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Microbial populations in Marion Island soils

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Mire and bog peats on Marion Island (46° 54'S, 37° 45'E) yielded higher plate-count estimates of viable aerobic bacteria and of fungi than did soils from slope areas when expressed on a soil dry weight basis. The single fjaeldmark site investigated contained very low numbers of soil microorganisms. Manuring by seabirds and seals markedly enhanced soil N and P contents and manured sites exhibited greater populations of soil bacteria and fungi than non-manured sites. Plate-count estimates of soil microorganisms from the various island habitats were approximately similar to those reported for comparable habitats at other southern subpolar areas. The microorganisms were associated with the particulate rather than the peat solution fraction. At manured sites large numbers of microorganisms capable of reducing NO₃⁻ to NO₂⁻ and, tentatively, of bacteria

forming NH₃ from NO₃⁻ were found. The numbers of bacteria at these sites capable of reducing NO₃⁻ to N₂ were low.

Moerasveengrond op Marioneiland (46° 54'S, 37° 45'O) het by berekening op 'n grondslag van die droë grondmassa hoër plaattellings aërobe bakterieë en swamme gelewer as grond van hellinggebiede. Klein getalle mikroörganismes het in 'n fjaeldmark-gebied voorgekom. Die uitskeidings van seevoëls en robbe het die grond se N- en P-inhoud asook die mikroöbevolking verhoog. Die getalle grondmikroörganismes in verskeie habitats op Marioneiland het ooreengekom met wat in soortgelyke habitats op ander suidelike subpoolgebiede gevind is. Die mikroörganismes was met gronddeeltjies eerder as met die grondwaterfraksie geassosieer. By gebiede wat deur diere

bewoon word, kom hoë getalle mikroörganismes voor wat NO₃⁻ tot NO₂⁻, en moontlik tot NH₃, kan reduseer. Die getal denitrifiserende bakterieë in die grond was gering.

Introduction

Marion Island (46° 54'S, 37° 45'E) is volcanic in origin and experiences a cool oceanic climate dominated by a high incidence of gale-force winds and very high precipitation. The distribution of the island plant communities is largely determined by wind exposure, soil water regime and the degree of trampling and manuring by animals. At many sites the growth of vascular plants is severely limited by climatic conditions, often aggravated by poor soil nutrient status (Smith 1977).

A scant *fjaeldmark* vegetation dominated by cushion-forming species occurs at higher altitudes (> 500 m above sea level) and on windswept rocky ridges of the lowland plain. Protected lowland slopes are well vegetated by fernbrake communities consisting of a continuous or almost continuous cover of *Blechnum penna-marina* often co-dominant with *Poa cookii*, *Acaena magellanica* or *Azorella selago*. The poorly drained basins between these slopes are occupied by bog and mire vegetation dominated by bryophytes and graminoid species (notably *Agrostis magellanica*, *Juncus scheuchzerioides* and *Uncinia compacta*). At many lowland sites seabirds or seals markedly modify the vegetation by allowing the growth of coprophilic and trampling-resistant species. Comprehensive accounts of the patterns occurring in the island vegetation are provided by Huntley (1971) and Gremmen (1981), who grouped the various plant communities into several complexes: slope, swamp (mire, spring and flush), salt-spray, biotic and wind-desert (*fjaeldmark*).

Soil microorganisms influence, and are influenced by, plant growth since they make available nutrients through mineralization and utilise extracellular products of the plant roots (Alexander 1977). Plant communities with a high productivity generally support greater numbers of soil microorganisms because of the increased availability of energy-yielding substrates (Holding *et al.* 1974).

Inspired by the IBP Tundra Biome Project, there has been a recent increase in microbiological literature describing relationships between soil microorganisms and site characteristics at northern subpolar areas. Little comparable work has been done on the microbial flora of sub-Antarctic terrestrial regions. This paper presents the results of plate-count enumerations of viable aerobic soil bacteria and fungi at 21 Marion Island sites. The sites represent a wide range of habitats which may be grouped into four community complexes: *fjaeldmark*, protected lowland fernbrake slopes, a variety of mire types and biotically influenced areas. In this account the term "biotic" refers to the influence of animals through manuring and trampling. At three sites, most probable number (MPN) estimates were made of the numbers of microorganisms reducing nitrate.

Methods

Microbiological analyses

After removing the living vegetation and surface litter a 13 cm-deep soil core was obtained using a stainless steel peat corer. The cores were transported to the laboratory in new polyethylene bags. Within 8 hours of sampling a longitudinal subsample was sliced from the centre of the core, placed in quarter-strength sterile Ringer's solution and shaken vigorous-

ly for 2 minutes. Serial dilutions of the suspension were plated onto Soil Extract Agar for bacterial enumeration and onto Martin's Rosebengal-Streptomycin Agar for fungal enumeration (Allen 1957). After incubation for 6 days at 20 °C visible colonies were counted. All microbiological analyses were carried out in duplicate and the results expressed on a soil dry weight basis by correcting for the water content of the fresh samples.

