Distribution and Abundance of the Antarctic Petrel

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Abstract.—Published and unpublished information on the distribution and abundance of the Antarctic Petrel (*Thalassoica antarctica)* is reviewed. Currently 35 colonies with approximately half a million breeding pairs are known. All but one of these known colonies are situated in East Antarctica. However, an estimate derived from at sea studies in three of four apparent centers of oceanic occurrence suggests a population as high as four to seven million breeding pairs (10 to 20 million individuals). In spite of the tentative nature of such an estimate, the difference with the colony-derived figure strongly suggests the existence of large, currently undiscovered colonies, particularly in western Antarctica and Victoria Land, where a complete mismatch exists between bird observations at sea and known colonies. In eastern Antarctica, in addition to undiscovered colonies, some known ones could be considerably larger than currently documented. *Received 16 June 1998, accepted 15 December 1998.*

Key words.—Antarctic Petrel, *Thalassoica antarctica*, breeding, distribution, pelagic, population.

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Human activities may affect Antarctic ecosystems directly or indirectly. Adequate information on the distribution and sizes of animal populations is needed to monitor change and to ensure appropriate conservation or management strategies. Such needs have been identified in the Protocol on Environmental Protection to the Antarctic Treaty and the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). As a consequence, the Scientific Committee for Antarctic Research (SCAR) Bird Biology Subcommittee (SBBS 1994) encourages integral documentation of all available data on the distribution and abundance of Antarctic seabirds. Publication of the Antarctic/Subantarctic penguin review by Woehler (1993) was the first result of this effort. Croxall *et al.* (1995) made the first review of one of the flying seabirds, the Snow Petrel (*Pagodroma nivea*). Several other reviews are currently underway. This paper compiles the current knowledge on the distribution and status of the Antarctic Petrel (*Thalassoica antarctica*), one of the species selected for monitoring in the CCAMLR Ecosystem Monitoring Program (CEMP).

The Antarctic Petrel is an endemic seabird of Antarctica. It breeds on coastal outcrops and islands as well as on exposed inland mountains (nunataks). Birds nest in the open on cliffs and mountain slopes. Colonies can be very large, with nests often closely packed together. The inland colonies can be situated at distances of over 200 km from the nearest open water during the summer chick rearing period (Wright and Wyeth 1971; Brook and Beck 1972; Mehlum *et al.* 1988). However, pre-breeding visits to the colonies during October (Pryor 1968; Luders 1977; Kamenev 1979) may require birds to commute over ice over distances that may exceed 2,000 km between feeding areas and nests (van Franeker 1996).

The breeding season of the Antarctic Petrel is highly synchronized: after their pre-breeding visit to the colony in October, all go

to sea in the beginning of November; they return and immediately lay their eggs in the last ten days of November; initial incubation shifts are long (about two weeks) but gradually shorten; chicks hatch in the second week of January and are guarded by parents for about 10 to 15 days; by the end of January all adults leave and only successful breeders pay short visits to feed their offspring; chicks fledge in late February to early March (van Franeker 1994a; Lorentsen and Røv 1995). Compared to other fulmarine petrels, the breeding cycle of the Antarctic Petrel is rather short and starts very early in the season. Combined with the distance between breeding locations and open water, this indicates that the species may respond early to relatively small effects of climate change such as changes in snowfall (van Franeker, unpublished) or extent of the seasonal sea ice.

Recent studies show that the diet of Antarctic Petrels is often dominated by epipelagic fish, mainly *Pleuragramma antarcticum,* in virtually all studies of chick-provisioning birds (Klages *et al.* 1990; Arnould and Whitehead 1991; van Franeker and Williams 1992; Norman and Ward 1992) and *Electrona antarctica* in large samples of birds at sea during all non-breeding seasons (Ainley *et al.* 1992). Squid was also a common prey in many at-sea studies (Falla 1937; Bierman and Voous 1950; Griffiths 1983; Ainley *et al.* 1992), and the dominant diet component during summer in the Ross Sea (Ainley *et al.* 1984). Crustaceans, mainly Antarctic Krill (*Euphausia superba*), are extremely common diet items by frequency of occurrence in all studies cited, but only occasionally dominate other prey on a mass/volume basis. Lorentsen *et al.* (1998) report an unusual crustacean component (67%) in chick diets in Dronning Maud Land, and two studies at sea in Prydz Bay, conducted during krill surveys, showed almost 100% krill in the stomach samples (Montague 1984; Nicol 1993). The general picture is that of a diet dominated by fish with opportunistic feeding on other prey types. This dietary choice of Antarctic Petrels should not lead to a lack of concern about potential competition with commercial krill harvesting. Indirectly, because of intermediate trophic levels, the demands of Antarctic Petrels on the Southern Ocean krill stocks (being also the prey of fish and squid) may be more important than when krill would be the only direct source of food.

