Census of breeding Antarctic Petrels *Thalassoica antarctica* and physical features of the breeding colony at Svarthamaren, Dronning Maud Land, with notes on breeding Snow Petrels *Pagodroma nivea* and South Polar Skuas *Catharacta maccormicki**

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Only about a dozen breeding colonies of the Antarctic Petrel *Thalassoica antarctica* are known, all confined to the Antarctic continent. In 1985 one of the largest colonies, situated in Mühlig-Hofmannfjella, Dronning Maud Land, c. 200 km from the open sea and at an elevation of 1600 m a.s.l. was censused around the time of hatching. The colony size was estimated at about 207,000 breeding pairs. Three minor colonies were discovered at Jutulsessen, Gjelsvikfjella.

Microclimatic measurements were made to evaluate the physical environment experienced by the breeding petrels and their chicks in the hostile Antarctic climate. The temperatures measured and energy budget made for the hillside, where the colony was located, showed that the nests of the Antarctic Petrel are placed at relatively favourable places. The northeast facing slope with the Antarctic Petrel colony absorbed large quantities of shortwave radiation during the birds' breeding season and provided suitable microclimatic conditions for breeding.

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The Antarctic Petrel *Thalassoica antarctica* breeds only on the Antarctic continent and adjacent islands (Watson 1975). Brook & Beck (1972) listed 9 breeding colonies, all but two with a population size of less than 1000 birds. Later Johnstone et al. (1973) reported the discovery of breeding colonies at Rauer Islands, East Antarctica. Several colonies are in the interior of the continent, and the largest colony mentioned by Brook & Beck (1972) is in Mühlig-Hofmannfjella, Dronning Maud Land. This colony was discovered in January 1960 by Soviet geologists, who estimated about one million birds to be present (Konovalov 1962; Konovalov & Shulyatin 1964). In another colony, the one at Scullin Monolith, on the coast of MacRobertson Land, about 50 pairs bred in February 1931 (Falla 1937; Rayner 1940). However, in 1986–87 the breeding population at this colony was estimated at 157,000 pairs, while a population of 3500 pairs was recorded at the nearby situated Murray Monolith (Alonso 1987).

During the Norwegian Antarctic Research Expedition (1984/85) we visited the colony in Mühlig-Hofmannfjella and nearby mountains. With sub-zero ambient temperatures all the year round the interior of the Antarctic Continent is one of the most hostile breeding bird habitats in the world. Even so a few seabird species breed there. In this paper we report the results of a

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census of breeding Antarctic Petrels in this area, and describe the physical characteristics of the breeding sites. In order to characterize the climatic conditions for breeding in the interior of the Antarctic Continent, radiation and energy exchange between the air and the ground, both in the snow free colony of petrels and at the glacier located below, are described in detail.

Methods

The location of the colony reported by Konovalov & Shulyatin (1964) is questionable, because the photograph presented in their paper actually shows the mountain Svarthamaren (at 71°53′S, 5°10′E), situated 200 km from the open sea at an elevation of 1600 m a.s.l. (Fig. 1 and 2). This contradicts their positioning of the colony at 4°E. Our visit to the area confirmed the colony to be located at Svarthamaren.

The Svarthamaren area was visited 11 January–15 February 1985. Other members of the expedition surveyed larger areas in Mühlig-Hofmannfjella and Gjelsvikfjella (5°20′E to 1°37′W). Their records of birds are also included here.

Census method

The Svarthamaren colony of Antarctic Petrels was censused 20–21 January, coinciding with the main hatching period. The Antarctic Petrel, like most other large procellariiforms, is a surface nester, and the nest is placed directly on the ground. The number of nest sites with birds apparently incubating or brooding chicks and the number of individuals not associated with a site or chicks were counted in 96 study plots, each 3 × 3 m. The plots were regularly distributed along four lines (two crossing lines forming an × in each of the two main sub-colonies) running from the bottom to the top of the colony. Colour photographs of the area were taken with a Pentax 6 × 7 camera to make a three-dimensional model of the mountain slope. Fixed points and terrestrial photogrammetric stations were measured by the expedition's topographers. On the basis of these data a map of the colony was compiled and the total area occupied by birds computed.

