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Biotic and chemical characteristics of some soils from Wilkes Land, Antarctica

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Abstract: Numbers of micro-organisms in soils from Wilkes Land varied widely. Bacteria, yeasts and filamentous fungi occurred in all samples analysed and the numbers of bacteria were positively correlated with the numbers of yeasts, and with pH. Moss protonema and seven species of algae and cyanobacteria were also present and measurable amounts of chlorophylls *a*, *b* and *c* were extracted from some samples. Only a few sites, those with moist sandy or gravelly soils free of extensive moss or lichen cover, contained the single mite species recorded.

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Key words: algae, micro-organisms, mites.

Introduction

The soils of the approximately 2% of Antarctica that is ice-free (Claridge & Campbell 1985) have developed under cold desert conditions (Ugolini 1970). The general aridity and sub-zero temperatures have inhibited chemical weathering and biological processes and this is reflected in their properties. Antarctic soils are mostly coarse-textured and often have a surface stone layer; salt accumulations are frequent (Claridge & Campbell 1985). The most pronounced biological activity probably occurs in surface soils warmed briefly by the summer sun and moistened by transient meltwater.

There have been several classifications of Antarctic soils (Campbell & Claridge 1969, 1987). The zonal soils of much of the moister part of coastal Antarctica are categorized as subxerous frigic soils. These include the ahumic soils which have no macroscopic vegetation (but which contain soil micro-organisms) and the protoranker soils which have mosses and lichens (Tedrow 1977). The intrazonal soils include the algal peats and ornithogenic soils; these and the azonal soils of recent stream beds are of relevance to the present study.

Antarctic soils support the simplest naturally occurring biotic communities anywhere in the world. Thus, they provide a unique opportunity to study whole communities and gain insights that might be applicable to more complex, less easily understood ones. The present study is a step in that direction. We present data for a broad spectrum of taxa from Antarctic soils of varying characteristics.

Study sites

The principal study areas were in Wilkes Land on the Bailey and Clark peninsulas and on the Windmill Islands just offshore. The sampling sites on the Bailey Peninsula were all in the vicinity of Casey base. On the Clark Peninsula samples were collected at intervals during a traverse southward from near the north-eastern edge, terminating at the abandoned Wilkes base. Sampling sites on the Windmill Islands were selected to cover nearly the entire north–south and inshore–offshore extents of the archipelago. Samples also were collected from the Haupt Nunataks, three outcrops protruding above the ice cap and separated from the nearest other land by 10 km, inland of the Vanderford Glacier (Fig. 1). The geology of these areas is discussed by Blight & Oliver (1977), and the avifauna of the Windmill Islands by Orton (1963).

A brief visit to Commonwealth Bay in George V Land permitted opportunistic collections of several samples there. Field work was carried out in January 1978.

At each site, samples were taken over the range of habitats available. At most localities only one or a few habitats occurred. The localities and sample sites are characterized in Table I.