At three sites perforated PVC tubes were driven into the holes made by the corer and the solution which entered the tubes sampled using sterile pipettes. Microorganism concentrations in the peat solution were determined using Soil Extract Agar and Rosebengal-Streptomycin Agar. The solution counts were compared with those associated with the solid peat particles.

MPN estimates of denitrifying bacteria were made according to the method and medium recommended by Valera and Alexander (1961). The production of gas and an alkaline reaction in the tube after 30 days incubation at 20 °C were taken to indicate denitrification. Many tubes showed an alkaline reaction without gas evolution and their contents were tested for NO₂⁻ and NO₃⁻ by the Gries-Ilosvay reaction. NO₃⁻ was reduced with Zn to NO₂⁻ prior to detection.

Soil chemical analyses

Soil pH was determined using a combination electrode immersed in a slurry of freshly-collected soil (1 part soil: 2 parts water). Soil moisture content was determined by drying a subsample of soil at 105 °C for at least 48 hours. "Available" P was determined using a resin-extraction procedure described in Smith (1979). A similar resin procedure using cation resin (Dowex AG 50W / 8) for NH₄⁺-N and anion resin (Dowex AG 1 × 8) for NO₃⁻-N was utilised to estimate the amounts of "available" inorganic N in the soils (V.R. Smith unpublished). All nutrient analyses were performed on soil within 12 hours of sampling.

Results and Discussion

Analyses of microorganism contents of the solid and liquid fractions of three nutrient-poor mire peats indicated that both bacteria and fungi were predominantly associated with the particulate fraction and that relatively few cells occurred in the peat solution (Table 1). The peat particles form sites of attachment for the microorganisms and are potential nutrient sources (Marshall 1978). The particles also represent high energy surfaces, possessing substantial cation exchange capacities (Smith 1978) and are therefore sites of potential nutrient accumulation from the aqueous phase. Several authors (Dexter *et al.* 1975, DiSalvo & Daniels 1975) have reported greater attachment of bacteria to high energy than to low energy surfaces and under low nutrient conditions coloniza-

Table 1

Numbers of microorganisms associated with the solid and liquid components of the peat at three mire sites.

Site:	Bacteria × 10 ⁴			Fungi × 10 ⁶		
	1	2	3	1	2	3
per g dry peat	237	1020	1250	417	257	47
per associated volume of soil water	3	7	11	12	4	2

Table 2

Soil microorganism counts* (mean ± standard deviation; range) from four Marion Island community complexes.

Community Complex	N**	Viable aerobic Bacteria ($\times 10^4$)	Fungi ($\times 10^6$)
Lowland slopes	4	200 ± 148; 20-366	92 ± 99; 15-232
Mires and bogs	6	569 ± 475; 42-1250	232 ± 241; 7-606
<i>Fjaeldmark</i>	1	10	0,05
Biotically influenced	10	6689 ± 16941; 94-54700	432 ± 494; 2-1570

* colony-forming units per g dry soil

** N = number of sites investigated

tion of particles by bacteria is greater than under high nutrient conditions, when they may be uniformly distributed within the aqueous phase (Jannasch 1958).

Bacterial and fungal counts from the four community complexes are presented in Table 2. Table 3 provides estimates from comparable sites at other sub-Antarctic and maritime Antarctic islands.

Mire and bog peats exhibited greater numbers of microorganisms per unit soil dry weight than did the more mineral slope soils. Bacterial counts from the bogs and mires ($42 \times 10^4 - 1250 \times 10^4 \text{ g}^{-1}$ peat), are broadly similar to those from boggy herbfields ($430 \times 10^4 - 1170 \times 10^4 \text{ g}^{-1}$) and wet grasslands ($710 \times 10^4 - 1790 \times 10^4 \text{ g}^{-1}$) at Macquarie Island and also to those from wet peat under moss banks at Signy Island ($0,4 \times 10^4 - 646 \times 10^4 \text{ g}^{-1}$). Fungal populations at the Macquarie Island sites are also approximately similar to the Marion Island bogs and mires (Tables 2 and 3). Soil bacteria counts from a *Festuca contracta* grassland on South Georgia were very much lower than grassland and mire sites at either Macquarie or Marion islands.

The *fjaeldmark* soil sample analysed in this investigation consisted of a skeletal conglomeration of fine volcanic ash with pebble-sized stones and possessed very small populations of microorganisms. The sample was collected from an area devoid of vegetation and Smith (1977) has shown that such soils contain very low quantities of organic matter and are extremely nutrient-poor. At areas where cushion plants occur, an appreciable amount of organic matter may accumulate so that the *fjaeldmark* microbial counts in Table 2 are probably representative of the lower values likely for the islands *fjaeldmark* complex. Other investigators have also found lower soil microorganism numbers at *fjaeldmark* than at herbfield or grassland soils on Macquarie Island (Table 3). However, the *fjaeldmark* sites investigated on this island contained appreciable organic matter contents (up to 12,5%; Bunt 1965), possibly explaining their relatively high microbial populations compared with the Marion Island sites.

