PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Bacteria, Fungi and protozoa in signy Island Soils Compared with those from a Temperature Moorland

O. W. Heal, A. D. Bailey and Pamela M. Latter

Phil. Trans. R. Soc. Lond. B 1967 **252**, 191-197
doi: 10.1098/rstb.1967.0011

Bacteria, fungi and protozoa in Signy Island soils compared with those from a temperate moorland

By O. W. Heal, A. D. Bailey* and Pamela M. Latter
The Nature Conservancy, Merlewood Research Station, Grange-over-Sands, Lancashire

During the past 100 years many papers have been published on Antarctic microbiology in general and that of the soil, snow and ice in particular. However, there are still contradictory statements in the recent literature concerning the scarcity or abundance of micro-organisms in Antarctic soil, the similarities and differences in the composition of the soil microflora and microfauna of Antarctic and temperate soils, and the extent to which the Antarctic micro-organisms are adapted to grow at low temperatures. Many of the microbiological studies of the Antarctic lack detailed information concerning the habitat and detailed comparisons with temperate soils. As a result of opportunities provided by the British Antarctic Survey, microbiological investigations have been made on Signy Island in the South Orkneys and on soil samples and cultures transported to England. The results of these studies are compared here with similar studies made on soils of the Moor House National Nature Reserve in northern England. The paper also draws on the considerable information available concerning the climate, vegetation and soils of the two areas.

Three groups of heterotrophic micro-organisms, bacteria, fungi and testate amoebae, have been studied to obtain information on their species composition, distribution and abundance in the soils. An examination of the temperature tolerance of some of the isolates was also made. Full results of these studies have been published or are in preparation (Heal 1965; Bailey in prep.; Latter & Heal in prep.; Latter & Cragg 1967; Latter, Cragg & Heal 1967).

Sites

Signy Island is approximately 8×5 km rising to 280 m above sea level. Its temperature regime and vegetation are typical of the maritime Antarctic zone and are described by Holdgate (1964) and in other papers in this Discussion. Six soils have been examined on Signy Island, including *Deschampsia* grassland, moraine, marble soil and peats under moss.

Moor House N.N.R. is an area of Pennine moorland approximately 550 m above sea level dominated by mixed moor vegetation (*Calluna–Eriophorum–Sphagnum*) on blanket peat with outcrops of Carboniferous limestone which bear grassland. It has a cold temperate climate (Manley 1936) with mean monthly air temperatures ranging from -1 to 11 °C compared with -12 to 1 °C at Signy Island. The geology and soils have been described by Johnson & Dunham (1963) and some aspects of animal ecology by Cragg (1961). The microbiology of four soil and vegetation types has been examined.

Although six sites have been examined on Signy Island and four at Moor House, the present paper concentrates on grassland sites on the two areas because they are most closely comparable in vegetation and soil type. The Signy Island grassland consists of a

* Formerly with the British Antarctic Survey.

turf of *Deschampsia antarctica* Desv. over fibrous peat or loam. The mineral soil, developed from quartz-mica-schist, contains between 10 and 40 % organic matter and has a pH 4·8 to 6·2 (Holdgate, Allen & Chambers 1967). At Moor House the *Festuca–Agrostis* grassland is on a shallow red-brown limestone soil with 18 to 36 % organic matter and a pH 4·6 to 5·6.

The quantity of micro-organisms

Quantities of micro-organisms in the two grassland sites have been estimated by standard dilution culture on tryptone soya or nutrient agar for bacteria and by the Jones & Mollison (1948) direct count method for bacteria, fungi and testate amoebae. The results (table 5) show that amounts of micro-organisms are similar in the two sites, the range of numbers overlapping in most cases. The only anomaly is the small amount of unstained mycelium in the Signy soil. The stained and unstained mycelium gives an approximate indication of the proportion of live and dead mycelium and the high proportion of stained mycelium in Signy soils is unusual. However, it was noted that staining was much less intense in Signy organisms than for comparable Moor House material. The significance of this is not understood.

There is, however, considerable variation in the numbers of micro-organisms in the different soils of the two areas. For example, dilution counts of bacteria on Signy Island vary from $16 \times 10^6/\text{cm}^3$ in grassland to 4×10^3 in peat under moss, while at Moor House they vary from 13×10^6 in the grassland to 8×10^3 in eroded bare peat.

The above results suggest that soil type has a much greater influence on quantities of micro-organisms than does the climatic zone.

The large quantity of micro-organisms present in the Signy Island grassland suggest a good food supply as a basis for the food chains described by Gressitt (1964) and Dalenius (1965). However, it should be remembered that the results recorded represent the standing crop. Because of the limited period of warm weather in which reproduction takes place the annual production may be much lower than in temperate soils.