METHODS

For the purpose of this paper, original sources of information in earlier compilations such as Watson *et al.* (1971), Brook and Beck (1972), Marchant and Higgins (1990), Warham (1990), and Del Hoyo *et al.* (1992) have been re-evaluated and new information, published and unpublished, was added. Drafts of this paper were presented to the SCAR Bird Biology Committee during meetings in Padua 1994 (SBBS 1994) and Cambridge 1996 (SBBS 1997) and were widely circulated to invite contributions from unpublished sources. Considering the paucity of information on breeding colonies, it was decided to include information from pelagic studies in this review.

The text provides detailed descriptions of all known or suspected breeding locations and also includes observations of birds passing overhead to indicate potential unknown breeding areas. Only confirmed breeding locations have been listed in Table 1 and Figure 1b to avoid any confusion. Place names and geographical positions are usually those supplied by the original sources.

BREEDING DISTRIBUTION AND NUMBERS

Table 1 and Figure 1b provide details of known breeding locations.

Coats Land

Brook and Beck (1972) report 5,000 to 10,000 "birds" on the Coalseam Cliffs immediately below Stewart Buttress of Mount Faraway, Theron Mountains (79°12'S, 28°45'W). Their wording and the time of season (6 January 1967) suggest that "birds" could be read as "nests," which would suggest 5,000 to 10,000 breeding pairs in the Theron Mountains. Even further south, Wright and Wyeth (1971) observed 200 birds circling the summit of Mount Provender, Shackleton Mountains (80°23'S, 29°55'W) and found two dead chicks and a mauled third one nearby. The same authors also mentioned 12 birds seen flitting in and out of buttresses on the western face of Mount Lowe, Shackleton Mountains (80°32'S, 30°20'W) (new nest sites observed 30 December 1970).

Table 1. Known Antarctic Petrel breeding colonies. Location numbers refer to figure 1b. Bird numbers as given by some sources have been listed as 'pairs' because counts were usually made in periods when most sites are attended by single birds. Only one source of information listed per location: see text for further details on for example colony size and on rejected locations.

Nr.	Location	Latitude	Longitude	Breeding pairs	Primary source
	COATS LAND				
	SHACKLETON MOUNTAINS				
1.1	Mount Provender	80°23'S	29°55'W	200	Wright and Wyeth 1971
1.2	Mount Lowe	80°32'S	30°20'W	12	Wright and Wyeth 1971
	THERON MOUNTAINS				
1.3	Coalseam Cliffs-Mt. Faraway	79°12'S	28°45'W	10,000	Brook and Beck 1972
	DRONNING MAUD LAND				
	VESTFJELLA				
2.1	Pagodromen	73°45'S	14°50'W	4	Sømme 1977
	GJELSVIKFJELLA				
2.2	Nupskammen, Stornupen	72°11'S	2°23'E	?	Ohta 1993
2.3	Jutulsessen west	72°03'S	2°36'E	1,500	Ohta 1993
2.4	Jutulsessen (RovC)	72°01'S	2°37'E	3,000	N. Røv, *in litt.*
2.5	Jutulsessen (RovB)	72°03'S	2°41'E	30,000	N. Røv, *in litt.*
2.6	Jutulsessen (RovA)	72°03'S	2°43'E	8,000	N. Røv, *in litt.*
2.7	Jutulsessen, Jutulhogget	72°02'S	2°51'E	5,500	Ohta 1993
2.8	Risemedet, Medhovden	72°01'S	3°18'E	200	Ohta 1993
	MÜHLIG HOFMANN MOUNTAINS				
2.9	Festninga, Austvollen	72°06'S	3°50'E	200	Ohta 1993
2.10	Hochlinfjellet, Hoggestabben	72°01'S	3°57'E	200	Ohta 1993
2.11	Hochlinfjellet, Stålsuten	72°03'S	4°08'E	100	Ohta 1993
2.12	Hochlinfjellet, Remplingen	72°05'S	4°18'E	500	Ohta 1993
2.13	Skigarden	71°55'S	4°36'E	300	Ohta 1993
2.14	Petrellfjellet	71°58'S	4°50'E	?	Ohta 1993
2.15	Svarthamaren	71°53'S	5°10'E	250,000	Røv *et al.* 1994
2.16	Kvitholten	71°48'S	5°53'E	300	Ohta 1993
	ENDERBY LAND				
3.1	Cape Ann, Mount Biscoe	66°09'S	51°22'E	1,000s	Bassett *et al.* 1990
3.2	Proclamation Rock	65°51'S	53°41'E	10s	Falla 1937
	MAC. ROBERTSON LAND				
4.1	Scullin Monolith	67°47'S	66°42'E	157,000	Alonso *et al.* 1987
4.2	Murray Monolith	67°47'S	66°53'E	3,500	Alonso *et al.* 1987
	PRINCESS ELIZABETH LAND				
	RAUER ISLANDS				
5.1	Buchan Island	68°47'S	77°46'E	5,000	Green and Johnstone 1986
5.2	Filla Island	68°49'S	77°52'E	1,100	Green and Johnstone 1986
5.3	Hop Island	68°50'S	77°42'E	1,000	Green and Johnstone 1986
5.4	Islet D west of Hop	68°50'S	77°40'E	10	Green and Johnstone 1986
5.5	Forpost Island	68°53'S	77°40'E	2	Green and Johnstone 1986
	QUEEN MARY LAND				
6.1	Haswell Island	66°32'S	92°59'E	1,100	Pryor 1968
	WILKES LAND				
	WINDMILL ISLANDS				
7.1	Ardery Island	66°22'S	110°27'E	275	van Franeker *et al.* 1990
7.2	Odbert Island	66°22'S	110°33'E	34	van Franeker *et al.* 1990
	Frazier Islands				
7.3	Nelly Island	66°14'S	110°10'E	10s	Murray and Luders 1990
	EASTERN WILKES LAND				
7.4	Lewis Island	66°06'S	134°22'E	25	Woehler and Johnstone 1991