Moraine sites on Signy Island possess mineral soils underlying an extensive rock cover and vegetated only by lichens and a few mosses. These sites and those consisting of schist and marble outcrops (Table 3) are comparable with Marion Island *fjaeldmark*. Surprisingly large numbers of bacteria were found at these Signy Island sites, especially in view of the fact that Holding *et al* (1974) showed that the Tryptone Soya Agar medium used gave consistently low viable counts, compared with other media over a range of subpolar and other sites.

Table 3

Soil microorganism counts (colony-forming units per g⁻¹ dry soil) at other southern subpolar localities.

Locality and site	Bacteria ($\times 10^4$)	Fungi ($\times 10^6$)	Total microorganisms ($\times 10^4$)
Macquarie Island (54°S) ¹			
<i>fjaeldmark</i>	120-310	23-45	
herbfield; boggy peat	430-1170	4-141	
grassland slopes	710-1790	13	
coastal tussock, influenced by seals	1520	141	
beach grassland	710	16	
Macquarie Island ²			
<i>fjaeldmark</i>			24-149
seal-influenced coastal site			253-509
Signy Island (60°S) ³			
old moraine	147-250		
new moraine	153		
marble knoll	3-28		
schists	86-425		
moss-banks	5-646		
grasslands	138-2300		
Signy Island ⁴			
grasslands	100-1600		
moss-bank	0.4		
Signy Island ⁵			
moss-bank (1-2 cm depth)	49		
moss-bank (6-7 cm depth)	116		
South Georgia (55°S) ⁶			
grassland (sheltered)	0.6-3.2		
grassland (exposed)	0.1-1.3		
Campbell Island (53°S) ⁷			
stunted shrub (0-2,5 cm depth)	620		
Stewart Island (47°S) ⁷			
grassland	37		

¹ Bunt (1965) table 3, and Jenkin (1975) Table 6. Czapek's agar.

² Bunt and Rovira (1955) table 2. Soil extract agar

³ Holding, *et al* (1974) table 1. Tryptone soya agar

⁴ Heal, Bailey and Latter (1967) table 5. Tryptone soya agar

⁵ Baker (1970), table 1. Tryptone soya agar

⁶ Smith and Stephenson (1975), table 10. Egg albumin agar

⁷ Stout (1961), table 5 (Stewart Island) and table 6 (Campbell Island). Glucose tryptone yeast extract agar and Gelatin nutrient agar respectively.

Biotically-influenced sites on Marion Island generally contained much larger populations of soil microorganisms than did uninfluenced sites. Contents of inorganic N and P were also substantially higher in the manured soils (Table 4). This supports previous observations by Lindeboom (1979), who found very high concentrations of bacteria in the soil solution of areas influenced by wandering albatrosses, penguins or elephant seals on Marion Island. At Macquarie Island, sites frequented by elephant seals also exhibited higher populations of soil microorganisms than did uninfluenced sites (Bunt & Rovira 1955).

The mean estimates in Table 2 of microbial populations for the biotic sites include counts from a coastal area subjected to deposition of guano and mollusc shells by kelp gulls and also

Table 4

Inorganic N and "available" P contents ($\mu\text{g g}^{-1}$ dry soil) at manured and non-manured sites.

	N	Inorg.-N	Available P
Non-manured sites	11	44 \pm 33	17 \pm 13
Manured sites	10	184 \pm 229	148 \pm 246

Table 5

MPN estimates of nitrate-reducing bacteria at three manured sites.

Site	Bacteria $\times 10^3 \text{ g}^{-1}$ dry soil			
	Product formed:	N_2	NO_2^-	$\text{NH}_3?$
1		20,2	2070000	35300
2		1,3	551	340
3		1,9	9240	1790

to manuring by rockhopper penguins. Here, bacterial counts were ten times and fungal counts double those at any other site. At Paradise Harbour (Antarctic Peninsula) Boyd, Rothenberg and Boyd (1970) found that sites similarly influenced by kelp gulls exhibited high inorganic N and P contents and also supported very large numbers of soil microorganisms.

MPN estimates of bacteria capable of reducing NO_3^- at three manured sites are presented in Table 5. Site 1 was the coastal area influenced by kelp gulls and rockhopper penguins, Site 2 the margin of a recently abandoned elephant seal wallow and site 3 an area adjacent to an occupied wandering albatross nest.

