i.e. the number of breeding pairs) in this colony was 74 per season. The population trends according to the three census methods (see Fig. 5) can be summarised as follows:

1. The number of *active nests* was always lower than the number of eggs laid due to many nest failures occurring immediately after laying. The number of active nests was highest at peak egg-laying (15 December), by which time 14% of the total number of eggs laid had been lost. Just before fledging, the number of active nests had decreased to 33% of the total number of eggs laid.
2. The number of *apparently occupied sites* was lower than the number of active nests due to undercounting of birds on nests, as not all were visible from the viewpoint. During the first half of incubation (15 December–15 January), the number of apparently occupied sites was about half the number of breeding pairs and decreased further to about 20% just before fledging.
3. The *total number of individuals* was highly variable and fluctuated around the total number of active nests during much of the season. The greatest number of birds in the colonies was recorded before the pre-laying exodus. As the season progressed, numbers of birds fluctuated widely due to influxes of non-breeding birds or failed breeders. Consequently, numbers of individual birds are not considered to be reliable indicators of breeding pairs.

In conclusion, all three methods underestimated the number of breeding pairs on Ardery Island. The number of apparently occupied sites in the period between egg-laying and hatching (*c.*20 December–20 January) was relatively stable and in that period represented approximately 40% of the number of eggs that actually had been laid in the colony.

Discussion

Based on available census data, the sum of colony estimates in Table 1 produces a global population of Southern Fulmars of about 400,000 breeding pairs. This is certainly an under-estimate of the real number of breeding pairs as it is largely based on the number of AOS or active nests. The actual number of breeding pairs (producing an egg) was obtained from data provided by the detailed colony

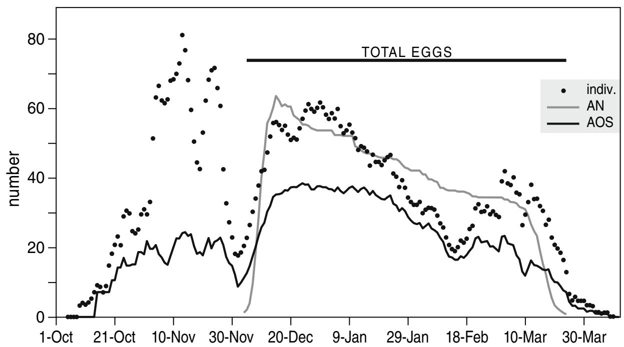

Fig. 5 Intra-seasonal trends in numbers of breeding Southern Fulmars. Distance-counts (AOS and total of individuals) are counted before entering the study area. In the colony, the nest contents of each individual nest was checked and number of AN counted. Data are averaged over three seasons, and distant censuses are presented as running averages over 7 days. On average 74 eggs were laid per season

study at Ardery Island. During much of the incubation period until hatching, the number of AOS represented only 40% of the number of eggs known to be laid in the colony, and rapidly decreased thereafter (Fig. 5). In Terre Adélie, Jenouvrier et al. (2003) found that by late December, 43% of the breeding population not breeding, but known to be alive.

The number of AOS in the Ardery Island colony has been derived from counts conducted from a nearby vantage point. Many of the counts in Table 1 were made during incubation, but some were made well after hatching, and from distant viewpoints. It is likely therefore that the number of AOS is around 40% of the actual number of egg-producing pairs. This proportion has been applied to the total figure of 400,000 pairs in Table 1, and the global breeding population of Southern Fulmars estimated to be at least a million pairs.

The current global estimate breeding pairs of one million breeding pairs is considerably lower than the previous estimate of 'several millions' pairs which was estimated for only a part of the distributional area (Croxall et al. 1984). In particular, the population estimates for important breeding areas such as the South Orkneys and South Sandwich Islands (Table 1) are much lower than previously reported, while those for the Antarctic Peninsula and King George V Land (which are relatively small on the global scale, Table 1) are considerably higher.

In translating breeding estimates to overall numbers of birds it has to be kept in mind that bird populations contain many non-breeders. In an earlier study on Ardery Island, Van Franeker et al. (1990) found that the number of regularly attended sites was twice as high as the number sites where eggs were produced. Furthermore, intensive ringing studies indicated that for every breeding individual, two non-breeders attended the colony.

Below we discuss in further detail why a global breeding estimate of one million breeding pairs is not very precise, why it should be interpreted as a minimum estimate, and whether the global population of Southern Fulmars is likely to change in the near future.

Precision and accuracy of the counts

The precision and accuracy of a count are the two principal sources of errors when counting birds (Bibby et al. 2000). Count precision is a measure of the natural variation in census values, and reflects the variation in results obtained during repeated counts under similar conditions. Estimated count precision, indicated by minimum and maximum reliable values is available for counts at 39 breeding localities (Table 1). Details on how the count precision was estimated are often lacking. Large colonies are typically counted by extrapolating estimates of snapshots of representative parts of the colony. Such estimates may deviate 40% or more from the estimated count (Poncet 1997; Convey et al. 1999). The use of photography in future surveys could increase count precision if individual birds are counted from high quality images.

Count accuracy is a measure of the bias present in the count data, and indicates how much the estimated value deviates from the true value. The accuracy of counts performed from a distance (distance-counts) can only be determined if they are compared with precise count data, preferably collected in the colony or at short distance from the nests. As most censuses in Table 1 were of inaccessible colonies counted from a distance, count accuracy is mostly unknown. Important factors that influence count accuracy are weather and colony location (especially colony topography). Colonies on cliffs and in coastal areas can often only be surveyed from sub-optimal viewpoints (e.g. from water or sea-ice), resulting in reduced numbers of birds being visible (Walsh et al. 1995; Bibby et al. 2000). Even under relatively favourable census conditions, many nests can be missed. In a study colony on Ardery Island, Wilkes Land, East Antarctica, where nests were counted from an elevated viewpoint overlooking the colony, an estimated 30–50% of the nests appeared to be hidden among boulders (Van Franeker et al. 1990; Fig. 5).