Microclimatic measurements

The following microclimatic parameters were monitored for a 2–5 week period in the Svarthamaren area using Aanderaa data loggers: incoming shortwave radiation, longwave atmospheric radiation, albedo, surface temperature, wind velocity and humidity. Shortwave and total radiation were measured with Moll-Gorczynski solarimeters and radiometers (type Simen Ersking), respectively. Humidity was measured manually using a psychrometer. Measurements were taken at our camp on the snow covered glacier below the mountain slope and above the horizontal surface of a flat stone block, measuring 6 × 8 m. Measurements were also taken in the colony on the NE slope of Svarthamaren as were soil temperatures at 2 mm, 0.13 m, 0.25 m and air temperature 1.5 m above the ground. The temperature 2 mm below ground surface was measured at three locations near a 0.5 m high stone block, one sheltered from solar radiation from the north, the other sheltered from the south and the third completely exposed. The measure-

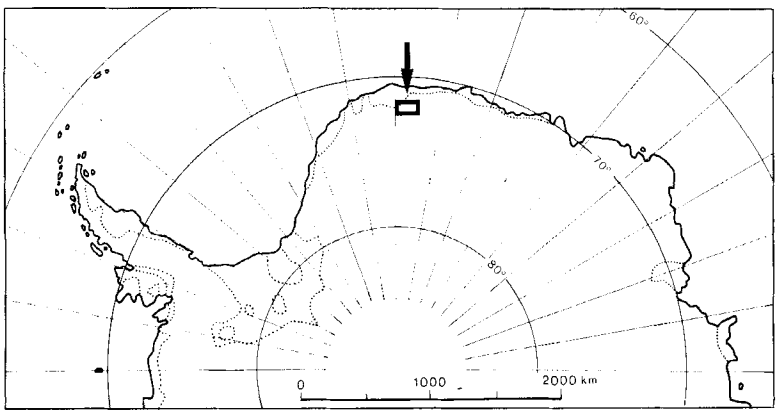

Fig. 1. The location of the investigated mountain ranges (Mühlig-Hofmannfjella and Gjelsvikfjella) in Dronning Maud Land, Antarctica.

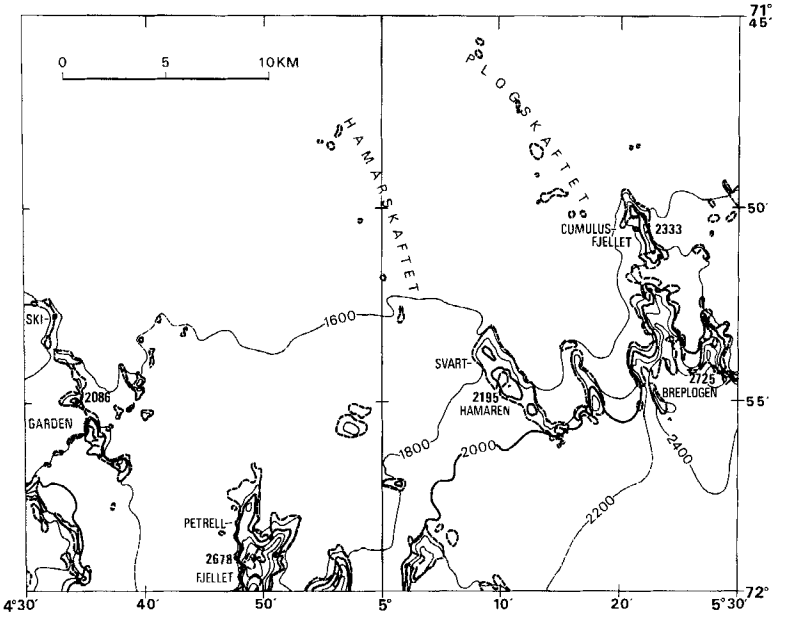

Fig. 2. Map of Svarthamaren and surrounding mountains in Mühlig-Hofmannfjella. Dashed lines indicate areas of bare rock.

ments in the slope were taken every 15 minutes during a 30 day period beginning on 15 January. Hourly values presented are means of four recordings. The sensors were platina resistance elements and the active part was approximately 1 mm.