Table 1. (Continued) Known Antarctic Petrel breeding colonies. Location numbers refer to Figure 1b. Bird numbers as given by some sources have been listed as 'pairs' because counts were usually made in periods when most sites are attended by single birds. Only one source of information listed per location: see text for further details on for example colony size and on rejected locations.

Nr.	Location	Latitude	Longitude	Breeding pairs	Primary source
	KING GEORGE V LAND				
8.1	Cape Hunter	66°58'S	142°20'E	1,000s	Falla 1937
	KING EDWARD VII LAND ROCKEFELLER MOUNTAINS				
9.1	Mt. Paterson	78°02'S	154°36'W	10,000	Broady *et al.* 1989

Dronning Maud Land

Two major breeding concentrations are now known in the inland nunatak areas of Dronning Maud Land. The largest known colony of the entire Antarctic continent was first described by Konovalov and Shulyatin (1964) and Konovalov (1964); they estimated a million birds at Svarthamaren, Muhlig-Hoffman Mts (71°53'S, 5°10'E). Recent Norwegian activities in this area have greatly improved information for this site (Mehlum *et al.* 1986, 1987, 1988; Røv 1990, 1991; Bech *et al.* 1991; Haftorn *et al.* 1991; Andersen *et al.* 1993, 1995; Lorentsen *et al.* 1993, 1996, 1998; Saether *et al.* 1993, 1997; Lorentsen and Røv 1994, 1995; Lorentsen 1995a, 1995b, 1996; Røv *et al.* 1994; Amundsen *et al.* 1996; Tveraa *et al.* 1997). The Svarthamaren colony is now estimated at about 250,000 breeding pairs:

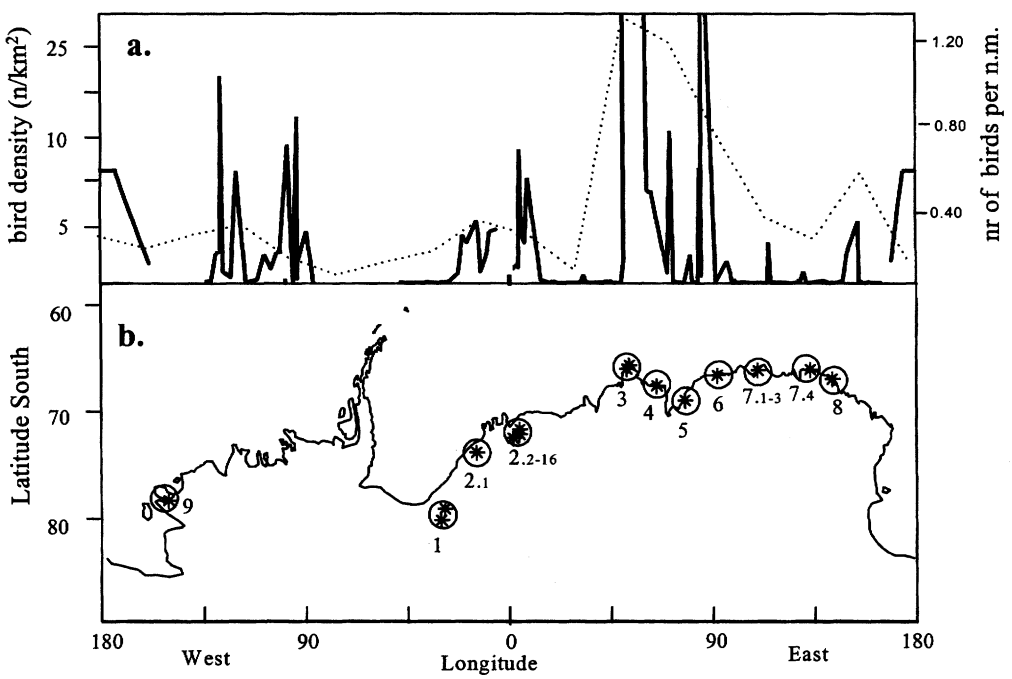

Figure 1. Distribution of the Antarctic Petrel. Circum-Antarctic pelagic distribution (Fig. 1a) is shown from a number of selected studies that produced quantitative data for longitudinal transects following the preferred marine habitat of Antarctic Petrels along the ice edge or shelf front. Solid lines in Fig.1a represent density figures (n km^{-2}) for the areas between 0° and 170°E (Veit and Hunt 1991); Ross Sea (shelf-edge average from Ainley *et al.* 1984); Amundsen and Bellingshausen Seas (Erickson *et al.* 1972); and Weddell Sea (Van Franeker 1996); the dotted line shows relative densities as number per nautical mile sailed (geometric means for blocks of 20° longitude) from Gavrilo (1997 a, b and unpublished). Locations of confirmed breeding (Fig. 1b) are shown with numbers referring to those in Table 1.

including non-breeders, the total number of colony-associated individuals was estimated at 820,000 (Røv *et al.* 1994). Reference breeding groups for population and demography studies were established at Svarthamaren in 1991 (Lorentsen *et al.* 1993). At least seven other small colonies, each with perhaps some hundreds of pairs, have been detected in the Muhlig-Hoffman Mountains (Ohta 1993).

Norwegian surveys (Mehlum *et al.* 1988) also revealed three breeding colonies of Antarctic Petrels at Jutulsessen in Gjelsvikfjella (72°05'S, 2°40'E). Røv (1990; *in litt.*) estimated these at 30,000, 8,000 and 3,000 pairs. Ohta (1993) mapped an additional four small colonies in the area: two at Jutulsessen and two on other Gjelviksfjella nunataks.

There is only one further breeding record from the extensive mountain ranges in Dronning Maud Land: Sømme (1977) mentions four breeding pairs seen by Winsnes in 1968 and one by himself in 1977 at the same locality at Pagodromen, Vestfjella (73°45'S, 14°50'W). Ryan and Watkins (1988) reported a single deserted egg at Snarbynuten, H. U. Sverdrupfjella, but suggest that this could be an accidental laying by a bird from the nearby Jutulsessen colonies. Roots (1954) interpreted flocks of Antarctic Petrels on several locations in Gburektoppane as 'must have been nesting' in the H. U. Sverdrupfjella, but there is no confirmation of this observation. Increased South African activities in the Ahlmannryggen area have produced many observations of flocks passing or even circling cliffs, but without records of breeding (Ryan and Watkins 1988; Swart 1989; Steele and Newton 1995). Large flocks of Antarctic Petrels have also been observed over the Schirmacher Hills (flying to Wohlthalmassivet?) but without evidence of breeding (Konovalov 1964; Richter 1983). Antarctic Petrels do not breed on Bouvet Island (Mehlum 1986; Bakken 1991).

Enderby Land

Two colonies of Antarctic Petrels are known in Enderby Land, but existing information is poor. During a short visit on 13 January 1930, Falla (1937) discovered a "small colony" with a "few" chicks on Proclamation Rock (65°51'S, 53°41'E). Recently, Gavrilo (1997a) reported Antarctic Petrels flying over, and possibly nesting on Proclamation Rock. No further data are available.

Mawson (1930) and Falla (1937) suggested a very large second colony must be present on Cape Ann, Mount Biscoe (66°09'S, 51°22'E), using terminology like "encrusted with guano from countless flocks of Antarctic Petrels and other birds" and "clouds of birds rising". Confirmation that Antarctic Petrels breed on Mount Biscoe is from Bassett *et al.* (1990) who observed pre-breeding nest attendance on 27 and 29 October 1985: from "numerous" site-attending birds on the mount's western massif and "vast" numbers flying around the eastern one they conclude that a "substantial" number may breed. E. J. Woehler considers "thousands of pairs" as an appropriate order of magnitude.

Kemp Land

Not known to breed.

Mac. Robertson Land

Conflicting information is available for the Antarctic Petrel colony on Scullin Monolith (67°47'S, 66°42'E), which was described by Falla (1937) as having "many" nests. Based on observations late in the breeding season (1-6 February 1987) Alonso *et al.* (1987) published an estimate of 157,000 breeding pairs in the colony. However, using similar counting techniques (extrapolation of densities in band-transects to total colony surface), a quick survey early in the breeding season (3 December 1982) indicated that the number of apparently occupied sites was in the range of one to three million (Montague 1984; Kerry and Montague *in litt.*)! Table 1 uses the estimate by Alonso *et al.* (1987) since it is better documented. However, after late January, population censuses of Antarctic Petrels are virtually impossible because of the mass departure of all non- and failed breeders, low attendance of successful breeders, unknown breeding success, and the inconspicuous nature of unattended nest-sites. It has to be

kept in mind that the Scullin Monolith colony may prove to be much larger when properly censused early in the breeding season.