Methods

Sampling

Sterile vials (10 cm long and 2.5 cm in diameter) were used

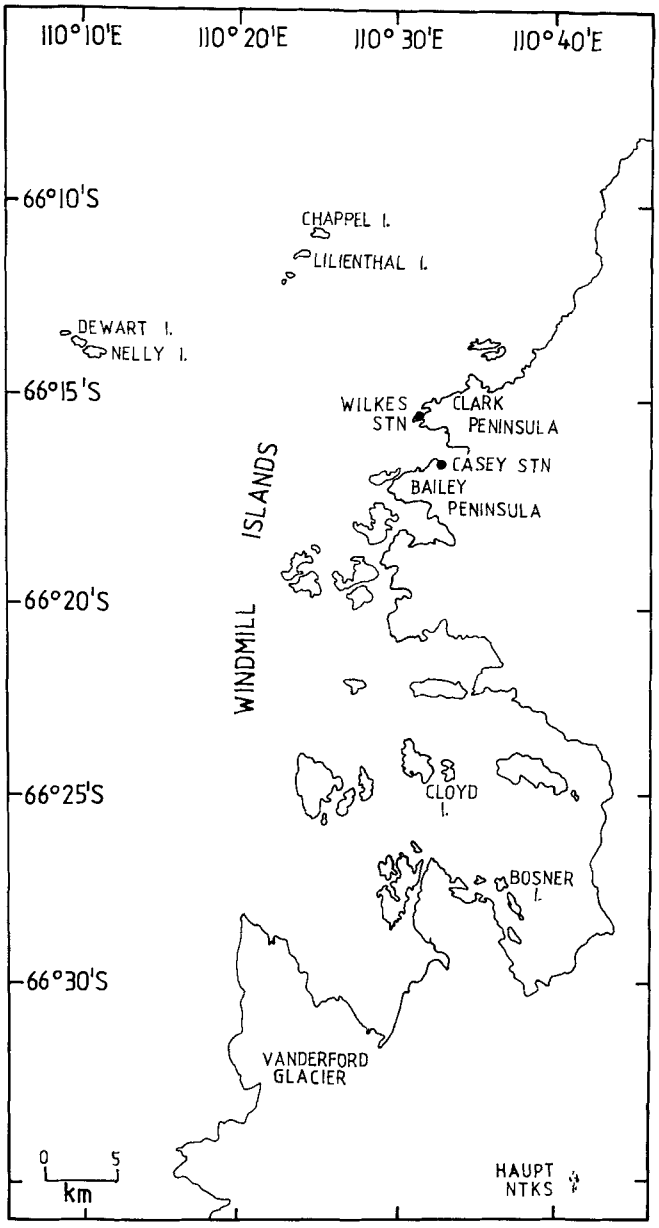

Fig. 1. Map of part of Wilkes Land showing localities where samples were collected.

as soil corers. They were pushed vertically into the soil by a twisting motion until they were full, or some obstruction prevented their further penetration. The vials with their soil cores were removed from the ground and capped with a sterile lid and labelled with date and locality. In addition, at eight selected localities non-sterile soil samples of about 1 litre volume were collected for chemical analysis. All samples were frozen within a few hours of collection. They were kept frozen during transport to the laboratory in Australia, except that during transport by air from Melbourne to Armidale, they thawed briefly but were still cold on arrival. They were refrozen and stored until analysed.

Analysis of soils

No moisture determinations were made on the large samples (Table II) used for chemical analysis as during transport these, though frozen, were not kept under conditions that completely insured against drying. Organic carbon was determined using the method of Walkely & Black (1934) and total nitrogen using that of Honda (1962). Soluble phosphorus was determined using 0.005M H_2SO_4 as an extractant (Kerr & von Steiglitz 1938). Electrolytic conductance, pH and total soluble salts were determined from 1:5 soil suspensions (Hesse 1972). Concentrations of total elements were determined by X-ray spectrography (Norrish & Hutton 1969).

At each sampling site a subjective description of the drainage and moisture characteristics of the soil was written; these appear in Table I. In addition, quantitative gravimetric moisture determinations were made on subcores (see below) of some of the samples used for microbiological extraction (Table IV).

Extraction of soil organisms

In the laboratory, the frozen soil samples were allowed to thaw and used for the study of soil algae, for the extraction and measurement of total chlorophyll content, and for the study of heterotrophic micro-organisms. The latter samples were sub-cored, using a cork-borer under sterile conditions, a different sub-core being allocated for each of bacteria, yeasts, fungi and determination of moisture content. Some samples were used for examination for protozoa. The remaining samples and the soil left after sub-coring was used for the extraction of metazoan animals.

Each of the taxa required different treatments:

Algae. Cores were homogenized at 10 000 rpm in an MSE homogenizer for 2 min in 100 ml of sterile water, and dilutions of 10^0, 10^1, 10^2, 10^3 and 10^4 were prepared. For each dilution 0.1 ml was transferred to 2% agar plates of Bold's Basal Medium (BBM) (Bold & Wynn 1978). This medium contains K_2HPO_4 and KH_2PO_4 which serve as buffers (Vonshak 1986). Surfactants were not used as they inhibit unicellular algae (Ukeles 1965). The drops were delivered from micropipettes held vertically 2 cm above the agar surface. Some plates were organically enriched with a soil extract prepared by boiling 1 kg of garden soil in 1 litre of water and filtering until clear. Twenty-five per cent (by volume) of the soil extract was added to the BBM medium. Oxoid Yeast Extract powder (L21) was added to the BBM mineral medium to give a final concentration of 0.05%. Plates were prepared with the culture solutions and 2% agar.

In order to promote rapid growth after inoculation, the plates were incubated at 18°C for three weeks under constant

Table I. Characteristics of sampling sites.