To compare the ambient air temperatures experienced by the open nesting Antarctic Petrels and the crevice-nesting Snow Petrel *Pagodroma nivea*, recordings were also made in an occupied Snow Petrel nest crevice. A thermistor connected to a Grant recorder was placed directly on the gravel surface inside the crevice, about 10 cm from the opening and 15 cm in front of the incubating bird. Measurements were made every 15 minutes for six days (25–30 January). Means of four successive values were used as hourly mean temperatures.

Area description – Svarthamaren

Topography

The Svarthamaren mountain (Fig. 3) is about 6 km long in the SE–NW direction, the highest point being 2195 m a.s.l. The northern part of the NE side is dominated by screes, reaching 240 m upwards from the base of the mountain. The slopes are covered by stone blocks and decomposed feldspathic sand (Y. Ohta pers. comm.). Above these screes, sloping 31–34 degrees, the rock is almost vertical. Beneath the slopes is a narrow area of flat ground bordered by glacier ice. The major features of this side are two 'amphitheatres' inhabited by the breeding Antarctic Petrels.

Vegetation

The flora and vegetation at Svarthamaren are sparse (Engelskjøn 1986), even when compared with other areas in Mühlig-Hofmannfjella and

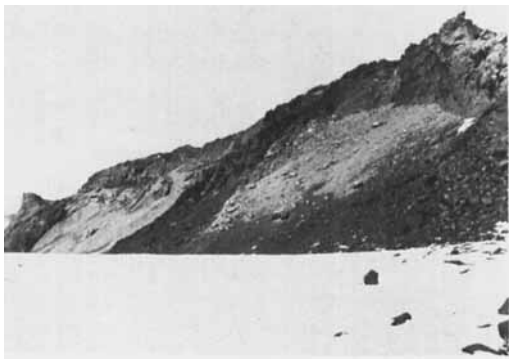

Fig. 3. The mountain Svarthamaren as seen from the northwest. The light areas in the hillside show the extent of the Antarctic Petrel colony.

Gjelsvikfjella. This is apparently due to the considerable elevation of Svarthamaren, the prevailing shortage of meltwater and the excess fertilization from the bird colony. The only abundant plant species is the foliose terrestrial green alga, *Prasiola crispa*, which occurs round the edge of the colony. Mühlig-Hofmannfjella have a fairly rich cyanophycean and lichenous vegetation, but in the Svarthamaren area only a few lichen species are found on erratics 1–2 km away from the bird colonies.

Climate

At Svarthamaren the sun is under the horizon for 2½ months during mid-winter and above the horizon from 15 November to 27 January during the austral summer. The Antarctic Petrel colony is sheltered against direct sunlight from the NE for 6–7 hours each day during mid-summer. Being so far inland the area is only slightly affected by the cyclones that buffet the coast. The climate is therefore little influenced by heat advected from the ocean, and radiation from the sun and the atmosphere is the main energy source. There is a close relationship between snow temperature at 10 m depth and the mean annual temperature 2 m above the snow surface (Loewe 1970). Measurements of snow temperature in the Mühlig-Hofmannfjella area at 10 m depth indicate a mean annual air temperature of −26°C.

Results

Census of colonies

The Svarthamaren Antarctic Petrel colony consists of two sub-colonies (Fig. 3). The northernmost covered an area of 63,166 m^2 (mean slope 31.3 degrees). The largest sub-colony covered 209,834 m^2 (mean slope 34.5 degrees). The total breeding area thus covered 273,000 m^2. The smallest sub-colony was situated in the eastern and central part of the outermost 'amphitheatre', while the largest comprised both the innermost 'amphitheatre', some plateaus above this and a smaller scree further to the east.

Fig. 4. The newly discovered Antarctic Petrel (hatched areas) and South Polar Skua breeding areas (solid lines) at Jutulsessen, Gjelsvikfjella. Photograph taken from the west.

