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Broadscale patterns in the distribution of aquatic and terrestrial vegetation at three ice-free regions on Ross Island, Antarctica

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Key words: Antarctica, vegetation, ecology, aquatic, terrestrial

Abstract

Distribution patterns are presented for selected aquatic algae, and terrestrial algae, mosses and lichens, at three large, coastal ice-free regions on Ross Island. Each region is unique in certain aspects of its vegetation. The variation in areal and quantitative occurrence of different components of the vegetation in diverse ponds and streams, and over exposed ground surfaces, is related to the levels of marine salts in the environment, fertilisation by birds, water availability, substratum type and degree of exposure. A comparison is made with other antarctic, coastal, ice-free regions where similar broadscale patterns have been recognised.

Introduction

The purpose of this investigation was to compare broadscale patterns in the distribution of macroscopic and selected microscopic vegetation at three large, coastal, ice-free regions in the vicinity of Cape Bird, C. Royds and C. Crozier on Ross Island. The survey included terrestrial algae, lichens and mosses, and aquatic algae in ponds and streams. Much of the terrestrial vegetation could be termed 'semi-aquatic' as it was usually flushed with percolations of meltwater for periods during summer. No attempt was made to compile complete species lists.

Similar data has been collected at other ice-free regions in the Continental Antarctic Zone (sensu Pickard & Seppelt, 1984), for instance the Vestfold Hills (68° 35' S, 77° 58' E; Broady, 1986; Pickard, 1986; Seppelt, 1986a, b), Mawson Rock (67° 26′ S, 62° 53′ E; Seppelt & Ashton, 1978; Broady, 1982a) and East Ongul Island (69° S, 39° 30′ E; Matsuda, 1968; Karasawa & Fukushima, 1977; Nakanishi, 1977). As in the present study, the influence of salt on the distribution of vegetation was noted to be marked, together with effects due to water and nutrient availability. On Ross Island there are distinct contrasts in the environment and vegetation at each ice-free region which allows further insight into the factors controlling distribution. The broadscale, descriptive data also provides a foundation, and direction, for the development of more detailed ecological and physiological investigations.

Botanical investigations have been made previously at the three study areas. Algae at Cape Royds were first described by West & West (1911), and Fukushima (1964) reported further on the diatoms. Goldman *et al.* (1972) made brief observations on pond and lake algae and Holm-Hansen (1964) cultured algae from ponds and soils. The nutrient physiology of algae in ponds at

C. Bird and C. Royds was studied by Vincent & Vincent (1982), and Howard-Williams *et al.* (1986) examined the characteristics of a stream at C. Bird. Observations on algae in four ponds at C. Bird were provided by Zaneweld (1969) and in a single pond by Spurr (1975). Mosses have been described from Ross Island (Greene, 1967) and Dodge (1973) included lichen records from C. Crozier and C. Royds. Longton (1973) described terrestrial plant communities at C. Royds and C. Bird but did not investigate broad-scale distribution patterns.

Study sites

C. Bird and C. Royds are on the west coast and C. Crozier is at the eastern extremity of Ross Island (Fig. 1). The extent of ice-free land at each locality approximates 15, 13 and 18 km^2 respectively. They have received little human disturbance, in contrast to the next largest ice-free area at C. Armitage which has been considerably perturbed by station activities. There are a small number of other coastal rock outcrops, all smaller in extent than C. Evans which covers about 1 km^2.

The general topography of each area is shown in Fig. 2. In the absence of published contour maps of C. Bird and C. Crozier, the landform features shown are from sketch maps made in the field with the aid of an aneroid barometer. C. Bird is bounded to the east by the edge of the Mt. Bird ice-cap and, except for five or six prominent hills, slopes down to the coast. Similarly, C. Royds slopes in a generally westerly direction and the eastern boundary comprises the snow and ice-fields below Mt. Erebus. In contrast, C. Crozier comprises the lower, generally easterly-facing slopes of Mt. Terror. The approximate boundaries of ice-fields and major snowfields and snowdrifts which persist throughout summer are displayed in Fig. 3.

Adélie penguin rookeries are located at all three areas. At C. Bird, the three rookeries, Northern, Middle and Southern Rookery, have approximately 25000, 1700 and 9600 breeding pairs respectively; at C. Royds there are 2000 and at C. Crozier 168000 pairs (Harper *et al.*, 1984; R. Taylor & P. Wilson, DSIR pers. comm.). There

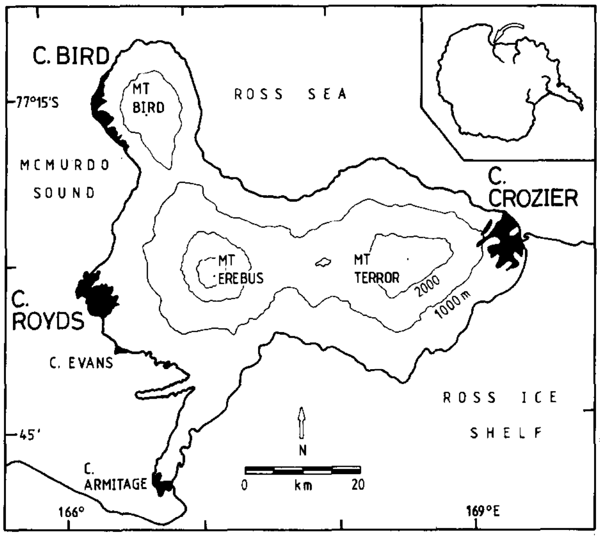


Fig. 1. Ross Island showing the location and approximate extent of the three major ice-free regions at Cape Bird, Cape Royds and Cape Crozier, together with other important features and contour lines at 1 000 m intervals. Inset, location of Ross Island.

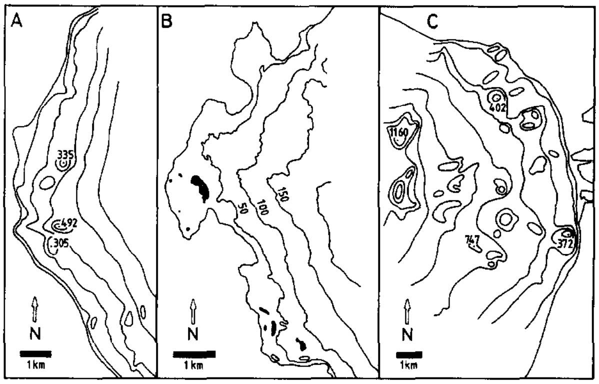


Fig. 2. Topography at A, Cape Bird; B, C. Royds and C, C. Crozier. C. Royds shows 50 m contours; C. Bird and C. Crozier show approximate form lines from field sketches. Spot heights are in metres. Lakes at C. Royds are shaded. Bases for maps are taken from: C. Bird, N.Z.M.S. 175/4, 1 : 25000, 1961 and Ross Island, Antarctica, U.S. Geological Survey, 1 : 250000 Reconnaissance Series, 1970; C. Royds and C. Barne, N.Z. Lands and Survey, 37/108, 1 : 10000, 1982; C. Crozier, N.Z.M.S. 175/16, 1:50000, 1962.

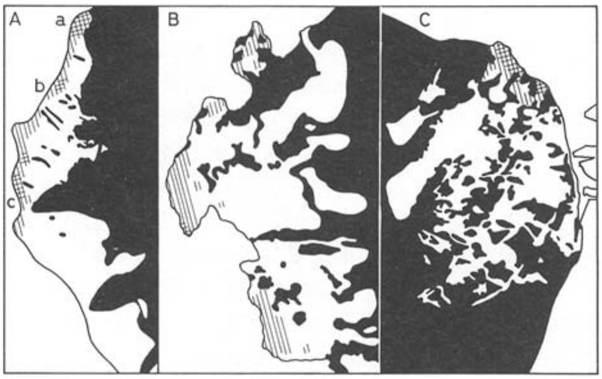


Fig. 3. Extent of permanent snow and ice-fields and locations of bird colonies at: A, Cape Bird; B, C. Royds; C, C. Crozier. Key: block-shaded areas are major snow and ice-fields; single hatching, skua nesting areas; cross-hatching, penguin rookeries; a, b, and c, locate Northern, Middle and Southern Rookery respectively at C. Bird.

