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SOILS AND THEIR MICROBIOLOGICAL PROPERTIES FROM A TRANSECT FROM CAPE HORN TO THE ANTARCTIC PENINSULA

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Abstract: Soils of the southernmost islands of South America (Cape Horn), the Falkland Islands, South Georgia, South Orkneys, South Shetlands, the Antarctic Peninsula and Poulet Island are described and analyzed for soil properties, soil taxonomy and microorganisms. Results showed a great variety of soils. Leptosols, gleysols, regosols, cambisols, podzols, andosols and histosols are described. Podzolization was found in all climatic regions. Influences of bird colonies can be demonstrated by extractable phosphate and low C/N ratios. The bacterial flora is described via total counts (range between 0.06-10.45$\cdot 10^9$ g^{-1} d. wt.) and biomass distributions (range between 0.47-102.7 μg C g^{-1} d.wt.) in different soil layers. Total number or total biomass are not related to geographic or internal soil patterns but to contents of organic matter. Similarly, mean cell volumes of bacteria (range between 0.06 and 0.1 μm^3) are found to be related to nutrient levels. Distributions of bacterial communities show individual patterns of soil profiles and are not related to an overall geographical pattern.

key words: Antarctic, soils, nutrients, microorganisms, size classes

Introduction

Soils of the maritime Antarctic regions have been summarized so far mostly as subantartic brown soils or protorankers (WALTON, 1984; CAMPBELL and CLARIDGE 1987; BOCKHEIM and UGOLINI, 1990), and only few soils of this region have been described as histosols (LEONARDI *et al.*, 1987; FABISZEWSKI and WOJTUŃ, 1993). Recently, subantarctic tundra soils as well as subpolar desert soils from Antarctica have been catagorized as leptosols, gleysols, regosols, cambisols, podzols, andosols and histosols (BÖLTER *et al.*, 1994; BLUME *et al.*, 1997). These soils, partly from the Windmill Islands and partly from King George Island, were located in terraced raised beach systems, periglacial areas and moraines which had different types of vegetation, *i.e.*, grass land, moss beds, lichen heaths. Soils from sub-antarctic islands have been chemically analyzed for Marion Island (SMITH, 1977, 1987), South Georgia (SMITH, 1985), and Îles Crozet (FRENOT, 1987).

However, soil descriptions and taxonomical classifications are rare. They have been summarized by WALTON (1984), SMITH (1993a, b) and by KANDA and KOMÁRKOVÁ (1997). There is a need to analyze soils from other regions of the subpolar region and maritime

Antarctic in order to obtain more comprehensive results about the soils, their pedogenesis and effects on life processes in the terrestrial environments of Antarctica.

This study presents soil data from several locations along a latitudinal transect from Cape Hoorn to the Antarctic Peninsula. Soil sequences are described with respect to the changing climatological regime and vegetation patterns, special attention is given to the microbial communities in these soils.

Materials and Methods

Soils were sampled during a cruise from South America to Antarctica. The sites examined are displayed in Table 1. Soils were described by soil color, texture, roots, humus content, definition of levels at various locations from December 22, 1994 to January 15, 1995. Soil color was determined from Munsell charts directly after sampling. The selection of depth levels follows the recommendations of FAO/UNESCO (1990) and AG BODEN (1994).

Actual water content (AWC: 105°C, 24 h), loss on ignition (LOI: 450°C, 12 h), phosphate (Pv: 105°C, 30% HCl), pH (0.01 M $CaCl_2$), nitrogen (N: colorimetric, JONES, 1991), carbon (C: coulorimetric, SCHEFFER and SCHACHTSCHABEL, 1989) were determined in the laboratory.

Subsamples were analyzed for microorganisms by use of an epifluorescence microscope. Samples were carried deep frozen to Kiel. Bacteria were identified after acridine orange staining and analyzed for length distributions via an image analysis system (LEITZ *Quantimed* 500). Methodological details on sample preparation, staining procedure and biovolume calculations can be found in earlier reports (BÖLTER, 1990, 1995; BÖLTER *et al.*, 1993). Parameters determined are total bacterial number (TBN), total bacterial biovolume (BBV), total bacterial biomass (BBM) and mean bacterial cell volumes (MCV). Further, shares (%) of total counts are presented for individual size classes of cocci (diameter: <0.25 μm; 0.25–0.5 μm) and rods (lengths: 0.5–3.0 μm, steps: 0.25 μm). Size classes were estimated from approximately 250 individual cell measurements per sample.

Results

Soil properties

Soil descriptions are given in Table 1. Most of the soils show processes of humification, some even to deep layers. Only at places with denuded areas and no active plant cover, we found patterns of unstructured soils with very thin layers of organic layers, *i.e.*, on Elephant Island in the vicinity of the glacier, on Deception Island with its special patterns of andosols, and on Paulett Island with its dense bird population. Accumulations of peat to great depth occur at Cape Horn in the humic climate of South America. Other peaty layers remain thin (<1 m) due to restricted and shallow plant growth and slowed humification processes. Soils from the Falkland Islands show weathered layers and dislocations of inorganic and organic matter resulting in podzols and Ortstein. The gradients of humification and production of differentiated soil layers follow a distinct trend from north to south.