The only survey of the nearby Murray Monolith (67°47'S, 66°53'E) was made by helicopter on 6 February 1987, and resulted in a colony estimate of some 3,500 pairs (Alonso *et al.* 1987; Johnstone 1987). As for Scullin Monolith, timing of the survey suggests that the actual population figure could be considerably higher.

No breeding is known in the inland mountain ranges of Mac. Robertson Land south of Prydz Bay. Recent Australian activities in the Prince Charles Mountains have only resulted in two sightings of Antarctic Petrels (Heatwole *et al.* 1991; Howard 1991).

Princess Elizabeth Land

The existence of breeding colonies of Antarctic Petrels on several of the Rauer Islands (68°51'S, 77°50'E) was first reported by Johnstone *et al.* in 1973. In December 1981, Green and Johnstone (1986) estimated a total of 7,112 nesting pairs (Buchan Island 5,000, Filla Island 1,100, Hop Island 1,000, west of Hop 10, Forpost Island 2). Lower estimates for 1985 by Green and Johnstone (1986), as quoted by Woehler and Johnstone (1991), could well be caused by different coverage, methods and time of season, and do not necessarily indicate population decreases. The Australian Antarctic Division has established reference breeding groups in the area, and petrels on Hop Island are intermittently studied (Whitehead *et al.* 1990; Whitehead 1991; Arnould and Whitehead 1991; Norman and Ward 1992; Norman *et al.* 1992; Van den Brink 1997).

Wilhelm II Land

Not known to breed.

Queen Mary Land

The only known breeding location in Queen Maud Land is situated on Haswell Island (66°31'S, 93°00'E). Detected on 28 November 1912 (Mawson 1915), this colony was the very first place where Antarctic Petrels were found nesting. Based on early breeding observations, Pryor (1968) and Kamenev (1979) estimated between 1,000 and 1,100 breeding pairs. The lower estimate of 250 pairs by Starck (1980) was made in late January 1979.

Wilkes Land

Orton (1963, 1968) first described the existence of small colonies of Antarctic Petrels on islands in the vicinity of the former U.S. base Wilkes (later replaced by the Australian base Casey). In the Windmill Islands (66°20'S, 110°25'E), breeding only occurs on Ardery and Odbert islands. Van Franeker *et al.* (1990) estimated about 275 breeding pairs on Ardery Island and 34 on Odbert Island, noting that such figures could be increased by some 50% if site-holding non-breeding pairs were included. Non-breeding attendance probably explains the variation between 250 (Cowan 1979) and 500 (Luders 1977) pairs in earlier estimates. Several Antarctic Petrel studies have been conducted on Ardery Island (Murray and Luders 1990; Van Franeker and Montague 1987; Bell *et al.* 1988; Van Franeker and Bell 1988; Van Franeker and Williams 1992; Van Franeker and Ter Braak 1993; Van Franeker 1994a, 1994c) and since 1996 an annual CEMP research program has been conducted in an Australian-Dutch cooperative project.

Murray and Luders (1990) also mention a small third colony in the vicinity of Casey station, detected in January 1974 on the northern side of Nelly Island, one of the nearby Frazier Islands (66°14'S, 110°10'E). Nesting here was also observed by E. J. Woehler in December 1989, estimating numbers at 50 to 100 pairs maximum.

Finally, Orton (1968) refers to seven nests of Antarctic Petrels on Lewis Island (66°08'S, 134°22'E) seen by station personnel servicing a weather station. From ANARE logbooks, Woehler and Johnstone (1991) estimated a maximum of 25 breeding pairs on this island.

Terre Adélie

Not breeding (Cendron 1953; Jouventin *et al.* 1984; Thomas 1986).

King George V Land

Although known since the Australasian Antarctic Expedition of 1911-1914 (Mawson 1915; Falla 1937), later visits (Cendron 1953; Isenmann *et al.* 1969) have not resulted in more accurate estimates for the number of Antarctic Petrels in the colony at Cape Hunter (66°58'S, 142°20'E). All sources indicate "thousands" of nests or breeding pairs as a general impression, but no thorough censuses have been conducted.

Victoria Land including Oates Land

This region comprises the Transantarctic Mountains along the western side of Ross Sea, and includes Balleny, Ross, Beaufort, and Franklin Islands. The status of Antarctic Petrels in this huge area with extensive mountain ranges is still very uncertain. There are no confirmed records of breeding.

Rumors of breeding have been strongest for the Balleny Islands (66°35'S, 162°15'E). Dawson *et al.* (1965) mentioned a small number of Antarctic Petrels on Sabrina Island on 9 and 10 March 1964, but stated that there was no evidence of breeding, but in the second week of March chicks have usually fledged and adults are not attending colonies (Van Franeker 1994a). Darby (1970) mentioned 'many' Antarctic Petrels on ledges of Sabrina Island in late February 1968 but made only distant observations from sea. Robertson *et al.* (1980) saw no Antarctic Petrels during several landings on Sabrina (and other Balleny Islands) in late January and early February 1965, 1973 and 1978 and suggest that Darby's observations would probably be of Cape Petrels (*Daption capense*). We conclude that at present there is no evidence for breeding on the Balleny Islands. Unfortunately, Harper *et al.* (1984) also quote Robertson *et al.* (1980) but confusingly list the Balleny Islands both as an unknown/questionable site, as well as a known breeding locality (cf. Tables 1 and 4 in Harper *et al.* 1984).