From the counts of incubating birds and chicks in the 96 sample plots the density of breeding pairs was estimated to be 0.76 ± 0.03 (mean ± SE) pairs per m^2. The frequency distribution of the number of nests in each square was not significantly different from normality ($p = 0.26$), Kolmogorov–Smirnov test), giving a total number of breeding pairs in the colony of 207,000 (±8000). The number of non-breeding fully grown individuals present was estimated to 0.59 ± 0.04 (mean ± SE) birds per m^2, giving a total of 161,000 (±11,000) non-breeders present in the colony at the time of the census.

In addition to the Antarctic Petrels about 500 pairs of Snow Petrels and 50 pairs of South Polar Skuas *Catharacta maccormicki* bred in the Svarthamaren area. Many of the Snow Petrels nested under large stone blocks within the Antarctic Petrel colony, but they seemed to prefer the parts of the screes with larger stones and more crevices round the periphery. The highest breeding density was found close to the NE base of the mountain. The skuas were confined to the narrow strip of flat ground between the glacier and the base of the slope where the Antarctic Petrels bred.

No other Antarctic Petrel colonies were recorded in Mühlig-Hofmannfjella. Two colonies were found high up in north facing slopes of Jutulsessen (3°E) in Gjelsvikfjella (Fig. 4), each in the order of 1000 pairs. The colonies were not thoroughly censused, but rough estimates were made from a distance. Another small colony was recorded further to the west (Fig. 4), but only about five abandoned nests were found. These were probably victims of predation by the approximately 50 pairs of South Polar Skuas nesting near-by. Single pairs of Snow Petrels were also found breeding in several of the nunataks in Mühlig-Hofmannfjella and Gjelsvikfjella. The species probably nests in suitable habitats all over these mountains.

Nest site description

Differently sized stones dominate the screes in which the Antarctic Petrel colony was located (Fig. 5). Nests were very often built close to and thereby in the shelter of a stone.

They were shallow scrapes (diam. 16–23 cm) in the sand or gravel, often lined with small stones or feathers and occasionally with dead petrel remains.

Flight from and to the colony

In the steep slopes the petrels had no difficulty in taking off horizontally from the nest. They then flapped with rapid wing beats to gain height, flew in circles close to the slopes and towards the northern summit of Svarthamaren. At the summit they soared to considerable heights above the mountain in an upstreaming thermal air flow before they left for the sea in flocks often numbering several hundred birds. When returning to the colony from the sea, they also appeared in flocks at great height above the mountain. They

Fig. 5. Nesting locality of Antarctic Petrels at Svarthamaren. South Polar Skuas nested at the base of the slope.

usually dropped almost vertically in the air towards the breeding colony and circled briefly above their nests before landing.

Microclimate

Radiation heat budget.—Radiation exchange at the earth's surface can be expressed as

$$(1)\quad Q_N = k - ak + L_{IN} - \sigma T_0^4 \qquad (W\,m^{-2})$$

where Q_N is net radiation, k is incoming shortwave radiation, a is the albedo of the surface, L_{IN} longwave radiation from the atmosphere, σ the Stefan-Boltzmann constant and T_0 the surface temperature in °K.

During days with clear sky the reflection of shortwave radiation from the snow surface (albedo) was about 90%, but only 17% from the horizontal rock surface and 11% from the petrel colony slope (Fig. 6). More shortwave radiation was received by the scree slope before noon than by a comparable horizontal surface. The slope surface also received shortwave radiation reflected from the adjacent snow and ice surfaces. The total amount of shortwave radiation energy received by the petrel colony slope surface totalled 37 MJ $m^{-2}day^{-1}$, and the surface temperature on gravel and stone occasionally exceeded 30°C at midday under clear and calm conditions. This led to a longwave radiation loss to the atmosphere of about 500 W m^{-2}. On overcast and windy days both the incoming shortwave and longwave radiation were reduced compared to calm and clear days.