This general pattern can be verified by individual descriptors. Bulk density increases

Table 1. Properties of samples taken from sites visited during the cruise.
Samples used for microbiological analysis are marked by an "m". Descriptions of soil layers and soil structure follow the recommendations of the AG BODENKUNDE (1994).

Date Location and site description	Sample	Depth (cm)	Munsell colour	Layer	Structure	Remark
15.1.95 Cape Horn						
55°58′S, 67°17′W						
Terri-gelic Histosol						
Vegetation 100%,	KH 1.1m	0–3	5YR3/1.5	H1	hemic peat	many roots
ridge 100 m a.s.l.	KH 1.2m	3–15	4YR2.8/2	H2	hemic peat	many roots
	KH 1.3m	15–30	4YR3/2	H3	hemic peat	some roots
	KH 1.4m	30–50	4YR3/2	H4	hemic peat	few roots
	KH 1.5	50–70	3YR2.5/2	H5	hemic peat	
22.12.94 Falkland Isld., New Island						
51°43′S, 61°16′W						
Stagni-folic-histosol						
Vegetation 100%,	FA 1.1m	0–5	10YR2.5/1, 10YR2.5/2	O1	coh-fcr	many roots, strong humified
slope 15°SSW,	FA 1.2m	5–20	5YR2.5/2, 5YR7/1	O2	coh-sub	many roots, sand grains bleached
20 m a.s.l.	FA 1.3m	20–30	5YR2.5/1	Ah	sub-pri	many roots, sand grains bleached
	FA 1.4m	30–35	10YR3/2-9YR5/4	AB	coh	few roots
	FA 1.5m	35–45	7.5YR5.5/8, 10YR6/4	Bg1	sub-coh	stones bleached on top
	FA 1.6	45–50	7.5YR3/8, 2.5 YR6/4	Bg2	coh	w-mottles
Stagni-cambic-Leptosol						
Vegetation 80%, rocks,	FA 3.1m	0–8	10YR4/4	Ah	fcr	many roots, organic layer
hill ridge, 50–60 m a.s.l.	FA 3.2m	8–10	10YR5/6	Bgw	coh-pla	few roots
	FA 3.3m	10–20	10YR6/4, 7.5YR5/8	Bg	co	many concretions
22.12.94 Falkland Isld., Carcass Island						
51°15′S, 60°36′W						
Gley-fibric-histosol						
Tussock grass area behind	FA 5.1m	0–17	10YR3/3	O1	fibric peat	many roots, humification
dunes, close to beach	FA 5.2m	17–20	10YR2/1	O2	sapric peat	roots, humification
	FA 5.3m	20–40	10YR5/1	Ah/C	fcr-si	some roots, humification
Haplic Podzol						
Tussock grass in dunes,	FA 6.1m	0–10	7.5YR7/1, 7.5YR5/2	AE	fcr	roots, fumification
vegetation 50%	FA 6.2m	10–18	5YR3/4	Bmh	co-ma	few roots
	FA 6.3m	18–23	10YR3/2.5	fAh	cfr-si	
	FA 6.4	23–30	10YR5/2.5	E	si	

Table 1. Continued.

26.12.94 South Georgia, Cumberland Bay						
54°17′S, 36°30′W						
Dystric Cambisol						
Vegetation 100%, moss	SG 1.1m	0–10	7.5YR2/2	Ah	cr	many roots
grasses, partly snow,	SG 1.2m	10–27	9YR3/5	Bw	cr	few roots
75 m a.s.l.	SG 1.3m	27–40	10YR3/4, 10YR6/7	Bgw	coh	some mottles (6YR5/8, 7.5YR3.5/2)
Stagni-cambic Podzol						
Vegetation 100%,	SG 2.1m	0–5	10YR3/4	Ah	cr	many roots
slope 45° SSW, 75 m a.s.l.	SG 2.2m	5–14	10YR4.5/3	AE	fcr	many roots
	SG 2.3m	14–22	7.5YR3/4	Bh	fcr	many roots
	SG 2.4	22–30	10YR5/4	Bs	fcr	roots
	SG 2.5	30–40	6YR4/6	Bhs	cr-pla	few roots
	SG 2.6	46–55	2.5YR5/5	Bw	pla-sub	few roots
	SG 2.7	55–70	5YR4/3	Cg	co-sub	mottles
Fibric Histosol						
Vegetation 100%, moss	SG 3.1m	+5–0	moss cover			
(close to SG1 and SG2)	SG 3.2m	0–5	7.5YR2/2	H1	fibric	many roots
	SG 3.3m	5–14	10YR2/2	H2	hemic	
	SG 3.4m	14–27	10YR2/2	Ah	fcr	
27.12.94 South Georgia, Golden Harbour						
54°10′S, 37°28′W						
Humi-gelic Gleysol						
Slight depression on	SG 4.1m	0–5	moss cover			very wet
slope 2°E, 50 m a.s.l.	SG 4.2m	5–10	5YR3/2	H1	fibric	many roots
	SG 4.3m	10–20	10YR3/2	Ah	fcr	many roots
	SG 4.4m	20–35	5Y4/2	AC		>35 cm permafrost
29.12.94 South Orkneys, Coronation Island						
60°45′S, 45°10′W						
Fibri-gelic Histosol						
Vegetation 50%, mooses	SO 1.0m	+4–0	moss cover			
and lichens, polygones,	SO 1.1m	0–12	5YR3/2	H1	fibric peat	
slope 20°WSW,	SO 1.2m	12–20	2.5YR2.5/2	H2	hemic peat	
200 m a.s.l.	SO 1.3	20–28	5YR2.5/1	H3	hemic peat	wet, >28 cm : rock
Humi-gelic Leptosol						
Vegetation 100%,	SO 2.1am	+4–0	vegetation cover			
(*Deschampsia antarctica*),	SO 2.1bm	2–9.5	7.5YR3/2	O	hemic org. layer	many roots
slope 20°S, 180 m a.s.l.	SO 2.2m	9.5–16	15YR2/2	Ah	pla-coh	many roots
	SO 2.3m	16–30	3YR2.5/2	Bw	coh-pla	stones>70%