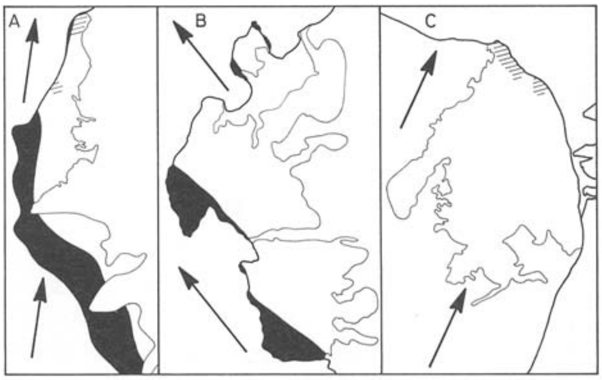
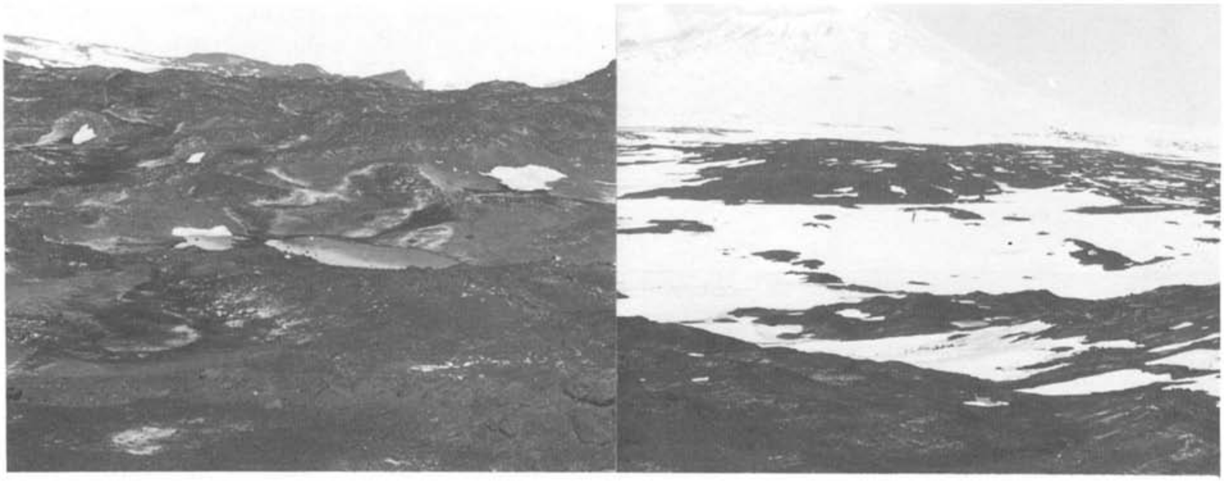


Fig. 6. Approximate directions of prevailing strong winds (arrows) and approximate areas of ground over which sea-spray is deposited (block-shaded) due to wind action on areas of open water at A, Cape Bird; B, C. Royds and C, C. Crozier. Line shading indicates areas of high salt levels due to bird concentrations. Fine lines enclose the major extent of ice-free ground (simplified from Fig. 3 and shown also in Figs 5, 6, 13–23).

are also substantial populations of skuas, breeding pairs being estimated as 399, 183 and 1000 at C. Bird, Royds and Crozier respectively (Ainley *et al.*, 1986).

There are high salt concentrations in a proportion of the soils and aquatic habitats. A comparison of heavily salt-affected, and relatively salt-free areas at C. Royds are shown in Figs. 4 and 5. Close to the coast the salts are largely derived from sea-spray blown during high winds across areas of land immediately downwind of open water (Fig. 6). Wind direction was inferred from snowdrift orientation in the lee of hills and from meteorological observations during the



Figs. 4-5. A comparison of two areas at Cape Royds. Fig. 4 (left). Ground which receives windblown sea-spray. The white stains are salt crusts on rock and soil surfaces. The large pond is approximately 20 m long. Fig. 5 (right). Extensively snow-drifted ground on the lower slopes of Mt. Erebus (3270 m). The area beyond the frozen lake (Blue Lake) does not receive windblown sea-spray.

survey. These are in close agreement with earlier wind observations made by Simpson (1919). Evidence of sea-spray deposition was provided by a greatly increased incidence of white salt crusts on the surfaces of rocks and soils and in the generally increased salinities of pondwaters (Fig. 7). Salts of marine origin have been shown to be quantitatively most important in the McMurdo region, with lessening influences with increasing elevation and distance inland (Keys & Williams, 1981). Marine salts are also transferred to land by birds, in their faeces and excretions. This effect would be most marked in penguin rookeries.

Methods

Observations were made over one period of three to four weeks at each region during the summers of 1982-83 and 1984-85. Extensive notes were made describing the location and abundance of vegetation during traverses on foot over the large majority of each region. Traverse routes were varied in order to cover as wide an area as possible. Locations were plotted on large scale maps. These records were transformed into presence and absence date within 0.5 by 0.5 km squares of a grid covering each region. This has inevitably resulted in some loss of resolution, particularly at boundaries of vegetation change, but is adequate for demonstrating broadscale patterns.

At C. Royds and C. Crozier the conductivity of water in streams and ponds was measured using a Model 33 S-C-T meter (Yellow Springs Instument Co.) and at C. Bird salinity was assessed by taste. Samples of algae were removed for microscopic examination using light microscopy.

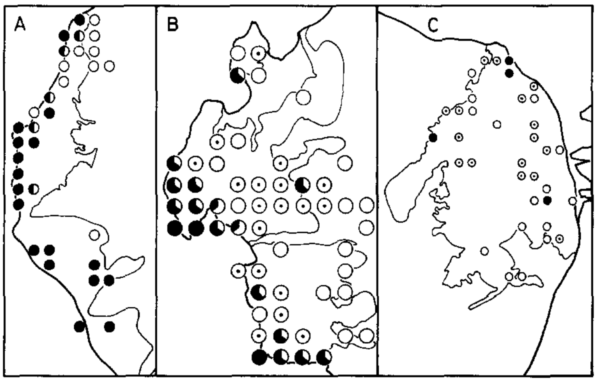


Fig. 7. Pond water taste and conductivity at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence of ponds in 0.5 by 0.5 km grid squares: C. Bird, taste of water in all ponds in each square, ○ fresh taste; ● brackish to saline; ◐ both categories; C. Royds and C. Crozier, conductivity (mSm^{-1}) of all ponds in each square; ○ < 50; ⊙ < 300; ◐ ○ to >300; ◐ 50 to >300; ● > 300.

Results and discussion

Algae, lichens and mosses were found at all three regions in a wide range of aquatic and terrestrial habitats. However, the frequency of occurrence and abundance of different communities contrasted markedly from region to region. The broad distribution patterns in ponds and streams and over exposed ground are described below, together with discussion of controlling factors and results of studies elsewhere. Algae included in this account are those forming macroscopic growths visible to the unaided eye and species which, although not growing in such abundance, are characteristic of certain habitats. A systematic list of these algae is presented in Table 1 together with a summary of the habitats in which they were found.

Algae in ponds

Pond types

Four distinctly different categories of ponds were recognised on the basis of the nature of their catchments. Their distribution within the ice-free regions is shown in Fig. 8. and examples illustrated in Figs. 9–14.