Locality	Site No.	Site	Soil	Birds	Vegetation	Moisture
Bailey Peninsula; Casey base	1	Outwash sediments inland of glacial moraine, near snowbank	Sand with gravel and small stones	Nil	Abundant mosses and lichens above site	Moistened by melt-water
	2	2 m down slope from 1	Same as 1 but shallower	Nil	Same as 1	Moister than 1
	3	Same as 1 but 7 m uphill from snowbank	Same as 1	Nil	Same as 1	Moist
	4	5 m uphill from 3	Same as 1 but stonier	Nil	Moss cover nearly complete; larger rocks 90% lichen-covered	Drier than 1–3
	5	100 m inland from 1–4; 3 m from melt-water channel	Same as 1–4 but with large boulders	Nil	Nil	Damp
	6	Same as 5, but 25 cm from melt-water channel	Same as 5	Nil	Nil	Wet
	7	Seaward side of moraine	Same as 1	Nil	Nil	Same as 4
	8	Same as 7	Same as 7	Nil	Heavy moss cover	Same as 4
Clark Peninsula	1	South side of hill, near summit	Sand under flat rocks	Nil	Rock lichen-covered	Well drained
	2	South side of hill, near summit	Organic matter under lichen mat	Nil	Abundant lichens	Well drained
	3	South side of hill, near summit	Peat and sand	Nil	Deep moss bed on peat	Damp
	4	Wilkes base, at edge of pond	Sand	Nil	Nil	Wet
Haupt Nunataks	1	Nunatak	Sand and gravel	Nil	Lichens present	Wet and dry patches
	2	Nunatak	Sand and gravel	Nil	Lichens present	Well drained
	3	Nunatak	Sand and gravel	Nil	Nil	Well drained
	4	Nunatak	Sand and gravel	Nil	Nil	Well drained
Commonwealth Bay	1	30 m NW of Mawson's Hut	Gravelly soil beneath gneiss slabs	Nil	Nil	Moist
	2	40 m NW of Mawson's Hut	Same as 1	Nil	Nil	Moister than 1
	3	Sheltered rock cavity 25 cm deep near Mawson's Hut	Gravelly soil on clay	Nil	Covered by *Prasiola crispa*	Moist
Chappel Island	1	Adélie penguin walk-way beside melt-water channel	Organic mud and feathers	Adélie penguins, cape pigeons, skuas	*Prasiola crispa*	Wet
	2	Algal bed among rocks	Rocky	Many nearby	*Prasiola crispa*	Moist
	3	Adélie penguin walk-way	Organic mud	Adélie penguins	Nil	Moist
Lilienthal Island	1	Upland soil	Brown organic soil	Not at site	Nil	Moist
	2	Near melt-water channel	Organic mud and decayed feathers among boulders	Yes, as evidenced by feathers	Green algae	Wet
Dewart Island	1	Edge of snow patch	Sand and gravel	Few (see Orton 1963)	Nil	Wet
	2	Red snow	Nil	Same as 3	Nil	Frozen
Nelly Island	1	Small, melt-water seep	Gneissic gravel and rock	Many of 7 species (see Orton 1963)	Heavy cover of *Prasiola crispa*	Wet
	2a	Edge of melt-water channel	Soft mud	Same as 1	Nil	Wet
	2b	1 m from melt-water channel	Soft mud	Same as 1	Nil	Moist
	2c	2 m from melt-water channel	Soft mud	Same as 1	Nil	Damp
	3	Side of hill	Down wash of gravel and bird bones	Same as 1	Nil	Moist
	4	Crevice in gneissic rock	Gravel and feathers	Same as 1	*Prasiola crispa*	Moist
	5	Rock crevices	Organic soil	Same as 1	*Prasiola crispa*	Moist
Bosner Island	1	Western side, just below snowbank, northern exposure	Deep ground and weathered rock	Nil	Nil	Wet
	2	Lee of rocks	Gravel	Nil	Lichens and algae	Wet
	3	Melt-water channel on west of island	Algal scum on soil at edge of channel	Nil	Algae	Wet
	4	Upland soil	Gravel and rocks, underlain by fine sand	Nil	Algae	Well drained
Cloyd Island	1	Lee of rocks	Sand and gravel	Nil	Nil	Moist beneath
	2	Lee of rocks	Sand and rock chips	Nests nearby	Mat of *Prasiola crispa*	Well drained
	3	1 m from melt-water channel	Small stones on sandy clay	Nil	Nil	Wet

Table II. Characteristics of some Antarctic soils.

Locality (site)	Loss on ignition (%)	Organic carbon (%)	pH	Electrolytic conductance (ms cm^{-1})	Total soluble salts (%)	P 0.005M H_2SO_4 extr. (μg g^{-1})	Total N (%)	Chemical composition (%) Fe	Mn	Ti	Ca	K	P	Si	Al	Mg	Na	S (μg g^{-1})
Commonwealth Bay (2)	3.3	1.5	5.2	5.25×10^{-5}	0.02	365	0.248	4.52	0.14	0.25	1.26	3.38	0.08	30.36	7.14	1.10	1.63	620
Casey base (1)	3.8	0.2	6.0	1.63×10^{-5}	0.005	1377	0.053	3.60	0.12	0.32	1.69	2.74	0.22	30.87	6.88	0.84	1.78	120
Casey base (4)	8.3	3.2	5.1	5.40×10^{-5}	0.02	378	0.230	2.40	0.08	0.20	1.45	2.66	0.11	30.73	6.61	0.66	1.63	490
Casey base (7)	1.5	0.1	5.7	5.70×10^{-5}	0.02	886	0.034	3.56	0.11	0.30	1.86	2.08	0.15	32.08	7.14	0.84	1.93	80
Haupt Nunatak (1)	2.9	1.2	5.5	3.00×10^{-5}	0.01	303	0.090	4.75	0.09	0.20	3.22	1.54	0.04	30.26	6.51	1.59	1.63	170
Nelly Island (2)	40.2	12.3	8.1	1.60×10^{-3}	0.54	29333	3.540	1.80	0.04	0.11	9.80	0.62	7.06	6.21	1.99	2.82	0.37	17×10^3
Dewart Island (2 – red snow)	0.2	0.04	7.1	3.15×10^{-5}	0.01	960	0.011	4.74	0.09	0.56	2.52	2.76	0.10	31.90	6.45	0.99	1.78	100
Cloyd Island (1)	2.0	0.4	7.5	6.35×10^{-4}	0.21	1886	0.052	2.85	0.05	0.26	1.81	3.39	0.25	31.85	6.67	0.72	1.93	240

