A COMPARATIVE STUDY OF PROTOZOA INHABITING *Drepanocladus* MOSS CARPET IN THE SOUTH ORKNEY ISLANDS

By H. G. SMITH

ABSTRACT. 40 species of Protozoa (11 Mastigophora, 13 Rhizopoda and 16 Ciliata) were recorded from cores of moss-carpet peat from stands of *Drepanocladus uncinatus* at 15 sites widely distributed through the South Orkney Islands. Numbers of Testacida in the peat varied from less than 300 to 1,170/g. fresh weight. The species richness and numbers of Testacida at these sites were mostly lower than at sites in other island groups in the maritime Antarctic. Association analysis of the results showed the South Orkney Islands to be divided into two "faunistic provinces" (eastern and western), the division between them coinciding substantially with a major petrological division in the islands' geology. Sites in the eastern province were more species rich but contained fewer Testacida than those in the western province. It is suggested that this was owing to the stands of moss carpet in the eastern province having a higher nutrient status so providing habitats for more protozoan species, but also experiencing harsher local climates so supporting lower numbers of Testacida than the western province.

THE terrestrial protozoan faunas of the Antarctic have been investigated by several authors in recent years (Decloitre, 1960, 1964; Sudzuki, 1964; Heal, 1965; Dillon and others, 1968; Smith, 1972, 1973*a*) who published lists of species of Protozoa recorded from a variety of habitats in different parts of the Antarctic zone. Heal (1965) and Smith (1972, 1973*a*) also gave estimates of numbers of Testacida. These investigations revealed variation in the protozoan fauna, both within and between geographical regions and within and between habitat types, so great that it was difficult to draw definite conclusions about what factors determine the distribution and abundance of terrestrial Protozoa in the Antarctic. It appeared, however, that it might be possible to understand how the environment influences numbers and distribution, if intensive studies were made in which some environmental variables were kept constant. Accordingly, the fluctuations in population sizes of selected protozoan species and in some environmental factors were determined in two contrasting habitats at specially designated sites on Signy Island, South Orkney Islands (Smith, 1973*b*, *c*). These studies successfully showed that the *numbers* of Protozoa in these sites were influenced by physical environmental factors, particularly temperature and moisture, and possibly also by biotic factors; they also indicated that some protozoan species are specific to either acid moss-peat habitats or to alkaline animal-guano habitats; but they gave little indication of how the environment influences the *distribution* of the majority of protozoan species and did not explain why there is considerable variation in the protozoan fauna of different sites of the same habitat type. In an attempt to answer this question, a comparative study was made of the protozoan fauna of the peat of 15 stands of *Drepanocladus uncinatus* moss carpet, widely distributed through the South Orkney Islands. It was hoped that, by keeping the vegetation type constant and by limiting the study to a single island group with presumably the same regional climate, the results of the study would make it possible to relate site differences in the protozoan fauna to differences in local site characteristics and in moss-peat properties, as well as providing substantial data for comparison with other island groups in the maritime Antarctic. *Drepanocladus uncinatus* was chosen because this moss species has considerable morphological plasticity associated with a wide ecological amplitude (Gimingham and Smith, 1971) and so would be likely to be found in sufficient quantity to have formed a layer of peat below the growing shoots (so forming a habitat for Protozoa) in areas from which other peat-forming moss species would be absent.

FIELD METHODS

At each site investigated, a suitable stand of *Drepanocladus* was selected for study. Six randomly distributed cores were taken, each consisting of green moss shoots and the underlying organic layer which was usually a few centimetres thick. On rare occasions when there was a greater thickness of peat below the moss, the top 5 cm. only were taken.

The following characteristics of the sites were noted at the time cores were taken: altitude,

aspect and temperatures (ambient air, moss surface, moss peat at 20 mm. depth). Altitude to 5 or 10 m. accuracy was estimated by interpolation between contours of maps (D.O.S. 510, 1963; Admiralty chart 1775). Aspect was determined with a prismatic compass. Moss and peat temperatures were taken with a right-angled soil thermometer. Ambient temperatures were abstracted from the meteorological records of R.R.S. *John Biscoe*. Note was also made of the presence of any marine birds or mammals whose activities might influence the terrestrial fauna, and of the geology of the area in which the sites were situated.