Table 1. Continued

30.12.94 Elephant Island						
61°10′S, 55°30′W						
Eutri-gelic Regosol						
Vegetation 33%, (mooses,	EL 1.1m	0–1	N3.5/0	Ah	si-coh	some roots
lichens), moraine slope	EL 1.2m	1–10	5B4/1	C1	coh	
10°E, 10 m a.s.l.	EL 1.3m	10–40	5BG4/1	C2	coh	
	EL 1.4m	40–60	5BG4.5/1	C3	coh	(no permafrost at 60 cm)
31.12.94 Paulett Island						
63°33′S, 53°18′W						
Ornithogeli-gelic Regosol						
slope 45°S, 40 m a.s.l.	PO 1.1m	0–1	10YR2/2	Ah	pri-coh	some hyphae
close to bird colonies	PO 1.2m	1–10	9YR2/2	C1	si	
	PO 1.3m	10–30	9YR2/2	C2	si	
	PO 1.4m	30–40	6YR3/2	C3	si	>45 cm: permafrost
1.1.95 Paradise Bay, Antarctic Peninsula						
64°53′S, 62°53′W						
Fibri-gelic Histosol						
Ridge, 30 m a.s.l.	PB 1.0	+3–0	moss cover			
	PB 1.1m	0–5	5YR4/1	L		dead moss
	PB 1.2m	5–20	5YR2.5/2	H1	fibric peat	
	PB 1.3m	20–25	5YR2.5/2	H2	hemic peat	>25 cm: rock
1.1.95 Peterman Island						
65°04′S, 59°18′W						
Fibri-gelic Histosol						
Vegetation 5–10%, (moss),	PE 1.0m	0–2	5YR4/2		moss cover	
trough filled with debris,	PE 1.1m	2–4	10YR6-3/1	Ah1	si-coh	
close to penguin colony	PE 1.2m	4–6	5Y4/1.5	Ah2	coh	
	PE 1.3m	6–10	5Y3/2	Ah3	coh	
	PE 1.4m	10–18	10YR3/2	AC	si-coh	>18 cm: rock
2.1.95 Deception Island						
62°55′S, 60°64′W						
Gelic-dystric Andosol						
Flat ridge, 5 m a.s.l.	DI 1.1m	0–1	10YR2/1.5	A(h)	si	some moss thalli
vegetation >5%	DI 1.2m	1–10	10YR2/1	C1	si	
	DI 1.3m	10–30	7.5YR2.5/1	C2	si	

generally with depth; exceptions can be found in profiles with strong homogeneity either because of their peaty character (KH1, PB1) or their unstructured soil layers (PO1, PE1, DE1). Increasing stone content is only partly responsible for this, *e.g.*, in profiles FA1, SG2 and EL1. The low levels of bulk density, due to high peat content, mostly show high actual water content, *i.e.*, a high water holding capacity.

Much more pronounced relationships can be demonstrated between bulk density and LOI or C_{org}-contents by their inverse relationships. The correlation between LOI and C_{org} is highly significant over this wide range of values ($LOI = 1.9 \cdot C_{org} + 4.85$; $r^2 = 0.8515$; $n = 58$). Exceptions are mainly due to those samples with very low C_{org}-values where internal errors become more evident.

There is a typical trend for the highest levels of organic matter to be in surface levels; peat soil, however, does not show such a pattern but remains contant even in deep layers. This holds true for the deep peat soil at Cape Horn (KH1) as well as in the shallow peat at Paradise Bay (PB1). C/N- ratios mostly decrease with depth, indicating an accumulation of refractive material in surface layers.