Species composition of the microflora and fauna

Taxonomic studies on fungi and testate amoebae showed that the Signy Island grassland contained slightly fewer species than the Moor House grassland. Thus only 15 species of microfungi were recorded in the *Deschampsia* grassland after repeated isolations from dilution cultures and Warcup plates on Czapek-Dox agar, while 25 species were recorded from the Moor House grassland in a more limited study using Warcup plates with Lochhead soil extract and Sewell slide traps with Czapek-Dox agar. Similarly, only one species of toadstool was observed on the Signy site compared with six species at Moor House. For testate amoebae 18 and 28 species were recorded from the Signy and Moor House grasslands respectively using similar numbers of soil extract cultures and Jones & Mollison slides. Preliminary studies suggest a similar restriction in the number of bacterial strains.

On Signy Island the fungi of the *Deschampsia* grassland were dominated by sterile dark forms of mycelium with *Verticillium* and *Geomyces* spp. also common. *Mortierella* spp. were common in the other soils. In a preliminary study of bacteria of the *Deschampsia* grassland

Gram-negative rods, including *Pseudomonas striata*, *P. arvilla* and *P. boreopolis* (kindly identified by Dr Margaret M. Taylor) were the commonest bacteria in the upper horizons, with *Arthrobacter* spp., *Streptomyces* sp., micrococci, and bacilli, including *B. subtilis*, also present. As noted by Flint & Stout (1960) chromogenic bacteria were common in the Antarctic soil. On a soil extract/yeast extract agar, pink, orange and yellow colonies comprised 20 % of the colonies from the Signy grassland, but only 8 % of those from the Moor House grassland.

Table 5. The quantity of micro-organisms/cm^3 in grassland soils of Signy Island and Moor House

	Signy Island	Moor House
fungi		
stained	66–400 metres	160–600 metres
unstained	0–12 metres	100–400 metres
bacteria		
direct count	$7\text{–}26 \times 10^9$	$2\text{–}8 \times 10^9$
dilution count	$1\text{–}16 \times 10^6$	13×10^6
testacea	9×10^3	7×10^3

The testate amoebae are the only group for which we have numbers of particular species and in a limited study direct observations showed that one species *Corythion dubium* Taraneck constituted 72 % of the population in the grassland. This high proportion of one species is characteristic of extreme habitats where a large number of individuals is associated with a restricted number of species. This was also observed in the Antarctic by Decloitre (1964) and Penard (1913) for testate amoebae and by Corte & Daglio (1964) for fungi.

The majority of forms isolated from Signy soils have been identified as known temperate species and no obviously different forms were observed, corresponding with the observations of di Menna (1960) for yeasts and Corte & Daglio (1964) for fungi. However, a number of common temperate soil forms present at Moor House were not recorded from Signy Island soils. Most of these belong to a few distinct genera, in particular the fungi *Penicillium*, *Trichoderma* and *Mucor* and the testacean genus *Nebela*. Many of these organisms have resistant stages which are readily transported by wind, and studies of the Antarctic air spora show the presence of micro-organisms of wide geographic distribution which do not grow under the Antarctic conditions (Corte & Daglio 1964; Sieburth 1965). On Signy Island sterile Czapek-Dox agar plates exposed to the atmosphere at 6 to 8 ft. above ground level developed a high proportion of *Penicillium* spp. but no penicillia were isolated from the soil. The results indicate that although the soil receives a wide variety of temperate micro-organisms as an aerial inoculum, only some of these grow and survive under the prevailing conditions.

Growth in relation to temperature

Fungi and bacteria isolated from Signy Island and Moor House soils were tested for their ability to grow at low temperatures to find if their temperature tolerance was correlated with their distribution in the two sites.

Fungi isolated by standard plating techniques at 25 °C from all the soils on Signy Island and at Moor House were grown at 1, 14 and 25 °C and colony diameter after 10 days

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

growth was used as the criterion of growth. Twenty-five isolates belonging to at least eleven species were tested from Signy and seventy-one isolates from at least eighteen species were tested from Moor House. To facilitate comparison of the two floras which contain a mixture of fast and slow growing forms, for each species the growth at 1 °C is expressed as a percentage of its growth at optimum temperature. All the Moor House fungi and 88 % of those from Signy Island showed optimum growth at 25 °C, the remaining 12 % having optimum growth at 14 °C.

Table 6. The growth of fungi from Signy Island and Moor House in relation to temperature

Growth at 1 °C is expressed as a percentage of the growth at optimum temperature. The percentages are divided into three categories and the percentage of isolates in each category is shown.

growth at 1 °C as % of optimum growth	% of isolates	
	Signy Island	Moor House
more than 20 %	54	13
1 to 20 %	46	80
less than 1 %	0	8

The isolates from Signy Island showed a greater ability to grow at low temperatures than did the Moor House fungi (table 6). Thus growth at 1 °C was more than 20 % of the optimum growth in 54 % of the Signy Island forms compared with 13 % of the Moor House fungi.