Fresh cores were transported in polythene containers for laboratory examination. A small sub-sample of each core was preserved in Bouin's fixative.

Laboratory Methods

The following were determined for the cores of each site: species composition of the protozoan fauna (all taxa), numbers of Testacida, mean pH, mean moisture content (per cent dry weight) and mean loss on ignition (per cent dry weight). Protozoa were cultured by inoculating about 2 g. of each core on to soil extract agar in 9 cm. Petri dishes, with *Aerobacter aerogenes* (NCIB 418) as food source, and moistening with sterile 0·5 per cent NaCl. The cultures were examined at increasing intervals up to 2 months; species were identified morphologically. Testacida in the preserved sub-samples were enumerated by Couteaux' (1967) direct examination technique with ten replicates for each site.

The pH of each core was determined as soon as possible after collection using a glass electrode and a pH meter. Moisture was determined by oven drying at 100° C for 48 hr. and loss on ignition by ashing in a muffle furnace at 450–500° C for 10 hr.

Sites Investigated

Fifteen sites in the South Orkney Islands, ranging from Monroe Island in the west to Cape Dundas in the east, were sampled (Fig. 1). Collections were made during the period 9–16 February 1971, except for the site on Fredriksen Island which had been sampled in March 1970. The sites varied in altitude from 5 to 110 m. and were located in areas with differing geology: mica-schists, conglomerates and greywackes. In some cases numerous seals or penguins were seen in the vicinity of the site. The sites and site characteristics are listed in Table I, and the properties of cores from each site in Table II. Data on air, moss and peat temperatures (T_a, T_m and T_p) at the times the cores were taken are given in Table III. Single spot-temperature readings like these give little indication of the overall micro-climate of the sites. Since all readings were taken between 10.30 and 15.30 hr. (a period when the ground is

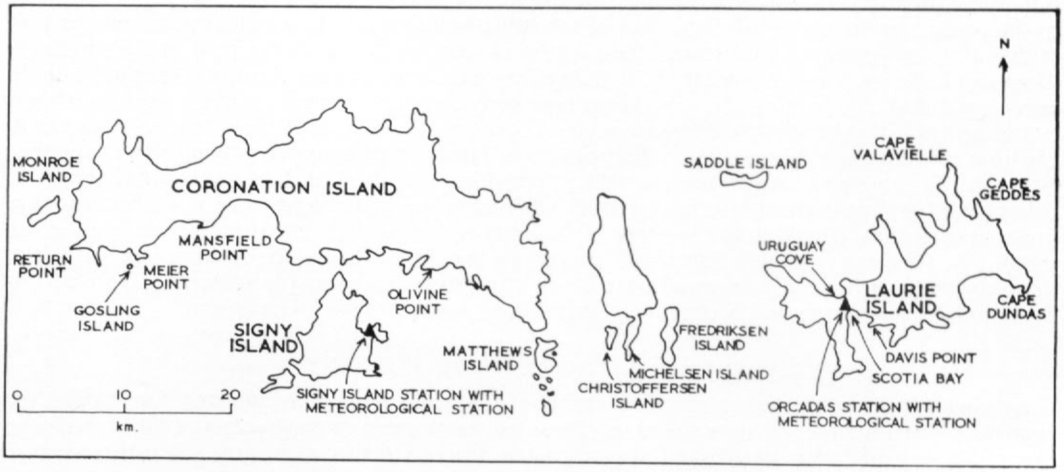

Fig. 1. Sketch map of the South Orkney Islands showing the location of sites where stands of *Drepanocladus* moss carpet were sampled.