Phosphate shows elevated concentrations (values of $>2‰$ in organic layers or $>0.5‰$ in mineral layers) only in the vicinity of bird colonies. This is highly pronounced in the South Orkneys, Paulett Island, and Peterman Island. At other places, the concentrations show low or only slightly enriched values.

Microorganisms

Table 2 gives an overview of the microbiological properties, as well as data on soil properties and organic matter, of the soils from this gradient. The bacterial counts show a variation between 10^7 and 10^{10} cells per gram dry weight, depending on substrate quantity, *i.e.*, with high relation to organic matter content. Highest counts were found in histosols and moss beds. Strong shifts to lower counts can be observed within depth profiles. At the same time, the bacterial biomass shows broad variability (between 0.1 and 100 μg C/g). This variation is also closely related to organic matter content. Mean cell volumes do not show such strong variability (0.047-0.11 μm^3). However, substrate quantity, and probably quality, is of great importance for this relationship. Pearson correlation analysis between these parameters shows significant positive relationships (0.1%-level, double-sided significance, $n = 61$) between AWC and LOI, BBV and LOI, TBN and BBV, MCV and BBV.

The view on the size distributions gives a more detailed picture (Table 3). There are no significant relations with any size class or LOI. TBN is related to rods of length classes 2.5-2.75 μm and 1.5-2.0 μm; BBV relates further to rods of 2.5-3.0 μm. MCV is negatively correlated to the abundance of cocci, and positively to rods in size classes from 0.75-2.75 μm. Similarly, negative relationships can be found between cocci and various classes of rod shaped bacteria. Low variability (<33%) of individual parts can be found only for cocci (d: 0.25-0.5 μm) and the size classes of rods (0.5-1.25 μm). This indicates that (only) these classes, which represent nearly 80% of the total counts, remain relatively stable in all samples and variabilty in the bacterial community, mainly on account of the other classes. No evident trend can be found for the latitudinal transect or between individual size classes and LOI. Only rods (2.25-2.5 μm) show a weak correlation (1%-level) with LOI. Increases of rods are always negatively related to decreases of cocci. This can be

Table 2. Data on bacteria, organic and inorganic matter and actual water content. For abbreviations of soil samples see Table 1. Soil texture according to FAO and US Soil Taxonomy (lo: loam, si: silt, sa: sand, gr: gravel); Bd: Bulk density; LOI: loss on ignition, Corg: organic matter after wet combustion and titration; Pv: extractable phosphate (at 105°C with HCl (30%)); TBN: total bacterial number; BBV: bacterial biovolume; MCV: mean bacterial cell volume; n.d.: not determined.