Low numbers of gas-forming bacteria were found at the three sites. It was assumed that the gas evolved was N_2 (Valera & Alexander 1961), but this was not established experimentally and N_2O may also have been formed. Lindeboom (1979) found low numbers of denitrifying bacteria in the soil solution of unmanured Marion Island sites ($1 \times 10^3 - 3 \times 10^4$ bacteria ml^{-1}), but substantially higher numbers at areas grossly contaminated by manuring. He showed that the highest denitrifying populations (up to 4100×10^8 bacteria ml^{-1}) occurred at sites containing high ammonium and nitrate concentrations and an abundance of energy sources in the form of organic compounds excreted by the animals.

Large numbers of bacteria capable of reducing NO_3^- to NO_2^- were found at all three sites. Several tubes showing an alkaline reaction also proved negative for NO_3^- , NO_2^- and gas production. It was assumed that dissimilatory nitrate reduction to ammonia by anaerobes as suggested by Thauer, Jungermann and Decker (1977) was responsible for this, but the presence of ammonia in the tubes was not tested for. At Macquarie Island, Bunt and Rovira (1955) found that 20–25 per cent of bacterial isolates from *Sjaeldmark* sites and 30–60 per cent from elephant seal-influenced sites were capable of reducing NO_3^- , but they did not indicate the end product formed.

Conclusions

Plate count enumeration techniques select for organisms capable of growing on the medium used and account for only

a fraction of the total population of soil microorganisms. Between-area comparisons of microbial counts made on different nutrient media must therefore be viewed with caution and it is within these restrictions that the results reported here must be considered. However, the available data suggest that bacteria and fungi counts from the various southern subpolar areas are broadly similar within habitat types, but that large differences occur between habitats within the same area. The South Georgia data set is anomalous in that bacteria counts from the island are lower than those reported for most ecosystems, including the relatively sterile dry valleys of Continental Antarctica (Benoit & Hall 1970, Cameron, King & David 1970).

The Marion Island data indicate that manuring by birds and seals markedly enhances soil microbial populations by adding nutrients and possibly energy sources to the soils. Mire peats contain greater numbers of bacteria and fungi than do the more mineral soils of slope areas if expressed on a soil dry weight basis. However, due to the greater bulk density of the slope soils ($0,13 - 0,16 \text{ g cm}^{-3}$) than the mire peats ($0,04 - 0,09 \text{ g cm}^{-3}$) the numbers of microorganisms at the two habitat-types are approximately similar on a soil volume basis.

Plate counts of fungi from Marion Island, although lower than the bacterial counts, are sufficiently high to warrant Bunt's (1965) assumption that fungi play a significant part in processes of decomposition under sub-Antarctic conditions.

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Animals as agents of erosion at sub-Antarctic Marion Island

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Birds and seals act as agents of erosion on the coastal lowlands of sub-Antarctic Marion Island. Erosion primarily occurs where birds congregate at high densities to breed and is accentuated by the soft-foliage vegetation, easily eroded peaty substrate and wet climate. Different groups of birds - flying surface breeders, flying subterranean breeders and flightless penguins - each have particular erosive effects. Penguins cause most erosion and even affect bedrock. Bird activity causes slumping on steep slopes. The erosive effect of seals is minor.

Voëls en robbe dien as bewerkers van erosie op die kustelike laaglaande van sub-Antarktiese Marion-eiland. Erosie kom hoofsaaklik voor waar voëls in hoë digtheid vergader om te broei en word beklemtoon deur sagte loof plantegroei, die maklik verweerbare turfagtige substraat en die nat klimaat. Verskillende groepe van voëls - vlieënd wat op die oppervlakte broei, vlieënd wat onderaards broei en vluglose pikkewyne, het elk 'n spesifieke erosie effek. Pikkewyne veroorsaak die meeste erosie en selfs ratsbeddings word geaffekteer. Die bedrywighede van voëls veroorsaak ineenstortings teen steil hoogtes. Die erosie effek van robbe is van minder belang.

Introduction

Nowhere is the proportion of sea to land greater than in the southern hemisphere between latitudes 40° and 60°S. This vast productive oceanic region supports large populations of seabirds and seals, all of which must return to land to breed and many also to moult. This results in large, seasonal concentrations of animals on the sub-Antarctic islands. The animals affect the islands in two ways: by transferring minerals and energy from the sea to the land (Burger *et al.* 1978, Siegfried *et al.* 1978, Williams *et al.* 1978) and by vegetation destruction and consequent erosion of the substrate. The role of birds and seals as agents of erosion at Marion Island (46°54'S, 37°45'E) is the subject of this paper.

Environmental Situation

Marion Island (area 290 km²) is the exposed section of a submarine shield volcano (Verwoerd 1971). The island is composed of two basalt lava suites; an older, massive and glaciated grey suite, and a young scoriaceous, blocky and unglaciated black suite. During the last (approximately)