TABLE I. LIST OF SITES STUDIED

Site number	*Location*	*Date sampled*	*Altitude* (m.)	*Exposure*	*Marine animals present*	*Geology* (reference)
1	Coronation Island Mansfield Point	9.2.71	20	East	—	qms (1)
2	Coronation Island Meier Point	9.2.71	10	East	Moulting chinstrap penguins	qms (1)
3	Gosling Island	10.2.71	15	North	Fur seals	qms (1)
4	Coronation Island Return Point	10.2.72	60	South	—	qms (1)
5	Monroe Island	10.2.71	40	South-south-west	Chinstrap penguin colony	qms (2)
6	Matthews Island	11.2.71	5	North-east	Weddell seals	Conglomerate (3)
7	Christoffersen Island	11.2.71	20	North-east	Elephant seals	Conglomerate (4)
8	Michelsen Island	11.2.71	60	East	Fur seals	Conglomerate (4)
9	Laurie Island Davis Point	12.2.71	10	South-west	—	Greywacke-shale (5)
10	Laurie Island Valavielle Point	13.2.71	15	South-east	Skuas	Greywacke-shale (5)
11	Laurie Island Cape Geddes	13.2.71	30	West	Moulting chinstrap penguins; fur seals	Greywacke-shale (5)
12	Saddle Island	14.2.71	100	South-east	Large chinstrap penguin colony	Greywacke-shale (5)
13	Laurie Island Cape Dundas	15.2.71	110	South-east	Adélie penguin colony	Greywacke-shale (5)
14	Coronation Island Olivine Point	16.2.71	50	South	—	qms (1)
15	Fredriksen Island	29.3.70	60	East	Chinstrap penguin colony	Greywacke-shale (6)

qms Quartz-mica-schist.

References: (1) Personal communication from Dr. D. H. Matthews; (2) West (1968); (3) Thomson (1971); (4) Thomson (1973); (5) Dalziel (1971); (6) Tilley (1935).

TABLE II. PROPERTIES OF CORES OF *Drepanocladus* MOSS-CARPET PEAT

Site number	*pH*	*Moisture*	*L.O.I.*
1	5·5±0·2	247±43	78±4
2	5·5±0·2	348±42	83±6
3	5·1±0·3	372±73	84±2
4	4·5±0·3	398±87	56±6
5	4·9±0·2	509±71	86±6
6	5·1±0·4	467±85	81±18
7	4·3±0·2	277±47	81±9
8	4·0±0·5	124±26	72±7
9	4·5±0·2	511±92	87±2
10	4·6±0·4	591±23	90±1
11	4·4±0·3	231±47	87±2
12	6·0±0·4	246±56	85±4
13	5·2±0·2	328±77	87±4
14	4·4±0·2	56±10	54±6
15	4·5±0·1	461±224	84±4

L.O.I. Loss on ignition (per cent dry weight).
Moisture Loss on oven drying (per cent dry weight).
Figures are means ±95 per cent confidence limits.

being heated by radiation), differences in the temperature intervals between the air and the moss (T_m–T_a), or between the air and the peat (T_p–T_a), will be related to permanent differences in local climate as will the temperature gradient (G) in the peat, given the same weather conditions; the extent to which weather conditions (particularly sunshine and wind speed) were not similar at the times sites were visited must be taken into account when making comparisons between sites. The temperature intervals and peat temperature gradients are also given in Table III.

PROTOZOAN FAUNA

Forty species of Protozoa were recorded from the cores: 11 flagellate, four naked amoeba, nine testate amoeba and 16 ciliate species (Tables IV, V and VI). Numbers of testate amoebae in the cores varied from below the threshold of reliably detectable numbers (300/g.) to slightly over 1,000/g. fresh weight; these results are listed in Table VII.

Comparison of the South Orkney Islands with other island groups in the maritime Antarctic

The South Orkney Islands sites were poorer in protozoan species than moss carpets which have been studied in the South Shetland Islands. The number of species per site ranged from 3 to 13 (mean 9·1) compared with 8 to 15 (mean 11·6) in five sites on Elephant Island in March 1971 (Smith, 1972) and 14 species in one site on Livingston Island in February 1971. They are similar, however, to numbers in sites farther south: seven and nine species in two sites on Galindez Island, Argentine Islands, seven species in one site on Cone Island and 11 species in one site on Pourquoi Pas Island in January and February 1970 (unpublished observations of H. G. Smith).