Sample	Depth (cm)	Texture	granules, stones	Bd (kg/l)	pH ($CaCl_2$)	Water (% of w.wt.)	LOI (% of d.wt.)	Corg (% of d.wt.)	C/N	Pv (‰ of d.wt.)	TBN ($10^9 \cdot g^{-1}$ d.wt.)	BBV (10^6 μm^3 $\cdot g^{-1}$ d.wt.)	MCV (μm^3)
KH1.1	0-5		0	0.1	4.3	77.7	94.8	45.0	20	0.89	2.62	264.3	0.101
KH1.2	5-20		0	0.2	4.0	83.2	96.4	36.0	n.d.	0.65	1.36	116.2	0.082
KH1.3	20-30		0	0.2	3.8	86.2	96.5	23.0	n.d.	0.48	0.74	61.5	0.083
KH1.4	30-35		0	0.2	3.7	85.0	95.6	45.0	n.d.	0.39	0.76	67.5	0.089
FA1.1	0-5		1.5	0.5	3.8	24.7	47.3	24.4	n.d.	0.81	0.19	13.6	0.071
FA1.2	5-20		0	0.3	3.4	29.6	58.5	28.6	n.d.	0.80	0.24	17.9	0.076
FA1.3	20-30	si, lo	7.0	0.7	3.2	45.0	10.9	13.5	17	0.04	0.23	14.5	0.062
FA1.4	30-35	si, lo	10	1.0	3.2	29.4	13.8	5.2	19	0.25	0.07	4.3	0.065
FA1.5	35-40	si, lo	14	1.5	3.7	16.6	4.2	1.3	18	<0.01	0.01	0.9	0.061
FA3.1	0-8	sa, lo	0	1.0	n.d.	28.9	20.5	8.3	16	0.47	0.37	26.0	0.071
FA3.2	8-10	lo	0.9	1.4	n.d.	17.3	6.6	1.3	17	0.02	0.11	8.1	0.076
FA3.3	10-20	lo	0.7	1.6	n.d.	14.3	3.1	0.6	17	n.d.	0.03	2.3	0.082
FA5.1	0-17		0	0.1	n.d.	79.6	77.6	33.0	16	1.33	1.68	101.4	0.060
FA5.2	17-20		0	0.6	n.d.	50.3	36.5	20.8	14	1.22	0.32	21.1	0.067
FA5.3	20-40	sa	0	1.0	n.d.	29.4	8.5	6.1	13	0.22	0.20	14.8	0.075
FA6.1	0-10	sa	0	1.0	3.9	1.2	3.4	1.5	15	<0.01	0.06	4.7	0.083
FA6.2	10-18	sa	0	1.2	3.6	4.2	1.9	0.8	19	1.9[a]	0.05	2.9	0.059
FA6.3	18-23	sa	0	1.2	3.6	7.8	2.4	1.2	24	1.4[a]	0.07	4.4	0.063
SG1.1	0-10		12	0.4	4.5	48.7	24.4	17.0	18	1.04	1.95	198.1	0.101
SG1.2	10-27	si, lo	42	1.1	3.9	32.2	11.3	3.3	13	1.40[a]	0.36	24.0	0.067
SG1.3	27-40	lo	33	1.2	4.0	27.0	6.8	3.3	12	1.63[a]	0.19	14.3	0.074
SG2.1	0-5	sa, lo	5	1.0	4.4	49.7	44.0	6.9	13	1.84[a]	0.47	40.4	0.085
SG2.2	5-14	sa, lo	19	1.3	4.0	40.3	14.6	5.6	11	1.80[a]	0.23	17.2	0.075
SG2.3	14-22	si, lo	30	1.5	4.3	46.0	17.5	7.1	13	2.73[a]	0.22	16.8	0.076
SG3.1©	+2-0	moss	0	0.1	4.5	88.9	91.8	44.0	37	1.88	3.27	280.4	0.086
SG3.2©	0-5					88.0	86.1	41.0	23		3.38	270.5	0.080
SG3.3	5-14		0.5	0.1	5.2	88.9	82.9	45.0	14	2.23	3.08	238.6	0.077
SG3.4	14-27		8.1	0.5	4.9	79.2	56.3	27.0	21	1.77	1.21	92.9	0.077
SG4.1©	0-5	moss	0	0.2	4.7	86.5	89.1	41.0	32	1.68	5.21	529.9	0.102
SG4.2©	5-10		35	0.7		82.8	61.0	33.0	18		1.33	99.5	0.075
SG4.3	10-20	lo	44	1.2	4.1	50.4	16.2	7.2	12	1.54[a]	0.24	20.4	0.086
SG4.4	20-35	sa, lo	32	1.5	4.2	31.3	5.3	2.1	11	2.07[a]	0.33	20.0	0.060
SG4.5	35-40	sa, lo	30	1.5	4.5	28.1	3.8	2.0	11	1.52[a]	0.21	11.5	0.054

Table 2. Continued.

Sample	Depth (cm)	Texture	granules, stones	Bd (kg/l)	pH ($CaCl_2$)	Water (% of w.wt.)	LOI (% of d.wt.)	Corg (% of d.wt.)	C/N	Pv (‰of d.wt.)	TBN ($10^9 \cdot g^{-1}$ d.wt.)	BBV (10^6 μm^3 $\cdot g^{-1}$dwt.)	MCV (μm^3)
SO1.1	0-12		0	0.2	n.d.	80.0	97.7	47.0	56	n.d.	1.91	129.1	0.068
SO1.2	12-20		0	0.2	n.d.	84.6	95.7	42.0	19	3.83[a]	1.87	126.7	0.068
SO1.3	20-28		71	1.9	n.d.	76.2	70.7	26.0	19	2.57[a]	0.62	28.9	0.047
SO2.1a	0-2©		0	0.1	3.7	70.2	83.9	44.0	12	5.17[a]	10.45	697.8	0.067
SO2.1b	2-9©			0.1				22.0	7.9		3.50	232.2	0.066
SO2.2	9-16	lo, sa	72	1.8	3.7	20.5	5.1	2.7	8.5	3.60[a]	0.17	12.0	0.072
SO2.3	16-30	lo, sa	69	1.8	3.6	18.2	6.6	3.3	9.8	5.85[a]	0.08	4.4	0.057
PO1.1	0-1		69	2.0	5.0	58.3	56.9	15.0	7.8	16.1[a]	1.99	177.1	0.089
PO1.2	1-10	lo, sa	72	2.2	4.0	28.7	6.1	2.3	5.6	17.7[a]	0.12	7.3	0.063
PO1.3	10-30	lo, sa	54	1.8	4.3	22.4	6.6	2.5	4.9	26.0[a]	0.16	8.8	0.056
PO1.4	30-40	lo, sa	53	1.8	4.1	20.3	6.0	2.5	4.9	26.0[a]	0.09	5.3	0.062
PE1.0	0-2	moss	21	0.1	n.d.	91.2	78.9	24.8	17	40.6[a]	9.00	1027.1	0.114
PE1.1	2-4	gr	98	2.5	n.d.	63.3	8.9	4.4	8.1	70.4[a]	0.90	76.8	0.086
PE1.2	4-6	sa, lo	51	1.8	4.8	39.0	11.5	4.6	n.d.	77.6[a]	0.23	15.6	0.070
PE1.3	6-10	sa, lo	37	1.6	5.4	36.4	10.3	4.4	7.0	n.d.	0.22	16.0	0.074
PE1.4	10-18	sa, lo	81	2.2	5.0	46.7	15.3	6.2	9.5	62.4[a]	0.19	15.5	0.082
PB1.1	0-5		0	0.1	3.5	82.8	98.1	40.4	41	0.77	1.66	164.7	0.099
PB1.2	5-20		0	0.1	3.5	82.3	92.8	41.9	21	1.13	2.42	135.0	0.056
PB1.3	20-25		0	0.1	3.8	68.6	76.7	27.9	10	2.40[a]	0.55	27.6	0.050
EL1.1	0-1	sa, lo	41	1.6	6.8	18.9	2.2	0.9	13	1.45[a]	0.69	61.6	0.089
EL1.2	1-10	sa, lo	54	1.8	7.4	14.4	0.6	0.1	8.1	1.74[a]	0.04	3.4	0.078
EL1.3	10-40	lo, sa	56	1.8	7.6	12.0	0.6	0.1	7.9	1.54[a]	0.02	1.2	0.064
EL1.4	40-60	sa, lo	64	2.0	7.4	17.5	0.7	0.2	11	1.65[a]	0.04	2.8	0.071
DI1.1	0-1	lo, sa	38	1.1	5.3	22.4	4.5	1.0	19	0.59	0.23	21.4	0.093
DI1.2	1-10	lo, sa	31	1.1	5.9	22.0	0.7	0.1	10	0.62	0.07	4.9	0.073
DI1.3	10-30	sa, lo	34	1.2	6.0	15.5	0.4	0.4	10	0.45	0.03	2.7	0.086