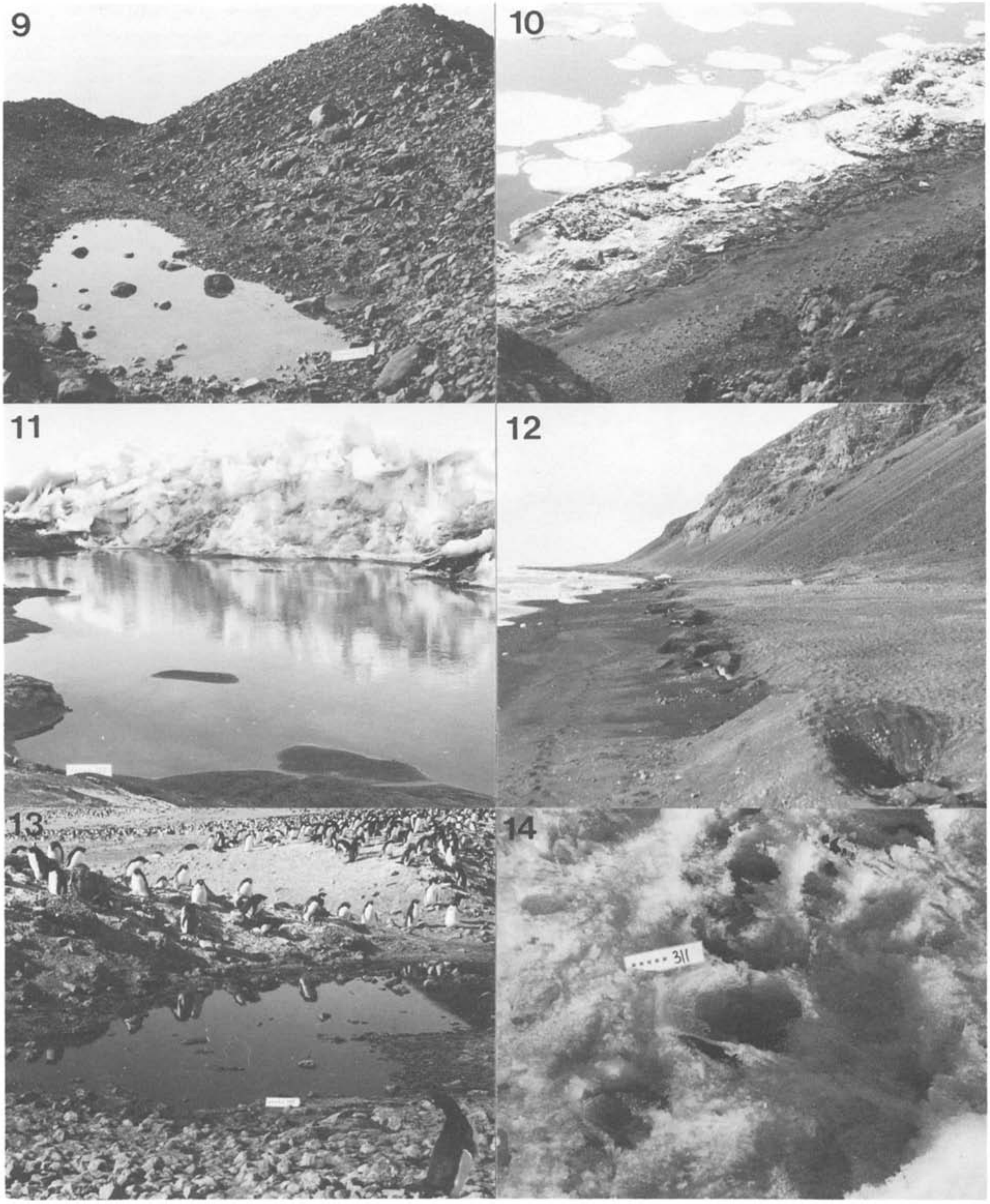
Most numerous were ponds which have been termed 'typical ponds'. These were found in depressions in glacial till (Fig. 9), volcanic tephra and lava, and beach sands. They numbered 45, 145 and 45 at C. Bird, Royds and Crozier respec-

Table 1. Dominant and characteristic algae of terrestrial and aquatic habitats of ice-free regions on Ross Island.[1]

Systematic list of algae	Habitats[2]										
	1	2	3	4	5	6	7	8	9	10	11
CYANOPHYTA											
Chroococcales											
Gloeocapsa kuetzingiana Naeg.	+						+				
Chamaesiphonales											
Chroococcidiopsis sp.								+	+		
Oscillatoriales											
Oscillatoriaceae (including *Lyngbya, Oscillatoria* and *Phormidium* spp.)	+			+		+	+		+	+	+
Nostoc sp.	+						+				
Nostoc commune										+	
Scytonema sp.							+				
CHLOROPHYTA											
Volvocales											
Brachiomonas cf. *submarina* Boh.	+										
Chlamydomonas cf. *snowiae* Printz.			+								
C. cf. *subcaudata* Wille	+	+									
C. sp.					+						
Ulotrichales											
Klebsormidium sp.	+										
Ulothrix sp.	+	+				+	+				
Chaetophorales											
cf. *Coccobotrys* sp.								+	+		
cf. *Desmococcus* sp.						+					
Ulvales											
Prasiola calophylla (Carmich.) Menegh.						+				+	
P. crispa (Lightf.) Menegh.											+
Prasiococcus calcarius (Boye Pet.) Vischer								+		+?	+?
CHRYSOPHYTA											
Bacillariophyceae											
Centrales											
Melosira setosa Grev.	+										
Pennales											
Navicula cryptocephala Kuetz.	+	+									
N. muticopsis v. Heurck	+			+							
N. shackletoni West and West	+										
Pinnularia cymatopleura West and West				+							
Tropidoneis laevissima West and West	+	+									
CRYPTOPHYTA											
cf. *Chroomonas lacustris* Pa. and Rutt.	+										

[1] See text for a comparison of frequency of occurrence and abundance of growths at Cape Bird, C. Royds and C. Crozier.

[2] Habitats are as follows: 1–4, ponds; 1, typical; 2, shoreline; 3, rookery; 4, cryoconite; 5, snowfields and snowdrifts; 6, streams; 7–9, rock surfaces; 7, epilithic; 8, chasmoendolithic; 9, sublithic; 10–11, meltwater-flushed ground surfaces; 10, not significantly nutrient-enriched by birds; 11, in nutrient-enriched areas.



Figs. 9–14. Ponds at C. Bird. Fig. 9. A 'typical pond' in a depression in moraines in the north of the region. Fig. 10. Looking down onto a beach with sea-ice still attached along the shoreline; 'shoreline ponds' have formed along the landward edge of the ice. Fig. 11. A 'shoreline pond' fed by melt from coastal ice accumulations. Fig. 12. The same length of beach as shown in Fig. 11. after ice has broken away and melted completely. The 'shoreline ponds' have seeped away into the sand. Fig. 13. A 'rookery pond' in Northern Rookery. Fig. 14. Small 'cryoconite ponds' in the Mt. Bird ice-cap. The scale is in centimetres.

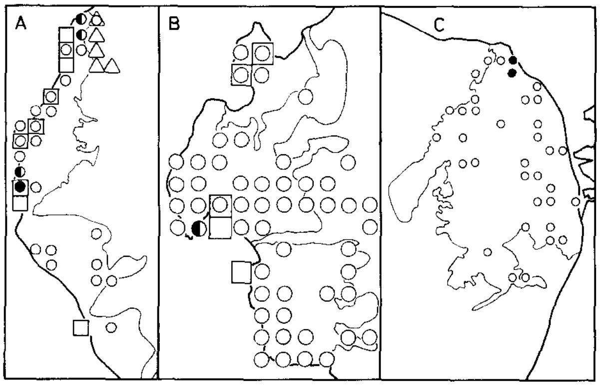


Fig. 8. Pond types at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence of ponds in 0.5 by 0.5 km grid squares: △ 'cryoconite ponds'; □ 'shoreline ponds'; ● 'rookery ponds'; ○ 'typical ponds'; ◐ both 'rookery' and 'typical' ponds.

tively. They include all ponds other than those in the three remaining categories described below. Several were visited by penguins and in particular by skuas and received some nutrient enrichment from these sources. Their areas varied widely from 1 to 4 000 m^2. All were shallow with a maximum depth of <2 m. Some dried out during the study period. Ponds in areas affected by sea-spray were predominantly of high conductivity (300 to $>2\,000$ m Sm^{-1}) and of saline taste, whereas outside these areas the majority were of lower conductivity (50–300 m Sm^{-1}) and of fresh taste (Fig. 7).

Small ponds formed along the shoreline due to the melting of sea-ice which had become grounded on sandy beaches (Figs. 10–12). These 'shoreline ponds' were frequent in the northern half of C. Bird, with about 25 in total, infrequent at C. Royds, 5 in total, and none were observed at C. Crozier. Strong winds blow a layer of dark sand over the grounded ice. Solar heating of this causes the underlying ice to melt, forming ponds of 0.2–200 m^2 and up to 30 cm deep (see Fig. 9 in Vincent, 1987). On complete melting of the ice the water drains away and only a small depression remains as an indication of the previous presence of a pond. These ponds were generally brackish to saline.

Within and directly adjacent to the nesting areas of penguins (Fig. 3) there were turbid, highly nutrient and organically enriched ponds (Fig. 13). The catchments of these 'rookery ponds', and the ponds themselves, contained substantial guano deposits and scattered bird carcasses. They numbered 9, 1 and 4 at C. Bird, Royds and Crozier respectively. All were saline with conductivities >300 m Sm^{-1}.