Table III. Presence and abundance of algae, cyanobacteria and moss protonema at various Antarctic localities. Values are means for all sites studied at a given locality.

Locality	Mean number of individuals × 10^3 cm^{-2} of soil surface (% of total for locality) Chlorophyceae: *Sphaerocystis oleifera* var. *antarctica*	*Chlorella conglomerata* (Atari) Oltm.	*Stichococcus bacillaris* Naeg.	*Prasiola crispa* (Lightf.) Ag.	Xanthophyceae: *Botrydiopsis constricta* Broady	Bacillariophyceae: *Navicula* cf. *pupula* Kuetz.	Cyanobacteria: *Plectonema notatum* Schmidle	Moss protonema	Total	Total species
Commonwealth Bay		35.3 (38)			58.7 (62)				94.0	2
Casey base	87.8 (34)	74.4 (29)	69.3 (27)		22.9 (9)			2.8 (1)	257.2	4
Clark Peninsula		702.2 (13)			4772.0 (87)				5474.2	2
Wilkes base		423.3 (78)			117.9 (22)				541.2	2
Haupt Nunatak		919.6 (94)			62.9 (6)				982.5	2
Chappel Island		145.4 (39)			192.5 (52)	7.9 (2)	23.5 (6)		369.4	4
Lilienthal Island		56.0 (85)	3.1 (5)		7.1 (11)				66.2	3
Nelly Island	14.9 (6)	6.4 (3)	192.9 (78)		32.8 (13)	0.1 (0)			247.1	5
Dewart Island		62.9 (8)	117.9 (15)		613.0 (77)	15.7 (2)			799.5	4
Cloyd Island		1094.0 (83)		0.6 (0)	201.6 (15)	17.1 (1)			1313.3	4
Bosner Island	1.6 (36)				2.9 (64)				4.5	2
Total localities (% of total)	3 (27)	10 (91)	4 (36)	1 (9)	11 (100)	4 (36)	1 (9)	(9)		

illumination from eight 30-watt daylight fluorescent tubes. The plates of the first dilution which gave less than 150 colonies per plate were counted. The counts were adjusted to the core diameter and dilution to yield counts of algae per cm^2 of soil. The abundance of photosynthetic organisms was assessed by chlorophyll estimates on soil samples carried out where duplicate samples were available (Nelly Island and Casey base). For these, soil cores were ground in a mortar and pestle with 90% (by volume) acetone. Extractions were repeated until these were colourless. The acetone fractions were pooled and centrifuged for 15 minutes at 375 g to remove fine sediments. After transfer to cuvettes their absorbances at 630, 647 and 664 nm were measured on a Perkin-Elmer spectrophotometer model no. 159. The absorbances of these samples were again determined after acidification using 1N HCl to convert all chlorophylls to phaeophytins. The chlorophyll concentrations were calculated (as mg cm^{-2} of soil surface) using the corrected absorbances, the volume of acetone used and the diameter of the soil cores.

Heterotrophic micro-organisms. A standard dilution culture technique was employed. Plates prepared from each dilution were incubated at 5°, 18°, 37° and 45°C. Bacteria were cultured on Trypticase Soya Agar with 30 µg ml^{-1} of Actidione to inhibit fungal growth. This medium was selected as it is a general one and was deemed to be suitable for most soil bacteria. Filamentous fungi and yeasts were cultured on Potato Dextrose Agar and Yeast Extract Malt Agar, each with 50 µg ml^{-1} of Ledermycin to inhibit bacterial growth.

Metazoans. A sample was thawed at room temperature then put into a 750 ml beaker of tap water and stirred briskly. The heavier particles settled out quickly upon the cessation of stirring; the finer sediments and metazoans remaining in suspension were filtered by vacuum using a Buchner flask. The filter paper with the fine sediment and animals was preserved in 70% ethanol and stored for later removal of metazoans. They were stained and embedded in Hoyer's medium on slides. Acarina were the only metazoans obtained.

Results

Soil analyses

Table II presents analyses of the soils from each locality. Soil pH ranged from slightly acid to mildly alkaline. There was some organic matter in all the samples analysed although the greatest amounts were in soils where Adélie penguins (*Pygoscelis adeliae*) and other bird species were present. Their faeces resulted in high levels of soil organic matter, phosphorus, sulphur and nitrogen, particularly at the Nelly Island site.