[a] samples are influenced by bird colonies,
© combined samples for some inorganic constituents.

seen also from the significant negative relationships between cocci and MCV.

Discussion

Soil properties

The soils analyzed during this study cover wide ranges of soil types. Those from Cape Horn and from the Falkland Islands are histosols, podzols and leptosols. They are generally covered by dense vegetation and thus form peats due to high productivity during

Table 3. Data on the bacterial communities by their size distributitons in % of total number of each sample. The first two classes refer to cocci diameter; all others to the bacterial length (μm).

Sample	Size classes										
	−0.25	−0.5	−0.75	−1.0	−1.25	−1.5	−1.75	−2.0	−2.25	−2.5	>2.5
KH1.1	2.1	11.5	24.3	19.8	20.2	12.4	4.5	3.3	0.8	1.2	0
KH1.2	3.8	20.4	28.8	17.1	16.7	6.7	4.2	1.7	0.8	0	0
KH1.3	6.5	23.7	28.0	12.1	15.1	7.8	2.2	3.0	1.7	0	0
KH1.4	5.9	18.1	23.2	16.0	21.9	8.0	3.4	0.8	1.7	0	0
FA1.1	3.2	27.9	31.1	16.9	12.8	5.5	1.4	0.5	0.9	0	0
FA1.2	4.9	17.0	24.7	27.8	18.4	4.9	0	2.2	0	0	0
FA1.3	9.5	28.9	29.8	18.2	7.0	4.6	0.8	1.2	0	0	0
FA1.4	6.0	31.0	31.5	13.9	7.9	7.8	1.4	0.5	0	0	0
FA1.5	13.2	28.1	29.7	13.5	9.9	3.1	1.0	0.5	1.0	0	0
FA3.1	7.6	26.4	24.0	20.0	12.0	6.0	2.0	2.0	0	0	0
FA3.2	7.7	22.0	30.5	16.3	12.6	5.7	2.9	1.2	1.2	0	0
FA3.3	4.7	17.4	26.3	16.9	23.9	5.6	2.4	1.9	0.9	0	0
FA5.1	12.6	28.5	28.1	13.8	11.0	3.7	1.6	0.8	0	0	0
FA5.2	8.6	27.2	25.9	16.8	12.1	8.2	0.4	0.9	0	0	0
FA5.3	6.4	24.4	24.8	18.4	15.0	7.7	1.3	0.9	1.3	0	0
FA6.1	5.3	19.5	23.9	19.5	18.6	6.6	3.5	1.3	1.8	0	0
FA6.2	17.4	32.6	25.6	9.1	6.5	3.9	2.6	2.2	0	0	0
FA6.3	11.6	30.7	24.4	13.3	12.4	4.9	1.3	1.3	0	0	0
SG1.1	2.0	16.4	23.2	15.6	20.4	12.8	4.8	2.4	1.6	0.8	0
SG1.2	11.1	25.4	26.6	18.4	11.1	2.9	2.9	0.4	1.2	0	0
SG1.3	5.0	25.5	30.0	15.9	11.4	8.6	1.4	1.8	0.5	0	0
SG2.1	5.0	24.8	20.7	15.7	19.4	7.9	2.9	2.1	1.7	0	0
SG2.2	6.5	25.2	20.0	24.8	13.0	6.5	1.7	0.9	1.3	0	0
SG2.3	6.9	26.1	27.4	13.5	14.3	6.5	2.9	1.2	1.2	0	0
SG3.1	5.9	22.8	22.8	19.8	13.1	8.4	1.3	3.4	1.7	0.8	0
SG3.2	6.6	19.3	28.4	16.1	17.7	7.4	2.9	0.4	0.4	0.8	0
SG3.3	9.5	23.1	26.5	16.5	13.2	5.8	1.7	1.2	1.7	0.8	0
SG3.4	11.7	24.2	21.7	19.2	12.1	4.6	2.1	2.5	0.8	1.3	0
SG4.1	4.4	15.7	24.9	16.9	16.1	10.8	4.8	2.0	2.8	0.4	1.2
SG4.2	8.3	26.6	27.4	16.2	10.4	4.2	4.2	1.7	0.4	0.8	0
SG4.3	7.9	20.0	27.1	13.3	15.4	8.3	3.8	1.3	2.9	0	0
SG4.4	18.5	26.8	28.8	12.4	7.0	2.5	2.1	0	0.8	1.2	0
SG4.5	13.4	31.2	29.9	12.0	9.1	3.0	0.4	0	0	0	0