Mineral sediments ('cryoconite') melting into glacier ice form 'cryoconite ponds' (Wharton *et al.*, 1985). These were found only in the ice bordering the north-eastern edge of C. Bird. Here the hard ice surface was darkened by substantial mineral deposits which had melted into the ice on flat areas (Fig. 14). The ponds were generally cylindrical, 20–40 cm diameter and 20–30 cm deep, although occasionally they attained 5 m^2 in surface area. The waters were of low conductivity, less than 50 m Sm^{-1}. Their absence at C. Royds and C. Crozier was probably due to the sloping topography of most ice-fields and the relatively clean ice surfaces.

Algal flora

The majority of 'typical ponds' contained benthic felts dominated by *Phormidium*, *Lyngbya* and *Oscillatoria* irrespective of conductivity and salinity (Fig. 15). In contrast, macroscopic growths of

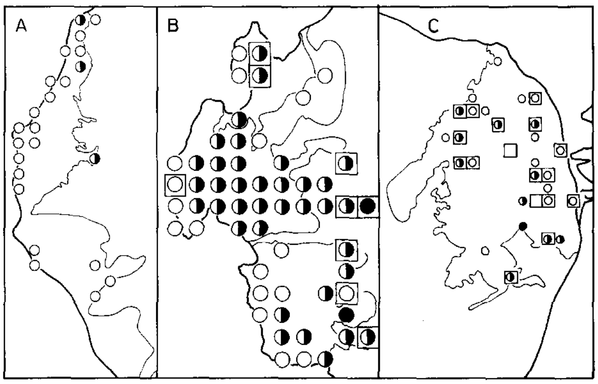


Fig. 15. Distribution of Cyanophyta in ponds at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares: ○ benthic felts dominated by Oscillatoriaceae; ● macroscopic colonies of *Nostoc* sp.; ◑ both Oscillatoriaceae and *Nostoc*; □ thin crusts and microscopic growths of *Gloeocapsa kuetzingiana*.

Nostoc sp. were encountered almost solely outside saline areas and were notably infrequent at C. Bird (Fig. 15). *Gloeocapsa kuetzingiana* was a frequent microscopic component within 'typical ponds' of low conductivity at C. Royds and C. Crozier alone (Fig. 15). However, it had a more restricted distribution at C. Royds where, except for a western coastal record, it was mostly confined to an eastern zone at the highest altitudes surveyed. In these ponds it dominated the relatively thin crusts which covered stones and gravel.

Other algae possessed distinct preferences for waters of high conductivity and were either absent or rarely found at C. Crozier. For instance in saline 'typical ponds', visibly yellow-green phytoplankton populations of cf. *Chroomonas lacustris* often developed (Fig. 16). These also frequently contained rich green growths of *Ulothrix* sp. (Fig. 16). This alga was frequent in 'shoreline ponds' associated with green benthic films of *Chlamydomonas* cf. *subcaudata* (Fig. 17) but the latter was infrequent in saline 'typical ponds'. A second species of *Chlamydomonas, C.* cf. *snowiae*, characterised the saline, nutrient-enriched 'rookery ponds' where dense unialgal populations developed (Fig. 17). It was not encountered in other habitats. Two saline 'typical ponds' at C. Royds contained small populations of the halophile *Brachiomonas* cf. *submarina* (Fig. 16).

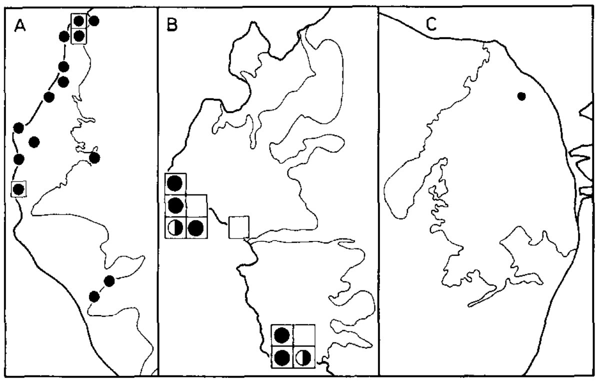


Fig. 16. Distribution of selected algae in ponds at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares; □ cf. *Chroomonas lacustris*; ● green filamentous growths of *Ulothrix* sp.; ◑ both *Ulothrix* sp. and *Brachiomonas* cf. *submarina*.

Diatoms were often abundant in saline ponds but infrequent elsewhere (Fig. 18). This is apparent in their widespread distribution at C. Bird, their almost total restriction to sea-spray affected areas at C. Royds and their rarity at C. Crozier. Three species were characteristic of saline 'typical ponds'; *Navicula shackletoni, Tropidoneis laevissima* and *Melosira setosa. T. laevissima* and *N. cryptocephala* dominated brown benthic films of diatoms in several 'shoreline ponds'. *N. muticopsis* displayed a wider range

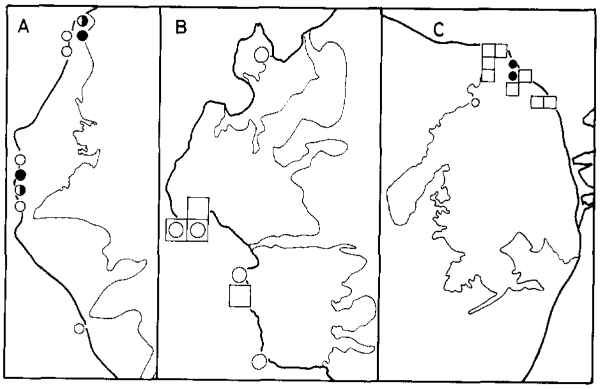


Fig. 17. Distribution of *Chlamydomonas* spp. in ponds and green snow at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares; ○ *C.* cf. *subcaudata*; ● *C.* cf. *snowiae*; ◑ both *Chlamydomonas* spp.; □ green snow dominated by an unidentified species of *Chlamydomonas*.

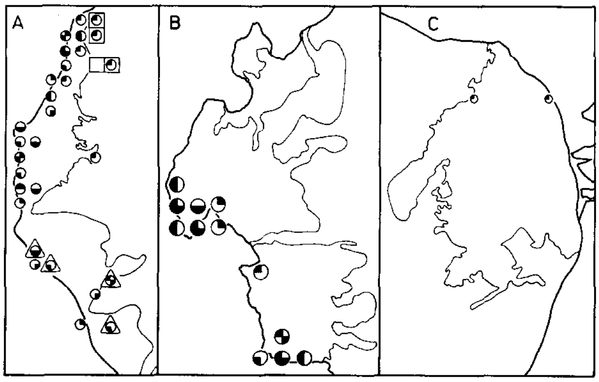


Fig. 18. Distribution of diatoms in ponds at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares; ◔ *Navicula cryptocephala*; ◒ *N. shackletoni*; ◐ *N. muticopsis*; ◐ *Tropidoneis laevissima*; □ *Pinnularia cymatopleura*; △ *Melosira setosa*.

of salinity tolerance being found at low abundance in 'cryoconite ponds' as well as in 'typical ponds'.

Pinnularia cymatopleura occurred solely in 'cryoconite ponds' at C. Bird (Fig. 18) and not in waters of similarly low conductivity in 'typical ponds'. 'Cryoconite ponds' also contained Oscillatoriaceae and unidentified chlorococcalean and chaetophoralean algae (Chlorophyta) at low abundance.

The abundance of Oscillatoriaceae and diatoms in lakes and ponds on Ross Island has been well known since reports by West & West (1911). Similar communities to those described above have been found elsewhere. In northern Victoria Land there were 'shoreline ponds' containing *Chlamydomonas* cf. *subcaudata* and *Ulothrix* sp., a 'rookery pond' with *C.* cf. *snowiae*, and *Nostoc* sp. as a frequent associate with Oscillatoriaceae in low conductivity 'typical ponds' (Broady, 1987). At Mawson Rock, ponds in saline areas were often dominated by diatoms, but also contained rich growths of green filaments resembling the *Ulothrix* sp. of this study (= *Urospora* sp., Broady, 1982).

The diatom flora of antarctic ponds has been shown to vary markedly with differences in water chemistry. Field studies by Fukushima (1961, 1964, 1967) and co-workers (Karasawa & Fukushima, 1977) showed *Tropidoneis laevissima, Navicula cryptocephala* and *N. muticopsis* to occur in saline ponds but that the latter prefered milder salinities. These observations were confirmed in culture for *T. laevissima* and *N. muticopsis* by Watanuki and Ohno (1976) and Watanuki (1979).

It is interesting to note that the first antarctic record of *Melosira setosa* was of marine specimens from the vicinity of the South Orkney Islands (Frenguelli, 1943). In northern Victoria Land it has been found in saline coastal pools (Broady, 1987).