Harper *et al.* (1984: Table 1) also suggest that possibly Scott Island (67°24'S, 179°55'E) is "occupied opportunistically" by breeding Antarctic Petrels: Del Hoyo *et al.* (1992) thus show it as a breeding location. Wilson and Harper (1996) observed one Antarctic Petrel alighting on a ledge in January 1982, but breeding was not confirmed and the highly eroded cliffs were considered to provide few secure nest sites. K.-J. Wilson (*in litt.*) expressed the view that Antarctic Petrels breed on Scott Island in very low numbers. However, from the description of the island ("a very small volcanic remnant subject to high seas and severe marine erosion"), the very few actual observations of birds near the cliffs even in early January, and the fact that there is no such thing as "opportunistic breeding" in fulmarine petrels, we conclude that at present there is no conclusive evidence for breeding of Antarctic Petrels on Scott Island.

Finally, possible breeding of Antarctic Petrels has been suggested for Cape Adare (71°18'S, 170°09'E). From massive movements of Antarctic Petrels along Ridley Beach during a windy day on 29 January 1961, Reid (1962) suggested that the species might nest at the head of the bay. However, there are no other records to support this. Murphy (1936) quotes observers at Cape Adare mentioning large groups of Antarctic Petrels at high altitude and 'flying southwards toward their breeding grounds' from November onwards. Although such observations could indeed indicate the existence of colonies in the Transantarctic Mountains of Victoria Land, inland records, even of birds flying past, seem to be lacking completely (Ricker 1964; Harper *et al.* 1984).

Edward VII Land

Siple and Lindsey (1937) mentioned Mt. Helen Washington, in the Rockefeller Mountains (78°06'S, 154°48'W) as a 'likely' nesting place because a large mixed flock of Snow and Antarctic Petrels was seen circling the mountain on 19 December 1934. However, a search all the way to the top only revealed nests of Snow Petrels but not of Antarctic Petrels. Since Broady *et al.* (1989) could not find any nests either, the existence of a colony on this location seems very un-

likely. This leaves the colony on the nearby Mount Paterson, Rockefeller Mountains (78°02'S, 154°36'W) as the only known breeding location in the area (Perkins 1945; Friedmann 1945) which was censused at about 10,000 nests by Broady *et al.* (1989) on 29 December 1987.

Marie Byrd Land

An observation of two birds flying over the Fosdick Mountains (Peak 5204; 76°S, 145°W) by Perkins (1945) seems to be the only inland record of Antarctic Petrels in Marie Byrd Land.

Ellsworth Land

Antarctic Petrels are not known to breed in the mountain ranges of Ellsworth Land. Although Tomo (1973) shows photographs of large aggregations of Antarctic Petrels on icebergs stranded along Peter I Island (68°50'S, 90°35'W), Antarctic Petrels are not known to breed on the island (Holgersen 1959; Tomo 1973; Mehlum 1986).

Antarctic Peninsula (Graham Land and Palmer Land) and associated islands

There are no known breeding locations of Antarctic Petrels is this area. Murphy (1936: 232) listed Antarctic Petrels as 'known to breed in the Antarctic archipelago' (western peninsula and the islands). However, in his detailed species account (pp. 638-640) there are no sources with confirmed breeding records anywhere in the area but only listings of non-breeding observations, in particular near Alexander Island.

Killingbeck (1962) reported for Adelaide Island (67°15'S, 68°30W) that although no nests had been found, it was possible that Antarctic Petrels were nesting (in October 1962 hundreds were seen moving southeast, and a group that landed showed courting characteristics). Given the extent of visits to the area since 1962, without positive reports, it must be very unlikely that they do breed on the island itself (Croxall *et al.* 1984; Croxall *in litt.*). However, migration to inland mountain ranges or across the Antarctic Peninsula to its eastern shores would not be a problem for the Antarctic Petrel. Also Arctic Terns are supposed to migrate across the peninsula south of Adelaide Island (Gudmundsson *et al.* 1992).