The presence of aerosolic salts of marine origin is indicated by variation in soil pH. The mainland sites are all slightly acid while those from the three island sites are alkaline in reaction. A higher electrolytic conductance and pH level is evident at the Nelly Island site; it was the most affected by avian faeces.

Soil phototrophs

Moss protonema, six species of algae and one species of cyanobacteria were found in the soil samples from the localities studied. The most common species was *Botrydiopsis constricta* which was found in one or more samples from every locality. The second most common one was *Chlorella conglomerata* from 10 of the 11 localities. All other taxa were found in four or less localities (Table III).

The richest locality was Nelly Island with five of the eight taxa present. Four localities (Casey base, Chappel Island, Dewart Island and Cloyd Island) had four taxa and the remaining six localities had only two or three taxa. No locality was completely devoid of phototrophic soil organisms.

The Clark Peninsula had a total density of soil phototrophs more than four times the value for the next highest locality (Cloyd Island). These were the only places where phototroph density exceeded a million colony-forming units (CFU) per cm^2 of soil surface.

Chlorophyll concentrations in the soil were extremely high at Nelly Island compared to Casey base. Mean values at Casey were: chlorophyll *a*, 14.3 µg cm^{-2} (3.3 SE); chlorophyll *b*, 7.2 (2.3); chlorophyll *c*, 7.9 (2.5). Comparable values for chlorophylls *a*, *b* and *c* respectively at Nelly Island were: 681.0 (191.5); 223.7 (56.4); 49.8 (12.6). The means of all three collectively were 30.1 (7.8) µg cm^{-2} and 954.4 (253.1) µg cm^{-2} for Casey base and Nelly Island respectively. The ratio of chlorophyll *a* : chlorophyll *c* was 13.7 for Nelly Island and 1.8 for Casey base.

Soil heterotrophic micro-organisms

All soil samples analysed contained bacteria, yeasts and filamentous fungi. Bacteria tended to be more numerous than the other two groups (Table IV). Their numbers ranged from *c.* 6000 to $> 9 \times 10^8$ g^{-1} dry wt of soil. Yeast abundance ranged from 1840 to *c.* 9.5×10^5 CFU g^{-1} dry wt of soil. Counts of filamentous fungi are harder to interpret as fragmentation of hyphae and dispersal of spores during processing can lead to exaggerated counts (Smith & Steyn 1982). Thus, the values of 1450–674 000 CFU g^{-1} dry wt of soil (Table IV) should be viewed as maximum values.

Six different species of filamentous fungi were identified from these samples. They were: (1) *Cladosporium cladosporoides* (Fresen.) de Vries, (2) *Chrysosporium pannorum* (Link) Hughes, (3) *Penicillium echinulatum*

Fassatiova, (4) *Pennicillium verrucosum* Dierckx var. *cyclopium* (Westling) Samson, Stolk & Hadlok, (5) *Penicillium* sp. and (6) *Epicoccum purpurascens* Ehrenb. ex Schlecht.

Spearman Rank Correlation analyses revealed that the numbers of bacteria and yeasts were positively and significantly correlated ($r = 0.815$; $P < 0.01$); this does not imply a causative link, but only that soils favourable for one group were also favourable for the other, and those unsuitable for one tended to be unsuitable for both. Numbers of bacteria and fungi were not significantly correlated ($r = 0.503$; $P > 0.05$) nor were those of yeast and fungi ($r = 0.286$; $P > 0.05$).

In a multiple regression analysis the numbers of bacteria were positively related to soil pH but not significantly related to soil moisture content. Various transformations of the data were tested (logarithms, arcsine) and the best-fitting regression model was:

(log bacteria) = 0.01 + 1.86 pH + 4.25 arcsine (% organic matter)

and provided an R^2 of 0.54. The effect of pH in this regression model was significant ($P < 0.025$) but the effect of arcsine organic matter was not ($0.08 > P > 0.05$).

There were insufficient counts of yeast and fungi to justify their inclusion in an analysis of multiple environmental factors.

No quantitative study of protozoa was made. Several soil samples were immersed in sterile water and then examined for protozoa. Several unidentified species were observed.

Two areas, Casey base and Nelly Island, were found to have the mite *Nanorchestes antarcticus* Strandtmann (Table V). In the former area, 35 (12%) of 289 soil samples from eight sites contained one or more mites. At seven sites on Nelly Island only one of 38 samples contained mites and then only one individual, a tritonymph. Mites were not found at any of the other localities: Clark Peninsula site 3 (2 samples), 9 (1); Haupt Nunatak 2 (1); Commonwealth Bay 1 (3), 2 (3), 3 (2); Chappel Island 1 (2), 2 (2), 3 (1); Lilienthal Island 1 (3), 2 (3); Dewart Island 1 (1); Bosner Island 1 (1),

Table IV. Presence and abundance of bacteria, yeasts and filamentous fungi in some Antarctic soils. NM = not measured.