Table 3. Continued.

Sample	Size classes										
	−0.25	−0.5	−0.75	−1.0	−1.25	−1.5	−1.75	−2.0	−2.25	−2.5	>2.5
SO1.1	9.2	34.9	21.4	11.8	11.8	5.9	3.4	1.3	0.4	0	0
SO1.2	12.7	22.7	28.4	15.7	10.0	6.1	3.5	0.9	0	0	0
SO1.3	18.4	38.8	28.8	6.8	3.6	3.2	0.4	0	0	0	0
SO2.1a	10.8	29.9	28.1	9.5	11.7	3.9	4.3	1.3	0.4	0	0
SO2.1b	10.8	27.9	28.3	11.2	12.8	6.0	1.2	1.6	0.4	0	0
SO2.2	9.5	23.9	30.0	12.2	11.9	3.7	2.9	1.7	0.4	0.8	0
SO2.3	15.5	34.7	23.9	10.5	9.6	3.4	1.7	0.8	0	0	0
PO1.1	6.1	14.2	28.3	17.0	19.8	8.5	2.8	0.8	1.2	1.2	0
PO1.2	11.6	26.4	27.6	12.4	14.0	6.0	1.6	0.4	0	0	0
PO1.3	14.9	42.6	19.3	10.4	6.8	2.4	2.4	1.2	0	0	0
PO1.4	12.1	32.1	24.6	15.4	7.5	7.5	0	0	0.8	0	0
PE1.0	1.6	15.6	18.9	18.4	20.5	11.5	4.9	4.1	2.1	0.8	1.6
PE1.1	6.9	20.2	28.8	14.2	17.2	4.3	3.9	2.2	1.3	0.4	0.9
PE1.2	8.1	27.4	28.6	16.1	12.1	4.4	0.8	0.8	1.6	0	0
PE1.3	5.6	26.8	27.6	16.0	13.2	6.0	2.8	1.6	0.4	0	0
PE1.4	6.0	27.3	26.5	15.3	8.8	7.6	3.6	1.6	2.0	1.2	0
PB1.1	6.2	28.9	19.8	12.8	11.2	10.3	3.7	2.1	0	2.9	2.1
PB1.2	19.1	32.3	26.3	9.6	6.0	3.6	0.8	1.6	0.8	0	0
PB1.3	24.3	33.1	20.5	10.5	7.1	2.9	0.4	0	1.3	0	0
EL1.1	5.0	16.3	23.3	17.9	20.4	11.9	2.9	1.3	1.3	0	0
EL1.2	9.8	21.3	26.6	12.3	14.3	10.3	2.5	2.1	0.8	0	0
EL1.3	6.7	26.5	30.3	17.7	12.6	6.3	0	0	0	0	0
EL1.4	4.3	24.4	30.4	16.6	16.2	6.0	2.1	0	0	0	0
DI1.1	8.6	26.2	18.5	14.2	12.0	9.9	3.9	3.4	2.2	0	1.3
DI1.2	5.9	24.9	29.5	13.5	16.0	5.9	1.7	2.5	0	0	0
DI1.3	8.2	18.6	23.4	18.2	13.0	10.4	5.2	3.0	0	0	0

summer but slowed degradation due to low winter temperature. The soils of the subantarctic forest and subantarctic tundra are enriched with organic matter. This can also be found on South Georgia, although content of organic matter is a bit lower and regosols are present. The more southerly islands near the Antarctic Peninsula show a subpolar desert climate and have mean annual temperature below 0°C. The dominance of cambisols, leptosols and regosols becomes evident.