DISTRIBUTION AND NUMBERS AT SEA

A wide array of literature and compilations by Watson *et al.* (1971), Marchant and Higgins (1990), and Del Hoyo *et al.* (1992) show that the Antarctic Petrel is truly a seabird of the high Antarctic. Its close association with sea ice and cold water-masses with icebergs has been documented frequently and, throughout the year, most birds remain well south of the Polar Front Zone (for example: Ainley *et al.* 1984, 1994; Bretagnolle and Thomas 1990; Erickson *et al.* 1972; Griffiths 1983; Ryan and Cooper 1989; Van Franeker 1996; Woehler *et al.* 1990). Observations north of the Polar Front to subantarctic islands and continental shores are rare in spite of a considerable number of publications (for example: Barlow 1979; Brown *et al.* 1982; Chadwick 1991; Johnson 1965; Meeth and Meeth 1977; Murphy 1936; Powesland 1986; Ryan *et al.* 1989; Sinclair 1981; Watson *et al.* 1971; Woods 1988).

The publications mentioned above and many others (for example: Abrams 1985; Cline *et al.* 1969; Cooper and Woehler 1994; Heinemann *et al.* 1989; Hunt *et al.* 1990, 1994; Joiris 1991; Kock and Reinsch 1978; Mochizuki and Kasuga 1985; Montague 1988; Plötz *et al.* 1991; Starck 1985; Thurston 1982; Van Franeker 1992; Van Franeker *et al.* 1997; Veit and Hunt 1991; Wanless and Harris 1988; Zink 1981a, 1981b) supply further details on main areas of occurrence, but methodological and seasonal differences prevent full integration of all these data.

For three areas, attempts have been made to quantify regional population sizes of Antarctic Petrels from extensive censuses conducted at sea.

Ross Sea

In the Ross Sea area (170°E, 160°W), Ainley *et al.* (1984) estimated that 3.9 million *individual* Antarctic Petrels were present at sea. This figure has been regularly misquoted as

3.9 million *pairs* in the Ross Sea sector (Marchant and Higgins 1990; Del Hoyo *et al.* 1992). However, taking into account nest-attendance of breeders and proportions of non-breeding immatures, Ainley *et al.* (1984) estimated that their observations represented a total of 5.1 million Antarctic Petrels in the Ross Sea population and a breeding population of 1,960,500 pairs (Table 17, page 80). They suspected that all these birds would have originated from populations in Marie Byrd and King Edward VII Lands.

Prydz Bay

Seabird counts made in the Prydz Bay area (58°E to 90°E; Mac. Robertson and Princess Elizabeth Land) were analyzed by Woehler (1995, 1997 and unpublished data). Annual geometric means for total numbers at sea during the summers between 1980/81 and 1992/93 vary considerably and average 1.7 ± 1.5 million Antarctic Petrels. Maximum numbers were observed in summer 1989, indicating over five million individuals at sea. Applying similar ratios as in Ainley *et al.* (1984), this would represent a total maximum population of about 6.5 million individuals and 2.5 million breeding pairs. In relation to this Prydz Bay estimate, Veit and Hunt (1991) reported a large flock estimated at one million Antarctic Petrels feeding on krill swarms offshore from the Mount Biscoe area (Enderby Land, 51°E-53°E) on 8 February 1983. This area, where Falla (1937) already reported "large flocks" of Antarctic Petrels, is actually somewhat west of the area censused by Woehler. Within Prydz Bay, Woehler (unpublished) observed another large flock of about a quarter of a million birds roosting on an iceberg in February 1993. Relatively small shifts in distribution of such birds in large flocks could thus contribute to the interannual variability in Prydz Bay estimates, supporting the use of Woehler's 1989 maximum figure rather than the average for Prydz Bay in a somewhat wider geographical sense.

Weddell Sea

Van Franeker (1996) used counts from the Weddell Sea to estimate Antarctic Petrel numbers in the Dronning Maud Land and Coats Land populations. Distribution patterns and densities at sea in pre-breeding periods suggest a total population in the eastern Weddell Sea and western Haakon VII Sea (25°W, 25°E) on the order of five million individuals, of which at least three million (1.5 million "pairs") attended colonies.

Circum-Antarctic Pattern

To check whether these regional areas reflect 'hotspots' or averages in a more uniform circum-Antarctic distribution, a number of comparable datasets (Ainley *et al.* 1984; Erickson *et al.* 1972; van Franeker 1996; Veit and Hunt 1991) have been combined into one graph of circum-Antarctic densities of the Antarctic Petrel (Fig. 1a; solid lines). These datasets were selected because their common denominator is that they represent quantitative longitudinal surveys following the preferred habitat of Antarctic Petrels in or near the marginal ice zone or the shelf front. Although the different density data should not be compared in detail (methodological and seasonal variation), the emerging pattern of Antarctic Petrel densities at sea shows some important features. Firstly, when going eastward from the Antarctic Peninsula to the Ross Sea, the at-sea densities for the eastern Weddell Sea, Prydz Bay and Ross Sea areas seem to confirm the existence of three discrete centers of pelagic distribution with relatively minor bird concentrations in between. For the first two areas, the distinct at-sea populations coincide with the location of large, known breeding concentrations in Dronning Maud Land and in Enderby and Mac. Robertson Lands. Breeding locations of sizes matching the at-sea population are not known for the Ross Sea population. Going further east, an apparent fourth concentration of Antarctic Petrels is present in the Amundsen and Bellingshausen seas with densities similar to those off Dronning Maud Land. There is no 'at-sea' estimate for this discrete regional population off western Antarctica, and its occurrence does not match the location of any known breeding colonies.