Locality and site		Counts per gramme dry wt of soil			Soil moisture (% dry wt)	pH %	Organic matter
		Bacteria	Yeasts	Fungi			
Commonwealth Bay							
	1	5.6×10^4	6.29×10^4	1.4×10^4	23.49	NM	NM
	3	5.9×10^4	8.08×10^3	1.45×10^3	16.45	6.6	NM
Casey base							
	1	1.21×10^4	NM	9.8×10^3	8.63	6.5	1.1
	3	1.60×10^5	3.82×10^3	5.36×10^4	13.79	NM	4.7
	7	1.45×10^4	NM	NM	10.44	6.5	NM
Clark Peninsula							
	1	NM	6.74×10^3	1.85×10^3	8.39	9.0	4.1
	1	3.10×10^8	9.48×10^5	6.74×10^5	8.39	9.0	4.1
	2	3.34×10^4	NM	3.18×10^4	14.52	NM	88.1
	3	7.06×10^4	NM	1.37×10^4	224.50	6.3	61.5
	3	NM	NM	NM	53.37	5.4	49.6
Haupt Nunatak							
	1	5.69×10^6	4.1×10^3	NM	0.51	6.5	2.2
	1	4.89×10^5	2.01×10^4	3.06×10^4	2.75	NM	NM
	3	2.4×10^6	NM	NM	0.92	6.7	1.3
	4	1.71×10^6	NM	NM	2.56	7.0	1.2
Lilienthal Island							
	1	2.67×10^6	NM	3.26×10^5	159.60	6.4	60.5
	2	1.35×10^6	NM	NM	152.60	6.7	38.1
Nelly Island							
	1	2.87×10^7	NM	NM	20.16	6.5	79.0
	2(a)	4.79×10^6	8.19×10^4	NM	48.63	NM	33.1
	2(b)	5.89×10^6	NM	NM	46.45	8.7	NM
	3	6.40×10^3	2.2×10^3	3.2×10^3	12.34	6.4	6.0
	3	1.35×10^7	8.19×10^4	NM	84.89	9.5	17.7
Dewart Island							
	1	2.46×10^5	NM	NM	300.51	6.7	13.2
Cloyd Island							
	1	2.05×10^4	1.84×10^3	NM	4.22	6.5	1.0
	2	6.11×10^4	4.8×10^3	NM	11.48	NM	4.2
Bosner Island							
	2	5.14×10^4	NM	NM	1.40	5.0	5.0
	3	2.22×10^5	NM	NM	360.54	6.9	NM
	4	9.78×10^3	NM	NM	15.21	NM	0.7

Table V. Distribution of *Nanorchestes antarcticus* in soils at Casey base and Nelly Island.

Casey base	1	2	3	4	5	6	7	8
no. of samples	120	27	27	44	29	9	28	5
% with mites	7	19	19	0	7	0	54	0
Nelly Island	1	2a	2b	2c	3	4	5	
no. of samples	8	8	10	8	1	1	2	
% with mites	0	0	10	0	0	0	0	

4 (1).

At Casey base the abundance of mites varied from site to site. At three sites no mites were found. Two of those (4, 8) differed from the other sites by having a heavy cover of mosses. The other (6) differed in being adjacent to a melt-water channel and was therefore an extremely wet site.

There was no site at Casey for which all of the samples contained mites; indeed, at only one (7) were there mites in more than half the samples. Site 7 was also the only site to have more than four individuals in any one sample; the maximum was 12 (Table V).

The sole immature mite on Nelly Island was taken from mud. Samples from mud 1 m on either side of it lacked mites and it may have been a 'stray' blown in from elsewhere. Most of the soils of the other localities examined for mites, but found to lack them, either had a covering of lichens, moss or algae, were of high organic content, or were very wet, and may have been unsuitable for *N. antarcticus* for these reasons. The two exceptions were Bosner Island, sites 1 and 4, which had sandy and gravelly soil without a heavy plant cover. However, these sites were represented by only one sample each and mites may have not been detected merely because of small sample size.

Of the 25 samples from Casey with mites, 9 (36%) contained 1 or more immature stages (tritonymphs, deutonymphs, protonymphs, larvae). In all but two cases, when immature stages were present adults also occurred in the same sample.

Discussion

The soil fauna and flora consisted of taxa previously known from the Antarctic biota. The only mite found during the present study was *Nanorchestes antarcticus*, a species Rounsevell (1977, 1981) has indicated as not usually associated with other mites. All of the sites with mites can be characterized as having sandy or gravelly soils, free of extensive moss or lichen cover, and moist but not waterlogged.