Although regarding *Pinnularia cymatopleura* as a 'freshwater' alga, Fukushima (1964, 1967) found specimens in 'typical ponds' of high chlorinity at C. Royds and C. Evans. In northern Victoria Land (Broady 1987) records are from freshwater 'typical ponds' as well as 'cryoconite ponds'. It is one of the most abundant non-marine diatoms in the multitude of ponds on the McMurdo Ice Shelf (Kellogg & Kellogg, 1987).

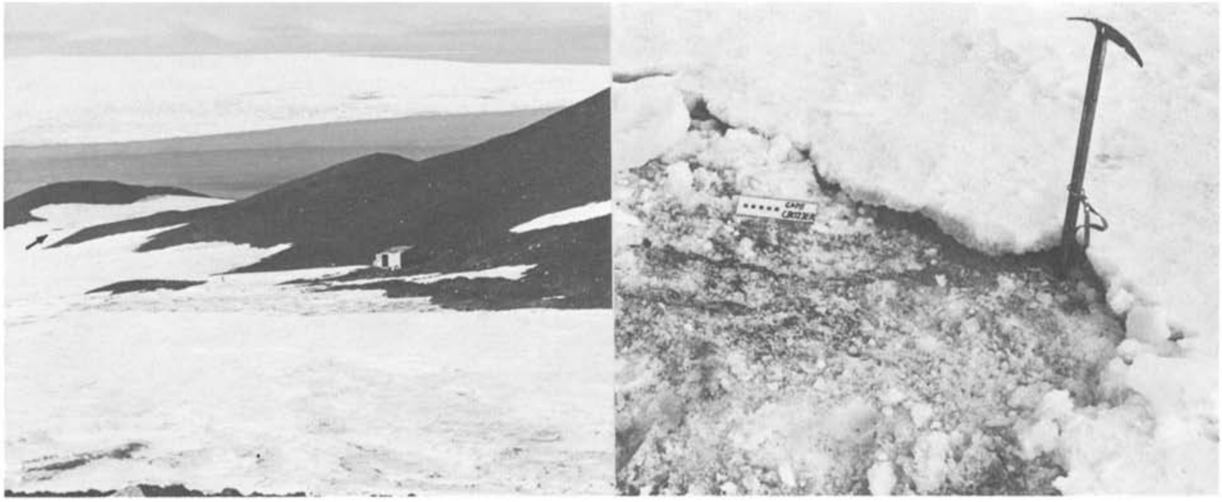
Saline ponds and lakes in the vicinity of Lützow-Holm Bay (Watanuki & Fukushima, 1978)) and at the Vestfold Hills (Wright & Burton, 1981) contain substantial populations of *Dunaliella* sp. but this was not observed in similar habitats on Ross Island.

Snow algae

Green snow occurred at C. Royds and C. Crozier (Fig. 17). All locations were close to the coast where there was substantial snow melt in progress and fertilization by birds. Meltwater from the drifts was always of low conductivity (3–46 m Sm^{-1}). The absence of snow algae at C. Bird is surprising but may be related to the general lack of large snowdrifts, persisting throughout summer, in areas traversed by penguins.

At C. Royds the algae formed small patches in snow on the coastal ice-foot, adjacent to the penguin rookery. Also, an isolated patch occurred further south, downslope from an accumulation of feathers and guano deposited by moulting penguins. C. Crozier had much more extensive areas covering more than 4 ha adjacent to the penguin rookeries and skua colonies (Figs. 19–20). All samples were dominated by an unidentified species of *Chlamydomonas*, associated with occasional *Ulothrix* – like filaments and diatoms.

There is only a single previous note of snow algae in the Ross Sea regions, on Possession Is. in northern Victoria Land (Koob, 1966). The occurrences on Ross Is. are the furthest south on record. The growth of snow algae in the proximity of nesting birds has been noted by Akiyama (1979) and the requirement for melting snow has been recognised, e.g. Llano (1962). Extensive areas similar to those at C. Crozier have been remarked on only once before in the Continental Antarctic Zone, by Llano (1962) who saw 'many acres' of red snow on the Wilkes Land coast.



Figs. 19-20. Snow algae at Cape Crozier. Fig. 19 (left). The location of the most extensive growths of snow algae at C. Crozier (indicated by the arrow) on a snowfield traversed by penguins and adjacent to skua nest sites. The field hut (3 m high) provides a scale. Fig. 20 (right). Rich green growths of snow algae (dark areas in foreground) revealed by breaking away a surface crust of icey snow. The scale is 10 cm long.

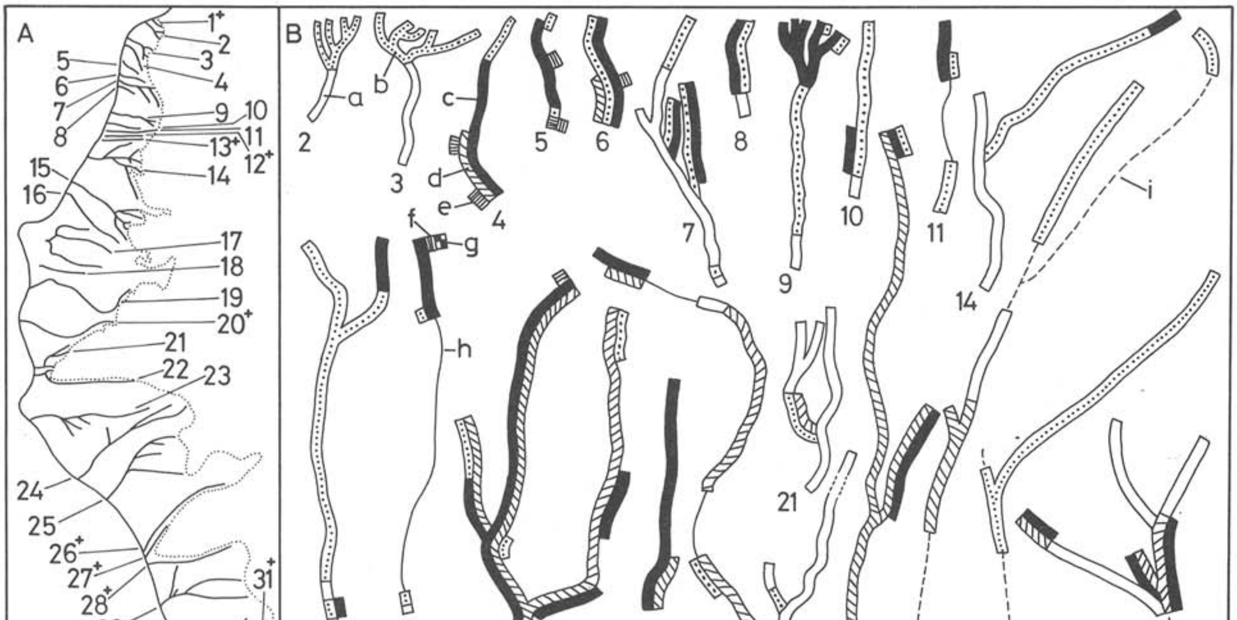


Fig. 21. Stream locations and their algal vegetation at Cape Bird. A, location of streams, + streams in which no vegetation was observed. B, distribution of macroscopic vegetation in streams: a, no vegetation observed; b, green epilithic crusts; c, oscillatoriacean felts; d, green filaments of *Ulothrix* sp.; e, foliose *Prasiola crispa*; f, colonies of *Nostoc commune*; g, ribbons of *Prasiola calophylla*; h, stream running below snowdrift; i, stretch of stream not examined.

Algae in streams

During summer, meltwater either percolates over the surface of wide areas of ground or flows within well-defined channels. Here a stream is regarded as the latter flow pattern. Streams are a major habitat for algae at C. Bird where there is a total length of approximately 48 km (Fig. 21A), but are of relatively minor importance at C. Royds and C. Crozier where they flow over only 8 and 4 km of ice-free ground respectively.

Streams vary greatly in physico-chemical and biological features. Notable differences occur in duration, volume and speed of flow, the loading of suspensoids and in water salinity. The abundance and type of vegetation varies from stream to stream and along the lengths of individual streams. The patterns found in streams at C. Bird were mapped in some detail (Fig. 21B).

Macroscopically visible vegetation was absent from 9 of the total 31 streams (Fig. 21A). These usually had rapid, relatively high volume peak flows, mostly derived from glacier ice rather than snowdrifts. They flowed over steep ground and contained an abundance of suspensoids which made the water turbid.