The presence of histosols and podzols is still important, although with slightly lower amounts of organic matter. This tendency fits into descriptions of Antarctic soils from other locations which have been analyzed in separate programs (BLUME *et al.*, 1996). These observations require the descriptions of pedogenetic processes by BOCKHEIM and UGOLINI (1990) to be modified by extending the zones of organic matter accumulation and

podzolization. The podzol found on Carcass Island (Falklands) is extremely acid; that from South Georgia shows only weak acidification, similar to podzols described from the subarctic tundra of northern Sweden (SCHLICHTING, 1963). Data of soils from King George Island and Casey Station (Wilkes Land) show that podzolization is not restricted to tundra environments but also occurs in subpolar desert environments (BLUME *et al.*, 1997).

Extractable phosphates with values of $>2‰$ in organic layers or $>0.5‰$ in mineral layers show the influence of bird excrement. These samples also show low values of C/N-ratios and only slight acidification, which is probably due to nitrification processes.

Strong accumulations of organic matter were also found on slope steps of hard rocks with meltwater stagnation, where peat is formed (at Paradise Bay and Peterman Island, see Table 1). Values of LOI show comparable data for Cape Horn, South Georgia, South Orkneys, and Paradise Bay. The amount of organic matter is at levels of >10 kg C_{org}/m^2, which is within the range of C-contents of tropical forests (BLUME *et al.*, 1996). The only exceptions are soils without any vegetation cover which have low amounts of carbon (<1–2 kg C_{org}/m^2), *e.g.* soils from Elephant Island and Deception Island. The latter appeared to be an andosol with volcanic glasses. Similarly, volcanic glasses and olivines have been found in topsoils of King George Island (BLUME *et al.*, 1996; BLUME *et al.*, 1997; SCHNEIDER, 1997).

Microorganisms

Total bacterial number and biomass follow the content of organic matter rather than showing relations to overall climatic patterns. Highest values were found at Coronation Island and Peterman Island in relation to peat content and probably to inorganic nutrients, as both sites were located in the vicinity (distance about 50–100 m) of penguin rookeries. TBN and BBV in surface soils range between $0.06 \cdot 10^9$ and $10.45 \cdot 10^9$ cells g^{-1}, which corresponds to 0.47 and 102.7 μg C g^{-1}. These values agree well with the ranges given in earlier reports from Antarctic sites (BÖLTER, 1992, 1995, 1996). ROSER *et al.* (1993) have reported even higher microbial C contents from penguin rookeries. They estimated the microbial C from ATP measurements to be between 180 and 1200 μg C g^{-1}. Those communities were dominated by bacteria (95% of the total biomass). These microbial carbon contents were much higher than those from remote areas. Hence, phenomena as described by AKIYAMA (1986a, b), the inhibition of soil algae growth by penguin excrements cannot be transferred to soil bacteria. Most of the soil samples during our studies show typical patterns of decreasing number and biomass. The most drastic decreases were found in Coronation Island and Petermann Island, where microbial communities are most closely related to organic matter.

The bacterial community at Peterman Island showed the maximal value of mean cell volume, another indication of a nutrient-rich milieu. This, however, cannot be verified in general. Mean cell volumes show very individual patterns for each site, depending on the actual size distribution. The mean cell volume of all samples shows a value which can be related more of continental Antarctic sites (BÖLTER, 1992) and are even lower in comparison to individual sites at Arctowski Station (BÖLTER, 1995). This, in conjunction with the data of number and biomass, however, shows that the bacterial community responds to momentary states of available nutrients and not to overall pedological patterns. MCV

data from arctic desert soil reveal significantly lower values, close to 0.05 μm^3 (BÖLTER and PFEIFFER, 1997). Thresholds of organic matter contents directly influence the microbial population.

KATO (1996) discusses shifts in cell morphology with respect to a depth profile of a limnetic environment. He concludes that bacterial cell volume represents an important tool for the description of bacterial communities. The mean cell volumes he found in Lake Kizaki, Japan (a mesotrophic lake) ranged between 0.029 and 0.085 μm^3; a sample from an eutrophic lake (Lake Suwa) showed values between 0.2 and 0.4 μm^3. Experiments with *E. coli* showed a variability between 0.53 μm^3 (starved cells) and 0.86 μm^3 (cells during logarithmic growth).

The evidence of other microorganisms, fungi and algae, has to be taken into account while dealing with total microbial biomass. This is especially important for algae and cyanobacteria which may contribute substantially to living soil organic matter in both barren soils and plant carpets (ROSER *et al.*, 1993; BÖLTER, 1996).

Conclusions

There is no evidence for a latitudinal gradient directly reflected in any of the parameters analyzed for this study. Organic matter, either LOI or C_{org}, shows its highest values at the most northern (Cape Horn) as well as at the most southern point of this study (Peterman Island). Bacterial biomass is obviously more influenced by organic matter content rather than overall climatic properties and shows close relations to organic matter and -probably- to its degradability. Also, maximal values of bacterial biomass can be found at sites with elevated or high levels of phosphate. Highest bacterial biomass is located in surface levels, independent of actual high C/N- ratios. Changes in bacterial communities as observed by size classes cannot be related to individual descriptors.

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