On the climatically milder Antarctic Peninsula and subantarctic islands, *N. antarcticus* occurs in a wide range of habitats but at Davis base in continental Antarctica it was most abundant at sites that received melt-water in a sandy habitat overlain with flat rocks, and where its microalgal food was present (Rounsevell 1977, 1981).

On the various Windmill Islands investigated, only one individual mite was found (Nelly Island). Rounsevell (1977) also noted absence of this species from offshore islands and suggested it was due to rapid drainage of melt-water to the sea and the absence of sandy lowlands. High soil salinity is also a potential restricting factor on islands. In the present study Nelly and Cloyd islands had high soil conductances. Many of the insular sites were rich in guano, a feature with which *N. antarcticus* is seldom associated (Rounsevell 1977, 1981).

Only nine taxa of filamentous fungi were recorded from the range of localities studied, which indicates that, in common with other regions of Antarctica, species diversity was low. The use of media high in carbohydrate may have resulted in the exclusion of slow growing species. However, the isolation of *Chrysosporium pannorum*, which is reportedly a poor competitor (Ivarson 1974) indicates that this did not occur in all cases.

The fungi identified have been recorded previously from soil and plant communities in the Antarctic. *Chrysosporium pannorum, Penicillium* spp. and *Cladosporium* spp. appear to be widespread (Fletcher *et al.* 1985), and the present results are a further indication of their importance in the Antarctic fungal flora. Their widespread distribution in natural ecosystems indicates that these fungi play a role in decomposition processes in these ecosystems. However, it was not possible to determine whether the present records came from spores or active mycelia.

Cameron (1971) suggested that *Penicillium* was the most common genus of fungi in the Antarctic, although Bailey & Wynn-Williams (1982) reported its absence from soils from six sites on Signy Island in the maritime Antarctic. *P. verrucosum* var. *cyclopium* (*P. cyclopium* Westling) may be one of the major representatives of *Penicillium* species recorded frrom soils near Casey in the present study and was one of the species most frequently recorded from other Antarctic locations, namely Sabrina Island in the Balleny Islands (Kerry 1979), Bunger Hills (Barker 1977) and Mac. Robertson and Enderby lands (Fletcher *et al.* 1985). It was also one of the most common *Penicillium* species isolated from litter and soil on Macquarie Islaland (Kerry & Weste 1985).

Present knowledge suggests that *Epicoccum purpurascens* is not common in the Antarctic, although the genus has been reported previously from the region (Cameron 1971).

The seasonally thawed soils of the Casey area were mostly relatively moist and some localities had more than negligible amounts of nutrients and organic matter. Compared to some other parts of continental Antarctica they were favourable habitats for bacteria.

The numbers of bacterial CFU in our samples fall within the range (2×10^4 to 3×10^8) reported from Mirnyy by Meyer *et al.* (1967), but higher than most of those reported by Boyd (1967) (2.7×10^5 or less for uncontaminated soils; some soils

from dry valleys in Victoria Land were apparently sterile) and Parker *et al.* (1982) (0–11.3 × 10^4 in soils from the Pensacola Mountains).

Parker *et al.* (1982) found algae in Antarctic soils but could not extract detectable amounts of chlorophyll. By contrast, the two samples tested in the present study (and which were not those with the greatest numbers of algae) yielded measurable chlorophyll *a*, *b* and *c*.

The algae and cyanobacteria recorded during the present study consist of taxa previously described from soils in Antarctica and/or the subantarctic islands (Holm-Hansen 1964, Kol 1970, Broady 1976, 1977*a*, 1979*a*, *b*, 1982, Parker *et al.* 1982). Using similar culture techniques, Broady (1977*b*) found similar species diversity and mean number of algae in moss turfs and peaty soils from Signy Island; he found 11 species of algae with total numbers ranging from 755–3639 × 10^3 cm^{-2}. In a later paper on the same region he obtained a wider range of densities (219–7641 × 10^3 cm^{-2}; Broady 1979*b*).

Despite this similarity with other studies, the reliability of our counts remains doubtful for several reasons. The chlorophyll determinations for Nelly Island and Casey base suggest that soils at Nelly Island have about thirty times higher algal abundance than do those at Casey base; however, this ratio is not paralleled by the actual algal counts. In addition, the ratios of chlorophyll *a*:*c* suggest that the algal flora of Casey base should have a significantly greater proportion of xanthophycean and bacillariophycean algae than Nelly Island; this is not shown by actual algal counts. There are several possible explanations: first, considerable time elapsed between the collection and analysis of the samples and the more sensitive forms may have lost some viability as a result. Second, although a variety of culture media was used, including organically enriched ones, some algae (certain cyanobacteria and diatoms) do not necessarily grow on the variations of the BBM medium used.