Air and soil temperatures. – During a calm, clear

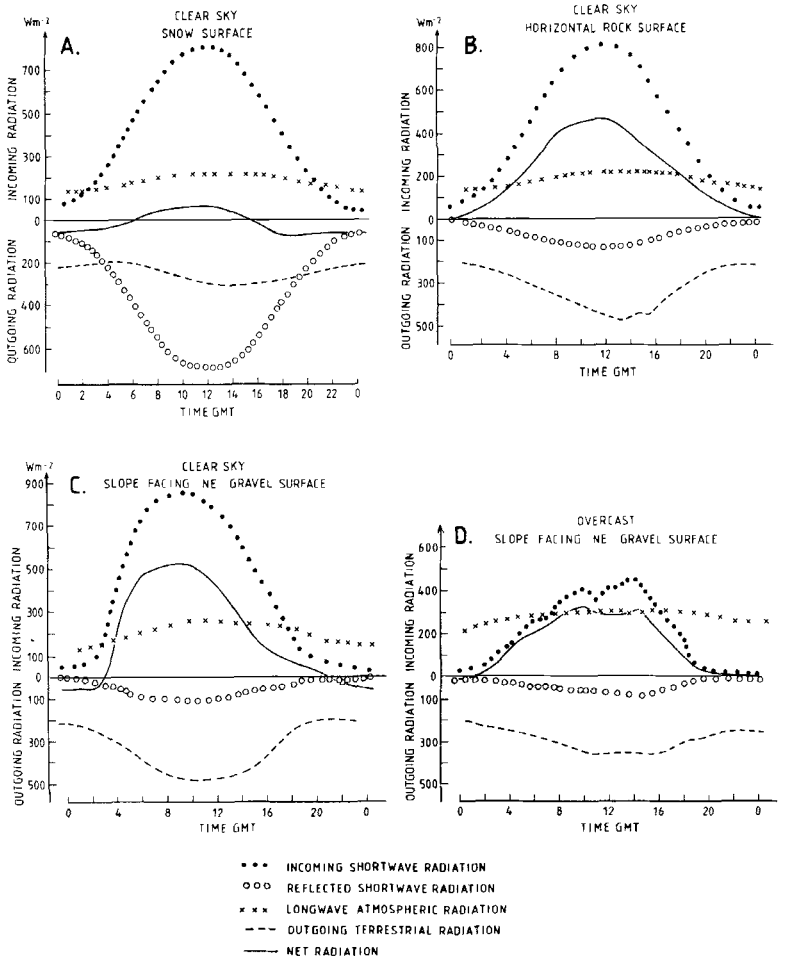

Fig. 6. Radiation budget for selected days in January 1985 at Svarthamaren. A. a horizontal snow surface (calm weather and clear sky), B. a horizontal surface of a stone block within the area of blue ice (calm weather and clear sky), C. the gravel surface of the NE facing slope in the petrel colony (calm weather and clear sky), D. same locality as in C but on an overcast and windy day.

day the air temperature reached −5°C at midday and fell to −15°C during the night when the area was affected by katabatic winds from inland (Fig. 7). Soil temperatures at depths of 0.25 and 0.13 m were constantly above 0°C with a daily range of 1.8°C and 3.7°C, respectively. Temperatures at 0.25 m depth reached a maximum c. 3 hours later than at 0.13 m and 8 hours later than at 2 mm. At 2 mm the temperature range was considerably wider and varied with respect to the degree of exposure and shade. The maximum was 13°C higher on the north side of the stoneblock than on the south side. There were steep vertical gradients in the temperature in the upper soil layer so that some of the variation 2 mm below the surface may be due to small inaccuracies in the vertical positioning of the sensor.

On a windy, overcast day (Fig. 7) the daily range and local differences were less. Nevertheless, the maximum temperature at 2 mm depth reached +10°C.

While on its nest the centre of an Antarctic Petrel's body is c. 10 cm above ground level. The actual air temperatures at this level were not measured. During the day, Svarthamaren and other nunataks represent small heat islands surrounded by cold air adjusted to the cold snow surface and not to a comparatively warm soil surface. Observations from similar investigations (Gjessing & Øvstedal 1975; Oke 1978; Kappen et al. 1981) show that this leads to very steep temperature gradients in the lowest, say 1 cm air layer, and the temperatures at c. 10 cm are only slightly different from the bulk air temperatures.