Thin green epilithic crusts were found on downstream faces of rocks and boulders and on the lower surfaces of large stones. Streams containing this type of growth alone, e.g. 2, 3 (Fig. 22) 22 and 25, were similar to those in which no vegetation was observed. Where crusts were found in streams which also contained other algae, they were dominant where flow rates were too great for establishment of the other algae. The crusts were dominated by cf. *Desmococcus* and *Phormidium fragile*.

Streams with a relatively slow, clear, peak water flow usually contained extensive reddish-brown felts, dominated by Oscillatoriaceae which covered the fines, gravel and small stones of the streambed. The most abundant felts were in streams 5, 17 and 18 and in the snowdrift-fed tributaries of stream 7. In other streams the felts were often sparse, thin and an indistinct grey.

Rich green epilithic filaments of *Ulothrix* sp. were dominant in some fast and gently flowing streams. They were encountered in most abundance in brackish to saline waters, e.g. streams 23 and 24 at C. Bird and some small flows in the sea-spray-swept areas at C. Royds (Fig. 23). However, at C. Bird the filaments were also abun-

Fig. 22. Stream 3 (see Fig. 21A) at Cape Bird. The vigorous, turbulent flow is derived from melt off the Mt. Bird ice-cap and contains a high loading of suspensoids. Sparse, epilithic green crusts occurred on downstream faces of rocks and boulders.

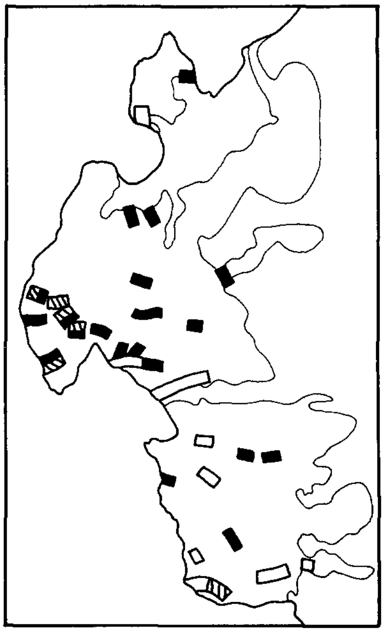


Fig. 23. Stream vegetation at C. Royds, indicating oscillatoriacean felts, green filaments of *Ulothrix* and stretches in which no algae observed; symbols as in Fig. 21.

dant in streams containing fresh water at the time of sampling, e.g. streams 17 and 19. They were not observed at C. Crozier.

Green ribbon-like plants of *Prasiola calophylla* were occasionally found attached to rocks and stones in fresh-water streams. However, this alga was most frequent in unchanneled melt flushes on saturated ground, as were *P. crispa* and *Nostoc commune* (see below).

There are distinct contrasts between the dominant algae in C. Bird streams and those described elsewhere. Although *Ulothrix* spp. were recorded by Hirano (1979) from a stream running into Lützow-Holm Bay, the species differ from the present specimens and were not noted to form luxuriant growths. Also, no specimens of the Ross Is. *Ulothrix* sp. have either been found in the ice-free valleys of southern Victoria Land (Broady, 1982b; Howard-Williams & Vincent, 1986; Howard-Williams *et al.*, 1986) or at Edmondson Point, northern Victoria Land (Broady, 1987). In those regions, rich growths of green filaments and ribbons comprise *Binuclearia tectorum*, *Prasiola calophylla* and *Tribonema elegans*. The former two species are rare in Ross Island streams and the latter has not been recorded. Additionally, species of *Gloeocapsa* and *Nostoc* have been commonly found in other areas but are rare in streams at C. Bird. Oscillatoriacean felts are ubiquitous. The major factor influencing these contrasts is considered to be the generally more saline C. Bird environment. Culture studies of the dominant taxa would help test this hypothesis.

At Signy Island, in maritime Antarctica, the stream flora (Hawes, 1988) contrasts markedly with that known from the Continental Zone, although oscillatoriacean felts are common in both. the most torrential streams are similar in containing sparse epilithic algae, however, these comprise solely diatoms. Additionally, the dominant filamentous chlorophytes are species of *Mougeotia*, *Zygnema* and a *Klebsormidium*-like alga. Despite these obvious contrasts, more revealing comparisons of stream floras will have to await the improvement of our taxonomic knowledge and the investigation of flowing waters in other regions.

Algae on exposed ground

Rock substrata

Epilithic algae were encountered where thin films of meltwater irrigated rock surfaces. Small growths numbered 3, 1 and 5 at Cape Bird, Royds and Crozier respectively. At the first of these, Oscillatoriaceae and *Ulothrix* sp. dominated the community, in contrast to *Gloeocapsa* spp., *Nostoc* sp. and *Scytonema* sp. in salt-free areas in the latter two regions.

Chasmoendolithic algae were present only in granitic, glacial erratic boulders. The predominant dark-coloured lavas were unsuitable for their development. Sixteen examples were found at C. Bird and just 2 at C. Crozier. No suitable boulders were present at C. Royds. Both green and blue-green growths occurred below thin flakes of rock, the former dominated by cf. *Coccobotrys* sp. and *Prasiococcus calcarius* and the latter by *Chroococcidiopsis* sp.

Sublithic (hypolithic) algae forming crusts on the undersurfaces of translucent stones lying on the soil were infrequent at C. Bird and absent from C. Royds and Crozier. Six quartz stones supported green and blue-green crusts. *Chroococcidiopsis* sp., *Phormidium* sp. and *Coccobotrys* sp. were dominant.

Compared with other regions, lithic algae were rare due to lack of suitable substrata. Epilithic communities were limited by the general absence of irrigated rock surfaces. At Mawson Rock (Broady, 1982a) and the Vestfold Hills (Broady, 1981a), 32 and 27 crusts of cyanophytes, dominated by *Gloeocapsa* spp. were restricted to salt-free areas. At the former region, meltwater- irrigated coastal rocks in salt-affected zones supported rich growths of *Ulothrix* sp. (= *Urospora* sp., Broady, 1982a) similar to the species found in saline ponds on Ross Island.

Endoliths are widespread where the geology of the country rocks is suitable, for instance in the southern Victoria Land dry valleys (Friedmann & Ocampo-Friedmann, 1984), the Vestfold Hills and Mawson Rock (Broady, 1981b). Similarly, it is only the paucity of translucent stones which restricts sublithic growths. If large numbers of stones had occurred, sublithic algae would have been frequent, as at the Vestfold Hills (Broady, 1986).

Particulate substrata

Soils are raw, mineral fines (lithosols) and ornithogenic soils with high guano content (Ugolini, 1970). Large areas of ground, particularly at C. Crozier, are covered by gravel and stones. Water availability at the surface varies greatly. At the maximum, melt water percolates over wide areas of ground, especially where covered by relatively poorly drained lithosols, and at the minimum moisture comes from the melt of occasional snowfall and snowdrift. Surfaces covered by gravel and stones are usually well-drained and relatively dry as water rapidly percolates down through the profile.

Distribution of Cyanophyta

Oscillatoriacean felts and macroscopic colonies of *Nostoc commune* (Fig. 24) were most abundant on poorly drained lithosols downslope from melting snowdrifts. Such ground was most extensive at C. Bird, where felt cover was almost continuous over areas up to 500 m^2, and in the central region of C. Royds coinciding with the terraced moraines recognised by Debenham (1923). The paucity of these algae at C. Crozier is related to the extensive occurrence of well-drained surfaces despite there being numerous large melting snowfields.

Similar to the ponds (Fig. 15), *Nostoc* was almost absent from saline areas whereas oscillatoriacean felts were present. This was most apparent at C. Bird where all but one record of *N. commune* was in the northern half.

Oscillatoriaceae and *N. commune* are well-known throughout the Antarctic Region on irrigated soils. Effects on *N. commune* similar to those recorded on Ross Island have been noted at Mawson Rock (Broady, 1982a) and the Vestfold Hills (Broady, 1986). At the latter region it occurred within the salt-affected zone only downslope from large melting snowdrifts where leaching by snowmelt probably removed restrictively high salt concentrations. This could also explain the southern record at C. Bird.