Despite these doubts and limitations, the soil algal and cyanobacterial flora appears to consist of abundant populations of relatively few species. Particularly in areas with nutrient input, e.g. penguin rookeries (Nelly Island) and seabird colonies (Cloyd Island), or with lichens or moss turfs, e.g. Clark Peninsula and Haupt Nunatak, algal and cyanobacterial populations are high, attaining densities of about 1 million phototroph CFU per cm^2 of soil surface. In turn, these data suggest that the density of soil phototrophs is largely determined by the nutrient status or the organic content of the area.

In the present study areas, the soils without guano were similar in dissolved salt contents but lower in pH than those supporting Acari and Collembola in south Victoria Land (Wise & Spain 1967, Spain 1971).

Salts of marine origin strongly influence soil pH in coastal Antarctica (Campbell & Claridge 1987). However, while the measured pH levels at the three island sites were greater than 7.0, they are still lower than those from coastal Victoria Land (Campbell & Claridge 1987). Soils from the Commonwealth Bay, Casey base and Haupt Nunataks sites were slightly acid and perhaps the higher precipitation of coastal Antarctica compared with Victoria Land may be responsible.

Excluding the ornithogenic soils, carbon levels are generally low but may increase where macrophytes are present. However, humus formation is minimal in these soils and much of the soil carbon probably reflects incorporated, but little-decomposed, materials (Campbell & Claridge 1987). Nitrogen levels are also low, as are the C:N ratios; Campbell & Claridge (1987) suggested that an external source of nitrogen may be available, perhaps from nitrogen-fixing organisms or from nitrate in the water-soluble salts. Levels of both these elements are commensurate with those of the protoranker soils in Victoria Land, although they are lower than those of the maritime Antarctic climatic zone (Campbell & Claridge 1987). Total phosphorus levels in the present soils were higher than those reported by Ugolini (1977) but lower than those reported by Holdgate *et al.* (1967) from Signy Island in the maritime Antarctic zone.

The soils known to be influenced by avian faeces showed large increases in the biologically-important elements C, N, P (total and acid-soluble), S, Ca, pH, soluble salts and a reduced C:N ratio. This is consistent with the results of Claridge & Campbell (1966) and Ugolini (1972). Even where no surface guano was noted organic matter could have been influenced by birds. In the ornithogenic soils of Antarctica, the influence of bird faeces on soil organic matter extends beyond areas of thick guano. Claridge & Campbell (1966) showed this in a series of soils from Victoria Land with increasing influences by Adélie penguins ranging from sites that were currently occupied to similar sites showing no evidence of previous occupation.

Decomposition processes and micro-organism activity in many Antarctic soils are largely inhibited by cold and aridity. However, slow losses of organic matter are reported from ornithogenic soils by Campbell & Claridge (1966) and Ugolini (1972) and must be correspondingly greater in locally moist areas. High levels of largely soluble phosphorus and nitrogen would be expected to encourage high productivity in micro-organisms during the summer periods when moisture and temperature conditions are more favourable than at other times.

Because of these considerations and previous analyses by Spain (1971) and Smith & Steyn (1982), it was predicted that a strong positive correlation of numbers of micro-organisms with moisture content and organic matter content of soils would be found. Such was not the case. Whereas the abundance of bacteria was strongly correlated with the pH of the soil, the more alkaline soils having a greater number of bacteria than the more acidic ones, moisture content of the sample showed no correlation and organic matter content a positive but insignificant one. Possible reasons for these results may be:

a. Water content is an ephemeral condition and when measured at the time of sampling may not accurately reflect recent history or long-term conditions (see Cameron 1971).
b. The highest content of organic matter occurred where soils were enriched by penguin or other seabird guano. Penguin faeces contains acrylic acid which acts as a microbial antagonist (Boyd 1967). The action of this chemical may have inhibited bacterial growth in the soils rich in organic matter. Meyer *et al.* (1967) found that guano had bacterial counts one fifth lower than the next most organic soil type.
c. The gravimetric determinations may not have been good indicators of water availability. Soil moisture is dependent on bulk density, grain size and other factors. For soils of different specific gravities, a given percent moisture content may reflect quite different water potentials. However, it appears from Table I that topography controlled the moisture status of many of the sampling sites rather than internal soil properties such as clay and organic matter content. The majority of the wetter sites were near ponds, on or beside melt-water channels, or at the edge of snow patches. In the wetter of these soils, free water would have been present when soil temperatures were above freezing and this is not related to the water holding capacity.

In the soils from well-drained sites, water holding capacity is of greater importance. Because of the generally low clay and organic matter contents of Antarctic soils (Campbell & Claridge 1987), water holding capacity is generally low. Spain (1971) showed that at a number of 'dry' locations in south Victoria Land, moister conditions were locally present at the edges of the snow-filled depressions and ice wedges that defined the frost polygons of patterned ground, and noted increased moss growth and presence of Acari at such sites. Whatever the cause, it is clear that within the range of environmental values encountered in the present study, pH had a greater effect on bacterial numbers than did the content of either organic matter or moisture.

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