Moor House fungi, which were not isolated from the Signy Island soils, showed relatively poor growth at 1 °C. Thus *Penicillium* and *Trichoderma* spp. showed growth at 1 °C which was only 4 and 1 % respectively of their optimum growth. In contrast, the growth at 1 °C of *Mortierella* spp. from Moor House was 25 % of their optimum growth and this genus was well represented in Signy soils.

A comparison of the growth of seven unidentified strains of *Mortierella* from Signy Island with six strains from Moor House shows that the former isolates were more cold-tolerant, growth at 1 °C being 43 and 25 % respectively of their optimum growth.

These results indicate that the fungal flora of Signy Island is restricted by the selection of cold-tolerant forms; the cold intolerant forms belong to a number of well defined genera. Although no species which occurred in both sites was tested in this experiment, the results for *Mortierella* and published information on yeasts (Soneda 1961) indicate that there is further adaptation by already cold tolerant forms. This selection and adaptation provides Signy Island with a fungal flora capable of growth at low temperatures and markedly more cold tolerant than the Moor House fungi.

A preliminary study of the temperature relationships of soil bacteria has been made using isolates from cores of *Deschampsia* grassland which were frozen and transported to England, and from cores of the Moor House grassland. Soil and litter suspensions were inoculated onto pre-poured plates of soil extract/yeast extract agar and incubated at 10 °C.

Forty-four randomly selected isolates from Signy Island and thirty-four from Moor House were grown on slopes of the same agar. The growth of each isolate at 1, 13 and 25 °C was assessed visually and compared. The results (table 7) show the marked ability of the Signy Island bacteria to grow at low temperatures. The majority of the Signy isolates grew best at 13 °C in contrast to the Moor House isolates, the majority of which showed best growth at 25 °C. This shift in the optimum growth temperature is similar to that recorded by Sushkina (1960) who compared isolates from an Arctic soil with those from a forest soil near Moscow.

Table 7. The growth of bacteria from Signy Island and Moor House in relation to temperature

The figures show the percentage of isolates and the temperature (°C) at which they showed maximum growth.

growth	Signy Island	Moor House
maximum at 25 °C	2	56
growth at 25 °C = growth at 13 °C	16	16
maximum at 13 °C	50	9
growth at 13 °C = growth at 1 °C	9	6
maximum at 1 °C	2	0
equal growth at 25, 13 and 1 °C	21	12

Summary and conclusions

A comparison of the bacteria, fungi and protozoa of a maritime Antarctic and a cold temperate site shows that the numbers of micro-organisms are similar in similar soils but vary greatly with different soil and vegetation types. This suggests that soil and vegetation type have a greater influence on numbers than does the climate. The number of species is restricted in the Antarctic soil and an examination of the fungal flora shows that the species present are typical soil forms found in temperate zones.

Studies on growth in relation to temperature show that the species present in the Antarctic soils are cold-tolerant forms which probably show further cold adaptation. The species which are absent belong to a number of well defined cold-intolerant genera. Although these were not isolated from the soil they probably occurred in the air spora. Thus the conclusion of Holdgate (1964) that ecological rather than distributional factors are of prime importance in determining the nature of Antarctic vegetation probably applies to micro-organisms.

The rate of decomposition appears to be slow despite the presence of large numbers of micro-organisms, in moderate variety, and adapted to grow in a cold climate. Cellulose films inserted in the soil to indicate the rate of decomposition showed considerable decomposition in the grassland site on Signy Island in 12 months, while on the limestone grassland site at Moor House similar films decomposed within 4 months. It is very unlikely that there is a shortage of available nutrients (see Allen & Northover preceding paper). Thus the slow rate of decomposition is probably a direct result of the low temperature and the restricted period during which microbial activity can take place. Douglas & Tedrow (1959) came to a similar conclusion for Arctic soils.

Although decomposition is restricted there is no marked accumulation of organic matter on the grassland site on Signy Island and the C/N ratio of 9 to 17 is typical of a soil in which decomposition is relatively complete. Thus although the rate of decomposition is restricted by the climate it can keep pace with production and the organic cycle appears to be comparable with that of the temperate grassland. In other areas on Signy Island there is accumulation of organic matter as peat under moss. Here decomposition does not keep pace with production but it is unlikely that this is a direct result of the restriction of microbial activity by low temperatures, as suggested by Bunt & Rovira (1955) for Macquarie Island. It is more likely to be a characteristic of the particular soil type which is controlled by the parent material, vegetation, drainage, climate and other factors.