Temperature of Snow Petrel crevice. – The temperature amplitudes between night and day in the Snow Petrel nest were considerably smaller than those experienced by the surface nesting Antarctic Petrels. Over a 6-day period the air temperature in the crevice varied from −8 to −3°C during night and from −3°C to +3°C during the warmest hours of the day.

Wind and humidity. – The colony was free from snow except for short periods after light snow falls. In the northernmost 'amphitheatre', the area which was the first to lose the sun during the afternoon was still covered in snow on our arrival in mid-January, and here no petrels bred.

The air humidity rarely exceeded 50%. Except for short periods after light snow falls the soil, at least down to a depth of 0.25 m, was very dry. There was therefore little evaporation from the hillside.

The cyclones that reached the ice edge to the north only occasionally resulted in strong winds in the Svarthamaren area. However, strong southerly katabatic winds from the Antarctic plateau blew almost every evening and night, and at an icefall 2 km to the southeast of Svarthamaren reached a velocity of 6–10 m sec^{-1}. In the colony's immediate surroundings, wind velocities were about 50% less, and at ground level, where the

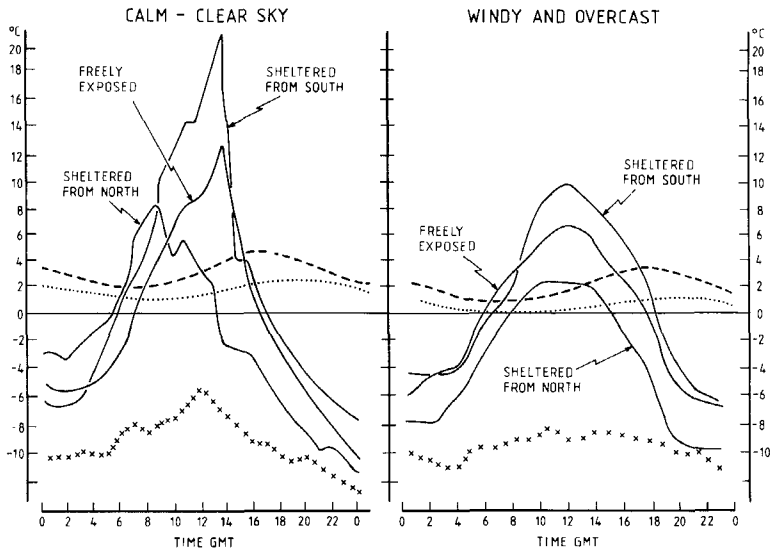

Fig. 7. Temperatures in the Svarthamaren petrel colony (15 January 1985). Measurements were taken in the air and in the soil on a calm day with clear sky and on a windy day with overcast, respectively.

×××× air temperatures 1.5 m above surface
. . . . . soil temperatures 0.25 m below surface
– – – soil temperatures 0.13 m below surface
——— soil temperatures 2 mm below surface.

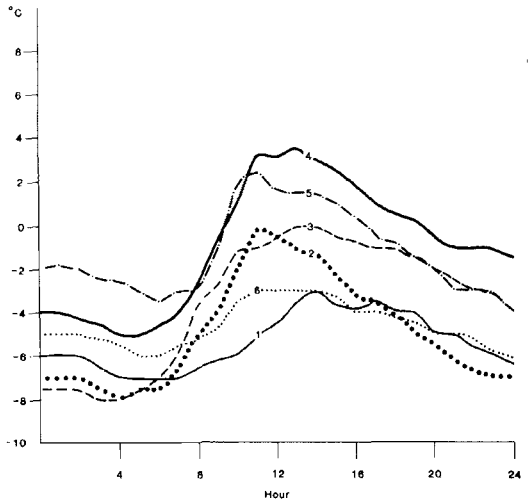

Fig. 8. Temperature changes in a Snow Petrel nest crevice during six days at the end of January (days 1–6 corresponding to 25–30 January).

petrels have their nests, the velocities were seldom more than 1–2 m sec^{-1}. Wind chilling thus probably played a minor role in the heat loss of adults and chicks in the colony.