Aerial or yacht-based photography is a census method that has not been used before to carry out Southern Fulmar censuses. Photography has many advantages for census surveys, such as the possibility of archiving images and the assessment of the count error by repeating the counts from the images. Furthermore, data on colony boundary and colony size can be obtained from photographic prints or digital images and used for future comparisons. Ideally, estimates derived from photos should be adjusted in order to take into account the proportion of birds not on nest and the proportion of nests without an egg. This requires count data obtained at close distance to the colony or by shore parties. For a detailed description on the methodology, we refer to Poncet et al. (2006) and Robertson et al. (2006).

In situations where more detailed repeated censuses are possible, we refer to standard methods developed (for Antarctic Petrels) by CCAMLR (1997).

Undiscovered colonies

The breeding localities are not evenly distributed over Antarctica (Fig. 1), which in some areas might also be related to differences in surveying efforts. Particularly in East Antarctica, the clustered distribution probably reflect a higher search effort around research stations. Thus, small colonies in these areas have a higher chance to be detected, and further away the research stations there are possibly still colonies to be discovered. For example, Barbraud et al. (1999) recently surveyed the coast along Terre Adélie and a part of King George V Land and found six new breeding localities.

Several at-sea distribution studies have reported high densities of Southern Fulmars close to the breeding grounds (Falla 1937; Bierman and Voous 1950; Holgersen 1957; Ainley et al. 1984; Montague 1988; Veit and Hunt 1992; Whitehouse and Veit 1994). However, high densities at sea may not necessarily indicate the proximity of breeding localities. For example, the discrepancy between at-sea numbers of 1.7 million birds (Cooper and Woehler 1994) and 16,500 breeding pairs on land, both recorded in the highly productive and well-surveyed Prydz Bay area, remains to be resolved. For example, the rich food supply in the Prydz Bay area attracts many seabirds (Woehler 1997) and possibly also non-breeding individuals or birds that are not breeding in the area. On the other hand, the breeding population estimates in this area are conservative and might underestimate the true size of the local population (E. Woehler, personal communication). The presence of Southern Fulmars in the Amundsen and Bellingshausen Seas during the breeding season (Gain 1914; Zink 1981; Hunt and Veit 1983; Gavrilo 1997) possibly indicates that there are still colonies to be discovered in the coastal area of West Antarctica. More systematic surveys are needed for these relatively poorly surveyed areas in addition to major breeding localities.

Possible threats

Currently, there is no evidence of serious threats to the global Southern Fulmar breeding population. Chemical contaminants such as organochlorine compounds and mercury have been found in eggs and adults of Southern Fulmars, but levels are generally low (Luke et al. 1989; Van den Brink et al. 1998). Plastic particles have been recorded in the stomachs of Southern Fulmars, but their rates of occurrence are low (Van Franeker and Bell 1988; Ainley et al. 1990). Long-term population trend data are available only for Ile des Pétrels in East Antarctica. This small colony has been monitored annually for more than 40 years, during which time its breeding population has increased slightly due to immigration from colonies elsewhere (Jenouvrier et al. 2003). The species usually breeds on precipitous cliffs and inaccessible rock ledges, and the largest breeding concentrations are found on remote oceanic islands that are rarely visited (Poncet 1997; Naveen 2003; IAATO 2005). At the few sites where visitors (including tourists, researchers and station support personnel) are able to access breeding sites, no disturbance impacts have been recorded and should they occur, are unlikely to affect the global population, although they may have an effect on the local population.

Fishery vessels attract Southern Fulmars (Whitehouse and Veit 1994; Weimerskirch et al. 2000; Wienecke and Robertson 2002) and frequent interactions with fishing gear have been observed (Marín 2004). Apart from one mortality in the South Atlantic Ocean (Vaske 1991 cited in Brothers et al. 1999) no fatal accidents of Southern Fulmars with long-lining vessels and trawlers have been recorded (White et al 1999; Weimerskirch et al. 2000; Kock 2001; Wienecke and Robertson 2002; Sullivan 2004). Increasing fishery activities could have positive effects due to increasing supply of discards, and negative effects due to increased competition for food resources. Pelagic krill fisheries operate in areas close to major breeding grounds in the Scotia Sea and Antarctic Peninsula (Croxall and Nicol 2004). The Antarctic Krill *E. superba* is the only food source that Southern Fulmars share with commercial fisheries (CCAMLR 2005) but it is probably not a major component of the Southern Fulmar diet (Van Franeker et al. 2001). Reduced krill stocks could affect breeding success and population growth, via effects on intermediate trophic levels such as fish and squid.

Recommendations

In order to facilitate future comparative surveys, it is essential that census methods are clearly described, and boundaries of breeding colonies be identified. Standardising the timing of the censuses (e.g. as close to hatching as possible) is recommended, but will be difficult due to logistical constraints. More studies are needed on intra-seasonal variations in population numbers in order to interpret censuses conducted at different times. Due to the inaccessibility of most colonies, most censuses need to be done by boat or aerial surveys. If possible, verification of distance-counts with censuses at closer distance is highly recommended to enhance the accuracy. The use of photography in censusing Southern Fulmar populations should be explored.

From Table 1, it follows that more detailed systematic surveys should be conducted, especially of the Clarence and Elephant Islands group, South Orkney Islands, South Sandwich Islands, Balleny Islands and Bouvetøya. We recommend that any information on the breeding distribution and abundance of Southern Fulmars be forwarded to the SCAR–GEB (http://www.birds.scar.org/contacts) and/or to the first author to enable the public database to be updated and revised.

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