Distribution of Prasiola species

Two species of *Prasiola* exhibited distinctly different distribution patterns (Fig. 25). Green foliose thalli of the nitrophilous *P. crispa* were common on water-saturated ground in the vicinity of bird colonies. In contrast, *P. calophylla* was intolerant of such high nutrient and salt levels and was also excluded from areas receiving windblown sea-spray. The relatively low frequency of occurrence

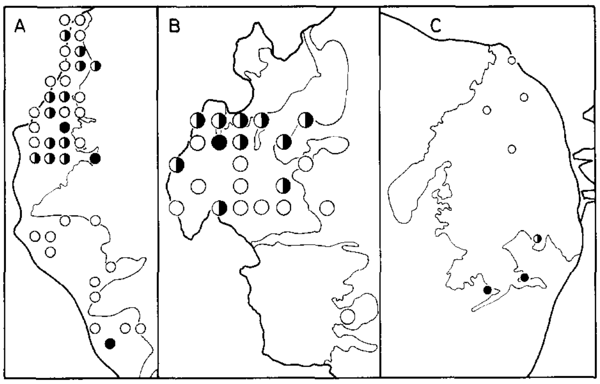


Fig. 24. Distribution of oscillatoriacean felts and colonies of *Nostoc commune* on exposed ground at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares; ○ Oscillatoriaceae; ● *N. commune*; ◑ both.

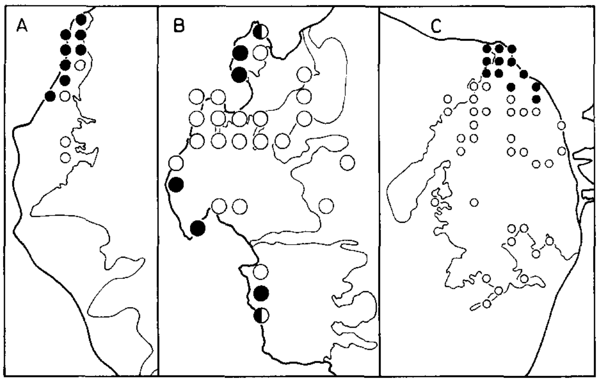


Fig. 25. Distribution of two species of *Prasiola* on water-flushed ground at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares; ● *P. crispa*; ○ *P. calophylla*; ◐ both.

at C. Bird is probably due to the generally higher salt levels over the region.

The ribbon-like thalli of *P. calophylla* were generally 1–4 cm long and attached by a holdfast to small stones and rocks in water seepage. The plants were often found immediately downslope from the downhill edges of snowfields where melt-water percolated between stones. Frequently they were not visible on upper stone surfaces but were revealed when the top layer of stones was over-turned exposing the algae attached to their lower sides and undersurfaces.

P. crispa has been recognised as an important antarctic alga in nutrient-enriched, moist habitats since the earliest days of collection (West & West, 1911) and it is no surprise to find it localised around bird colonies on Ross Is. However, *P. calophylla* is much more poorly known although recent data show it to be widespread in southern Victoria Land (Broady, 1982b, 1987 and unpublished records). There it often grows luxuriantly in channelled streams but is also found amongst boulders, stones and gravel where lesser percolations flow over and through the substratum. The latter growth pattern was predominant on Ross Is, due to the few channelled water flows at C. Royds and Crozier.

Crusts of green algae

Green algal crusts coated the surfaces of soils, gravel and stones at all three areas but were particularly abundant at C. Crozier (Fig. 26). There they were mostly confined to the northern half of the region outside the perimeter of the penguin rookery. They were often found encrusting stones below the ground surface, in a pattern similar to *P. calophylla*. However, directly adjacent to the melting edges of snowfields, where a water supply was readily available, there were abundant powdery growths over exposed upper surfaces. The identity of the dominant alga in these crusts cannot be confidently determined. Although closely resembling the sarcinoid *Prasiococcus calcarius*, it is possible that growth forms and life-stages of *Prasiola crispa* and *P. calophylla* have a very similar morphology. The crusts were dominated less frequently by cf. *Coccobotrys* sp. At C. Royds, similar crusts comprising cf. *P. calcarius* were predominantly encountered in areas receiving wind-blown sea-spray. At C. Bird green crusts were infrequent, and only on small areas of moist, mineral fines close to penguin colonies, but not where large quantities of guano were deposited. The flora of these was more diverse and although dominated by cf. *P. calcarius* and *Klebsormidium* sp. also contained over 20 species of other microalgae.

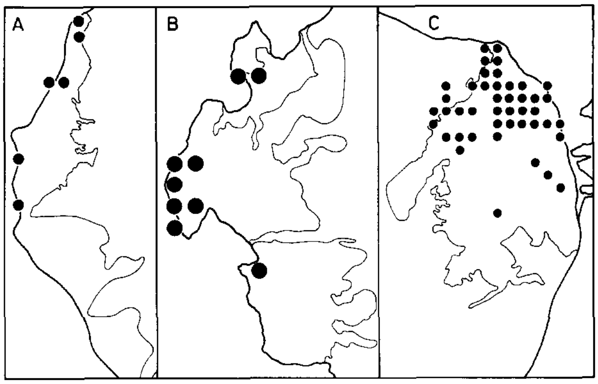


Fig. 26. Distribution of green algal crusts on exposed ground surfaces at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares.

The ecology of *P. calcarius* in Antarctica has been discussed previously in some detail (Broady, 1983). In particular, the preference for salty environments was emphasized. It is possible that the specimens observed in salt-affected areas at C. Bird and C. Royds, and around the periphery of the penguin colony at C. Crozier, are this alga. However, in such habitats, they would also be exposed to nutrient-enrichment from birds and could be a growth form of the nitrophilous *P. crispa*. Similarly, the more southerly records in the relatively salt-free areas of C. Crozier overlap the distribution of *P. calophylla* (Fig. 16) and they could be a growth form of that alga. This confusion will be resolved only by critical studies on unialgal cultures of isolates of these algae.

Lichens

Distribution patterns are shown in Fig. 27. Crustose lichens included *Biatorella cerebriformis,*

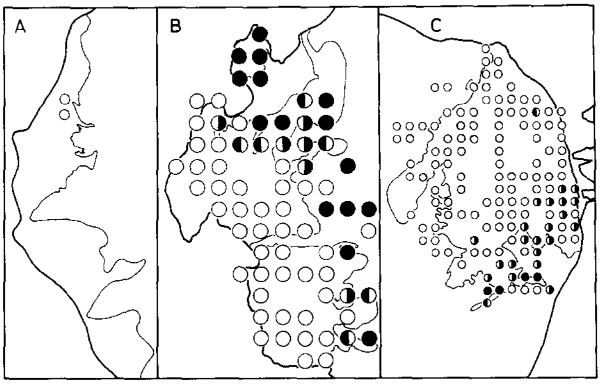


Fig. 27. Distribution of lichens at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares: ○ crustose lichens; ◑ *Usnea antarctica* and crustose lichens; ◐ *Umbilicaria aprina* and crustose lichens; ● *U. antarctica, U. aprina* and crustose lichens.

Candelariella antarctica and species of *Buellia, Caloplaca, Candelaria, Lecanora* and *Xanthoria*. Foliose lichens were represented by *Umbilicaria aprina* and fruticose by *Usnea antarctica*.

At C. Bird, lichens were extremely rare, being restricted to sparse growths of crustose *Caloplaca darbishirei*. This is possibly a response to the generally high levels of salt thought to occur over the region as a whole, even in the relatively protected northern half. In contrast crustose species were widespread and abundant at C. Royds and C. Crozier. At C. Royds they were absent from areas receiving maximum quantities of sea-spray, but outside these regions greatest abundance was at low altitudes close to the coast where nutrient input from skuas occurred. Similarly at C. Crozier maximum abundance was around the periphery of the penguin rookery, especially where nesting skaus were common. They were absent within the rookery where salt levels and mechanical disturbance were high. At higher altitudes, in both regions, most occurrences were of small, sparsely scattered *Buellia* and *Caloplaca*. A contrasting distribution was clearly seen with the foliose and fruticose species.

Usnea antarctica and *Umbilicaria aprina* were absent from C. Bird and at C. Royds and Crozier were present in a much more restricted area than crustose species. At C. Royds both occurred in a zone stretching from the northernmost coastal regions back in a southeasterly direction up onto the high slopes above the 150 m contour. At C. Crozier *U. antarctica* was found in a southeastern zone stretching from the coastal cliffs to a maximum altitude of about 300 m. *U. aprina* was more restricted and occurred in the southernmost part of the *Usnea* range except for one isolated record to the north.

These two species appeared to be restricted to areas of minimum salt levels and nutrient input, although northern occurrences at C. Royds occurred in the vicinity of nesting skuas. Observations made following periods of strong winds with snowdrifting indicated that it was in these areas that maximum accumulation of drift occurred, mostly on the downwind sides of boulders and knolls. It was in such microsites that the lichens were usually encountered. Subsequent melt would enhance moisture availability and could leach salts and nutrients from the substrata.