Discussion

Although our knowledge of the distribution of breeding birds in Dronning Maud Land is incomplete, the Antarctic Petrel appears to breed at only a few localities. The Svarthamaren colony is by far the largest, but smaller colonies occur about 100 km further west, at Jutulsessen. T. Winsnes (pers. comm.) reported four breeding pairs at the mountain Pagodromen in Vestfjella (73–74°S) in 1968–69, while Sømme (1977) observed one breeding pair in the same area. No other colonies have been reported by other expeditions to the mountains of the interior of Dronning Maud Land. However, the observations in the Schirmacher Oasis of large flocks of Antarctic Petrels flying southwards towards Wohlthalmassivet (71–72°S, 12–13°E) (Richter 1983) indicate that new colonies may be discovered in the future. The colony at Svarthamaren will be seen on satellite photographs (Landsat, thematic mapper). Remote sensing may therefore be a useful tool for finding new colonies in the parts of the Antarctic Continent not yet visited by scientists.

The Snow Petrel is known to nest at many localities in several parts of Dronning Maud Land. It probably nests in suitable habitats over most of the region. In addition to our observations in Mühlig-Hofmannfjella and Gjelsvikfjella, breeding is known in Vestfjella (13–15°W) (Sømme 1977; T. Winsnes pers. comm.), Heimefrontfjella (9–13°W) (Ardus 1964; Bowra et al. 1966), Ahlmannryggen (3–4°W) (La Grange 1962; Krynauw et al. 1983), H.U. Sverdrupfjella (1°W–2°E) (Norwegian Polar Research Institute unpublished), Orvinfjella (8–10°E) (Løvenskiold 1960; T. Winsnes pers. comm.), Schirmacher Oasis (11°40'E) (Richter 1983), Sør-Rondane (23–28°E) (Autenboer 1964; K. Shiraishi pers. comm.) and the coastal areas close to the Syowa Station (39–40°E) (H. Kanda pers. comm.). Most colonies of Snow Petrels are small, but two of the Vestfjella colonies (Skuafjellet and Audunfjellet) and Svarthamaren have 500–1000 pairs.

Konovalov (1962) estimated the population of Antarctic Petrels at Svarthamaren to be 1 million. Presumably this figure included non-breeders and chicks as there is only limited amount of space for nests. Both Konovalov's and our censuses were made in January, at the end of incubation and beginning of the chick period, and the number of breeders that failed prior to the census is unknown.

Svarthamaren and other nunataks surrounding the Antarctic plateau represent the climatic limit for terrestrial life on earth. The air temperature at 1.5 m height in this northeast facing colony would rarely exceed 0°C during the incubation and chick rearing periods, while soil temperature may exceed 30°C in the middle of the day and drop to below −20°C at night. Soil temperature below approximately 0.1 m depth would probably be constantly above 0°C during most of the nesting season. More than 90% of the diurnal net radiation sum is lost to the atmosphere as sensible heat, and the transport of latent heat is insignificant. A hillside facing north and sheltered against katabatic winds might even experience higher temperatures than those at Svarthamaren. Areas of bare rock facing north at Svarthamaren on a day with a clear sky in the beginning of January will be among those areas on earth absorbing the most shortwave radiation during a 24-hour period.

The breeding adult Snow Petrels and their chicks are neither directly exposed to sunshine during daytime nor to the extreme low ground

surface temperatures at night. They are exposed to more stable temperatures (mostly sub-zero, however) and a very low wind chill.

Even if the general climate of the interior of Dronning Maud Land is hostile to birds, the petrel breeding sites at Svarthamaren have a relatively favourable microclimate. The birds take advantage of the intense solar radiation during daytime and the relatively high air temperatures and the low wind speed at ground level on the slopes. In fact, overheating is sometimes a problem in both adults and chicks on warm days, as could be seen from their panting behaviour. Similar behaviour is recorded in Adelie Penguins *Pygoscelis adeliae* (Yeates 1968).

Due to the relatively favourable microclimate at Svarthamaren during the incubation and brooding periods, the Antarctic Petrels and the Snow Petrels were evidently not seriously constrained by energetic demands due to cold. Chicks, when left alone in their nest, have the thermoregulatory capacity to cope with sub-zero ambient temperatures (Bech et al. 1988, unpublished).

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