The pattern emerging from these different studies was recently confirmed (Gavrilo 1997a, b, unpubl.) by observations from a complete Antarctic circumnavigation during December 1996-January 1997. Preliminary analyses of Antarctic Petrel records, available as number of birds in transect per nautical mile (Fig. 1a; dotted line) show highest concentrations of birds around the Prydz Bay area, with numbers gradually decreasing eastwards to the Ross Sea. Distinct concentrations were also visible in eastern Weddell Sea and Amundsen/Bellingshausen seas. A separate Ross Sea concentration was less clear from the data, but this is probably due to the fact that the ship followed a track far south in the interior Ross Sea, whereas Ainley *et al.* (1984) found the Antarctic Petrels concentrated further north near the shelf edge.

DISCUSSION

Currently, 35 Antarctic Petrel colonies are known, almost all on nunataks and coastal outcrops in eastern Antarctica. The total number of breeding pairs known from these colonies is on the order of half a million of pairs. However, at-sea estimates of Antarctic Petrels suggest much larger populations. Numbers estimated in three hotspot areas (eastern Weddell Sea, Prydz Bay, Ross Sea) add up to roughly 16 million individuals representing approximately six million breeding pairs. Part of the at-sea counts were based on methods from the BIOMASS Working Party on Bird Ecology (1984, 1992), which could result in overestimates of birds in flight up to a factor of two (van Franeker 1994b). On the other hand, many authors of at-sea counts believe their estimates to be conservative because large concentrations of Antarctic Petrels resting on icebergs are often not included. Nevertheless, even when assuming maximum bias with a 100% overestimate, the above figures still represent eight million birds or three million breeding pairs. No regional at-sea population estimate is available for the fourth major center of pelagic distribution which probably exists in the Amundsen and Bellingshausen seas. Addition of bird numbers in this fourth area plus those in low-density areas all around the Antarctic would increase the total estimate derived from at-sea counts to the order of ten to 20 million individuals or four to seven million breeding pairs (the lower limit assumes a strong bias in methods; the upper limit is based on actual at-sea estimates). Limitations in methodology and interpretation of at-sea censuses require caution in the use of these estimates, but the difference with colony-derived estimates is overwhelming.

Thus, it is very likely that major breeding colonies of the Antarctic Petrel still have to be discovered, particularly in western Antarctica (Marie Byrd Land to Palmer Land) and also in Victoria Land. Patterns of distribution in areas such as Dronning Maud Land and Prydz Bay, where large colonies can be linked to bird concentrations at sea 'nearby', suggest that the Antarctic Petrels in the Ross, Amundsen and Bellingshausen Seas are also likely to have breeding locations in the area. The possibility that these groups contained non-breeding immatures almost exclusively was disproven for the Ross Sea at least (Ainley *et al.* 1984). Southward-moving flocks of Antarctic Petrels during October and November over locations such as Adelaide Island and Cape Adare support the possible existence of colonies in western Antarctica and Victoria Land. Along with further ornithological field surveys, advancements in technology such as high-resolution satellite images or application of small satellite tracking devices may assist future discovery of new colonies.

Even in the better known areas in eastern Antarctica, there is still plenty of opportunity for further discoveries of breeding sites and improved size-estimates for the ones that are already known. In particular, comparison of the at-sea densities off Dronning Maud Land with those off Enderby and Mac. Robertson lands suggest that the colonies of Mount Biscoe and Scullin and Murray Monoliths may be very much larger than currently believed.

Future colony estimates are best made in the early breeding phase, from the last days of November to early January. Since virtually all adult birds desert colonies during late January and breeding success is extremely variable (and often low), counts after this

date based on chick numbers may be extremely deceptive (see discussion for Scullin Monolith and notes on differences between 'early' and 'late' counts in various other locations). Proper estimates of numbers of breeding pairs in at least several of the larger colonies are crucial as a baseline to assess future population change and the potential influence of human activities. Initial suggestions for standard monitoring methods in the CCAMLR Ecosystem Monitoring Program were compiled by Mehlum and van Franeker (1995). Although most Antarctic Petrel colonies are in places where there is little concern for direct human disturbance, the potential impacts of climatic change and exploitation of krill and fish stocks need to be monitored to allow adequate conservation and management strategies.

REQUEST

The SCAR Bird Biology Subcommittee endeavors to improve knowledge on the distribution and population size of the Antarctic Petrel. This review demonstrated the existence of major gaps in such knowledge. To allow future updates of this status review, please forward any relevant information, old or new, to the first author (personal observations, travel-reports, reprints of papers, etc. on both inland and at-sea distributions).

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