The inability of most lichens to establish in salt-laden environments has been described at Mawson Rock (Seppelt & Ashton, 1978) and Vestfold Hills (Seppelt, 1986a; Pickard, 1986). At both regions, strong winds blow salt spray over land areas downwind from open sea and saline lakes in a pattern similar to that at C. Royds. The same factor could be responsible for the impoverishment of lichen communities on East and West Ongul Is. compared with richer communities on rock areas along the neighbouring coast (Nakanishi, 1977). The latter receive salt-free katabatic winds straight off the continent. Similar winds also probably occur at Birthday Ridge, northern Victoria Land, where Kappen (1985a) encountered lichens both inland and at the coast.

At the Vestfold Hills, the distribution of different lichen species varies markedly (Seppelt, 1986a). Of particular note in the present context is the greatly restricted occurrence of *Usnea antarctica* compared with most crustose species, and especially *Buellia frigida*. In more detailed analyses (Pickard & Seppelt, 1984; Pickard, 1986), a set of lichens including *U. antarctica* has been recognised as occurring near the ice-sheet and on inland margins of small coastal rock outcrops.

This pattern is considered to be a response to higher moisture availability and considerably less wind-blow salt, as has been suggested above for the relatively narrow distribution of *U. antarctica* at Ross Is. This relationship might also be true for *U. sulphurea* which is absent from the Ongul Islands but present on nearby coastal ice-free areas (Nakanishi, 1977). Additionally, Kappen (1985) described *U. sulphurea* as more prominent in the vegetation further inland at Birthday Ridge, northern Victoria Land. He also suggested nutrient enrichment from birds to explain richer coastal communities. Nakanishi (1977) noted a similar response at coastal Skarvsnes in Lützow-Holm Bay.

Mosses

Bryum argenteum, B. antarcticum and *Sarconeurum glaciale* have been recorded from Ross Is. by Longton (1973). No attempt was made to distinguish the separate species during this study. Similar to crustose lichens, mosses were intolerant of high salt levels in sea-spray swept areas and penguin rookeries (Fig. 28). However, at C. Bird they were clearly more widespread than the lichens. Here the greatest abundance, and 83% of all stands, was in the area stretching 3 km south from Northern Rookery. Stands occurred as isolated cushions to confluent carpets up to 10–20 m^2. Generally they were on water-flushed substrata, particularly the relatively poorly drained mineral fines (Fig. 29). Sites were protected from strong winds and were in positions more likely to be supplied with melt percolating from snowdrifts as they occurred on more or less north-facing slopes, in depressions and gullies, and on ground downwind of hummocks and knolls.

At C. Royds no stands exceded a few square meters in extent and most occurrences were of one or a few, small scattered cushions. 56% of records, and maximum abundance, occurred below 50 m altitude. Above this height moss was much sparser, especially in the southern half of the region which is more exposed to the strong south-easterly winds than are the west to north-west facing slopes in the north. 69% of stands were in this northern area.

At C. Crozier, mosses were sparse and widely scattered. Most records were of single or a small number of adjacent cushions each less than 10 cm^2 in diameter. More abundant growths were found only on north to northeast-facing slopes in the northern part of the region where 71% of all stands were found. They were not seen over large

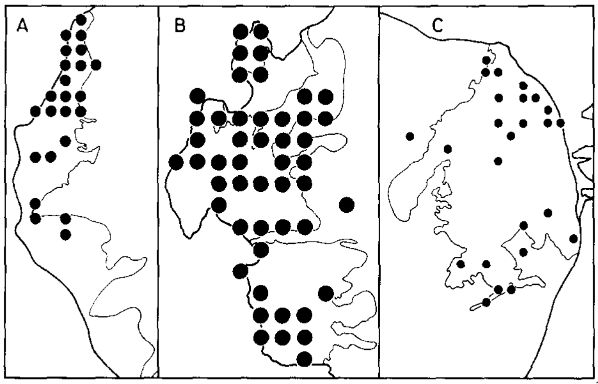


Fig. 28. Distribution of mosses at A, Cape Bird; B, C. Royds and C, C. Crozier. Symbols indicate presence in 0.5 by 0.5 km grid squares.

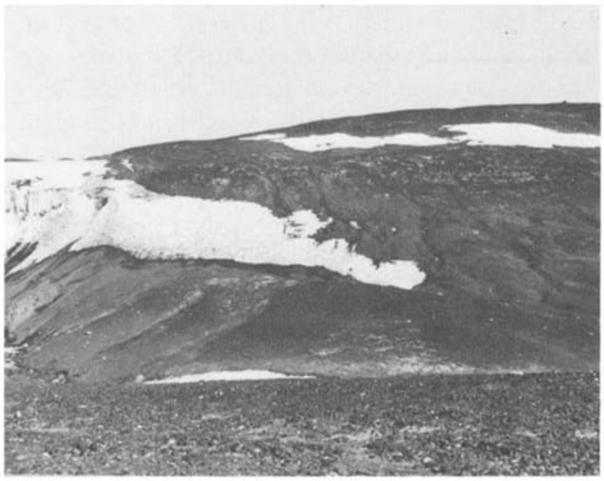


Fig. 29. Typical meltwater-flushed slopes, at Cape Bird, which supported moss growths. Cushions were found downslope from both snowdrifts, particularly in the shallow gullies. The foot of the hill is approximately 200 m distant.

areas inland, possibly due to the generally well-drained, stoney substratum not retaining sufficient moisture for their development. Isolated cushions were present up to a maximum elevation of 915 m but most were found below 300 m.

Mosses are absent from the most heavily salt-affected areas at the Vestfold Hills (Seppelt, 1986b; Pickard, 1986) and Mawson Rock (Seppelt & Ashton, 1978). This also appears to be the case at East Ongul Island although this is not stated by Matsuda (1968). The occurrence of mosses in the west and north-west of the island correlates with the presence of ponds of lowest chlorinity. This compares with an absence of mosses and presence of ponds of generally higher chlorinity to the east and south (Karasawa & Fukushima, 1977).

There are indications that mosses are more tolerant of salt than lichens. At the Vestfold Hills, Pickard (1986) distinguished certain areas as being basically occupied by only mosses, but considered that 'this is probably an artefact of collecting as a well-collected grid rarely contains only mosses'. Also, he noted with 'surprise' that grids with 'mosses only' co-occurred significantly with those containing saline lakes. At C. Bird mosses occurred widely outside the very confined distribution of lichens possibly due to the greater tolerance of mosses to the relatively high salt levels which occur throughout this region. Additionally, at East Ongul Island, mosses are frequent but the lichen flora is extremely poor (Nakanishi, 1977), possibly for the same reason.

Conclusions

It is apparent that major differences between the floras of different areas within individual ice-free regions on Ross Island, and between the regions themselves, are strongly influenced by the degree to which they are subjected to saline aerosols. Similar situations have been recognised in more northern, coastal continental, ice-free regions of East Antarctica, particularly at the Vestfold Hills (e.g. Pickard, 1986) and Mawson Rock (e.g. Seppelt & Ashton, 1978). However, such broadscale patterns have not been described in maritime Antarctica. There, the greater precipitation and subsequently greater volumes of fresh meltwater probably prevent the accumulation of such high levels of salt in soils and ponds.

This study has described distribution patterns at low resolution and those mostly of the dominant algae and broad groupings of lichens and mosses. Also, the environmental information is mostly subjective. The results serve as a base-line for more detailed studies with a greater quantitative component utilising statistical approaches to community analysis. In particular, the structure of algal communities in ponds and streams needs to be related to detailed data on water chemistry and temporal changes should be taken into account. It is probable that salinities of individual ponds change over the growing season as they melt out, evaporate and then re-freeze. The occurrence of species succession in response to such changes needs investigation. Also, there were indications that different crustose lichen species, and possibly moss species, exhibit different distribution patterns. No attempt has been made to distinguish them in the present report. These, and the distribution patterns of foliose and frutcose lichens, will be understood only when we can relate them to micrometeorological data and chemical analyses of their substrata and water supplies.

The data can also serve as a base-line for monitoring changes in vegetation over long periods. For instance, distribution patterns could alter in response to an amelioration of climate or to a change in the extent or persistence of sea-ice which would result in changes to the quantity of salt transferred to land. Additionally, an increase in human activity at these ice-free areas could result in damage to the plant communities. Knowledge of distribution patterns can help in the assessment of such effects and in the choice of areas requiring special protection.

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