The authors are very grateful to the British Antarctic Survey for providing the opportunity to work on the microbiology of Signy Island. We are also indebted to Dr Margaret M. Taylor of The Hannah Dairy Research Institute, Scotland for identifying the *Pseudomonas* spp., and to Dr A. H. Rose of the University of Newcastle for permission to use unpublished data of Miss J. D. Telford.

References (Heal *et al.*)

Bailey, A. D. (in preparation). Microbiological studies on some soils from Signy Island, South Orkney Islands.

Bunt, J. S. & Rovira, A. D. 1955 Microbiological studies of some subantarctic soils. *J. Soil Sci.* **6**, 119–28.

Corte, E. & Daglio, C. A. N. 1964 A mycological study of the Antarctic air. In *Biologie Antarctique*, pp. 115–20. (Ed. Carrick, R., Holdgate, M. W. and Prévost, J.) Paris: Hermann.

Cragg, J. B. 1961 Some aspects of the ecology of moorland animals. *J. Ecol.* **49**, 477–506.

Dalenius, P. 1965 The acarology of the Antarctic regions. In 'Biogeography and ecology in Antarctica'. (Ed. Mieghem, J. van and Oye, P. van.) *Monographiae biol.* **15**, 414–30.

Decloitre, L. 1964 Thecamoebiens de la XII ème Expédition Antarctique Francaise. *Exp. Polaires Françaises* (*Mission Paul Emile Victor*) Publ. no. 259, 47 pp.

Douglas, L. A. & Tedrow, J. C. F. 1959 Organic matter decomposition rates in Arctic soils. *Soil Sci.* **88**, 305–12.

Flint, E. E. & Stout, J. D. 1960 Microbiology of some soils from Antarctica. *Nature, Lond.* **188**, 767–8.

Gressitt, J. L. 1964 Ecology and biogeography of land arthropods of Antarctica. In *Biologie Antarctique*, pp. 211–22. (Ed. Carrick, R., Holdgate, M. W. and Prévost, J.) Paris: Hermann.

Heal, O. W. 1965 Observations on testate amoebae (Protozoa: Rhizopoda) from Signy Island, South Orkney Islands. *Br. Antarctic Surv. Bull.* no. 6, 43–47.

Holdgate, M. W. 1964 Terrestrial ecology in the maritime Antarctic. In *Biologie Antarctique*, pp. 181–94. (Ed. Carrick, R., Holdgate, M. W. and Prévost, J.) Paris: Hermann.

Holdgate, M. W., Allen, S. E. & Chambers, M. J. 1967 Factors influencing the availability of plant nutrients on an Antarctic Island. *Br. Antarctic Surv. Bull.* (in the Press).

Johnson, G. A. L. & Dunham, K. C. 1963 The geology of Moor House, a National Nature Reserve in north-east Westmorland. *Monographs of the Nature Conservancy*, no. 2, 182 pp. London: H.M.S.O.

Jones, P. C. T. & Mollison, T. 1948 A technique for the quantitative estimation of soil microorganisms. *J. gen. Microbiol.* **2**, 54–69.

Latter, P. M. & Cragg, J. B. 1967 The decomposition of *Juncus squarrosus* leaves and microbiological changes in the profile of *Juncus* moor. *J. Ecol.* (in the Press).

Latter, P. M., Cragg, J. B. & Heal, O. W. 1967 Comparative studies on the microbiology of four moorland soils in the northern Pennines. *J. Ecol.* (in the Press).

Latter, P. M. & Heal, O. W. (in preparation). Growth of fungi and bacteria from temperate and antarctic soils in relation to temperature.

Manley, G. 1936 The climate of the northern Pennines: the coldest part of England. *Q. Jl. R. met. Soc.* **62**, 103–15.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Menna, M. E. di 1960 Yeasts from Antarctica. *J. gen. Microbiol.* **23**, 295–300.

Penard, E. 1913 Rhizopodes d'eau douce. In *Deuxiéme Expédition Antarctique Francaise* (1908–10), *Sciences Naturelles: Documents Scientifiques*, pp. 1–16. Paris.

Sieburth, J. McN. 1965 Microbiology of Antarctica. In 'Biogeography and ecology in Antarctica'. (Ed. Mieghem, J. van and Oye P. van). *Monographiae biol.* **15**, 267–95.

Soneda, M. 1961 On some yeasts from the Antarctic region. *Spec. Publs. Seto mar. biol. lab. Japanese Antarctic Research Expedition, Biological Results*, no. 15, 10 pp.

Sushkina, N. N. 1960 [Characteristics of the microflora of Arctic soil.] *Pochvovedenie* **4**, 57–67.

BIOLOGICAL SCIENCES
THE ROYAL SOCIETY
PHILOSOPHICAL TRANSACTIONS OF