TABLE III. AIR AND MOSS TEMPERATURES AND MOSS-PEAT TEMPERATURE GRADIENTS AT SITES AT TIMES OF SAMPLING

Site number	*Time of day* (G.M.T.–03.00)	T_a (°C)	T_m (°C)	T_p (°C)	$T_m - T_a$ (°C)	$T_p - T_a$ (°C)	G (°C mm.$^{-1}$)
1	11.00	+0·7	+8·7	+5·5	+8·0	+4·8	−0·16
2	13.00	+0·6	+12·2	+6·9	+11·4	+6·3	−0·27
3	14.00	+0·6	—	—	—	—	—
4	10.30	+2·0	+5·2	+1·2	+3·2	−0·8	−0·02
5	14.30	+2·0	+6·9	+5·1	+4·9	−3·1	−0·09
6	10.30	+2·0	+11·4	+5·5	+6·8	+0·9	−0·30
7	14.00	+4·6	+8·9	+7·7	+7·5	+5·4	−0·11
8	15.00	+2·3	+7·9	+7·2	+5·6	+4·9	−0·04
9	15.00	+2·3	+6·8	+6·2	+3·6	+3·0	−0·03
10	11.00	+1·8	+2·9	+2·6	+1·1	+0·8	−0·02
11	15.30	+1·3	+3·8	+3·4	+2·5	+2·1	−0·02
12	15.00	+1·5	+2·5	+2·2	+1·0	+0·7	−0·02
13	14.30	+0·5	+5·1	+3·2	+1·0	+2·7	−0·10
14	15.00	+1·2	+7·2	+5·8	+6·0	+4·6	−0·07
15	11.30	−2·8	—	—	—	—	—

T_a Ambient temperature.
T_m Temperature of moss surface.
T_p Temperature of peat at 20 mm. depth.
G Temperature gradient in 0–20 mm. moss-peat horizon.

The numbers of testate amoebae in the South Orkney Islands sites (Table VII) were mostly very low compared with moss-carpet sites elsewhere, with numbers exceeding 1,000/g. at only one site (Mansfield Point) and ten of the 15 sites having numbers below 500/g. On Elephant Island (Smith, 1972) four out of five sites had numbers exceeding 500/g. and one of those had over 7,000/g. On Galindez Island two sites had 1,300 and 6,900/g. Only sites on islands in Marguerite Bay had numbers similar to those in the South Orkney Islands: one site on Pourquoi Pas Island had 420/g. and one site on Cone Island had 1,000/g.

Comparison of Signy Island with the rest of the South Orkney Islands

The figures for species richness and numbers of Testacida obtained for sites in the present study are in marked contrast to those obtained for Signy Island terrestrial reference site 2 (Smith, 1973*a*) from which 30 species of Protozoa were recorded in March 1971 when the numbers of Testacida were estimated at 4,050/g. fresh weight. These results suggest that local environmental conditions on Signy Island are less harsh than those throughout most of the South Orkney Islands group. This hypothesis is difficult to test because the only source of long-term meteorological data outside Signy Island is the Argentine station Orcadas, Laurie Island, situated on flat land between Scotia Bay and Uruguay Cove. Its topographical situation is atypical of Laurie Island and the rest of the South Orkney Islands, so its meteorological data

TABLE IV. COMPOSITION OF THE FAUNA: MASTIGOPHORA

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Oikomonas mutabilis Kent	+	–	–	+	–	–	–	–	–	+	+	+	+	+	–
Oikomonas termo Ehrenberg	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Polypseudopodius bacterioides Pusch	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Petalomonas angusta Klebs	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Allantion tachyploon Sandon	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Bodo saltans Ehrenberg	–	+	+	–	–	–	–	+	–	–	+	–	+	+	–
Cercobodo vibrans Sandon	–	–	–	–	–	–	+	–	+	+	+	–	–	–	–
Cercomonas crassicauda Alexeieff	–	–	–	–	–	–	–	–	–	+	–	–	–	–	+
Cercomonas longicauda Stein	+	+	+	+	–	+	+	+	+	+	+	+	+	+	–
Heteromita lens Muller	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Spongomonas uvella Stein	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
NUMBER OF SPECIES (total 11)	3	3	3	4	1	2	3	3	3	5	7	3	4	4	4

Table V. Composition of the fauna: Rhizopoda (Amoebida and Testacida)

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mayorella sp. Schaeffer	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Metachaos sp. Schaeffer	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–
Hyalodiscus sp. Hertwig and Lesser	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
Valkampfia sp. Chatton and Lalung-Bonnaire	–	–	–	–	–	–	–	–	–	+	–	–	+	–	–
Assulina muscora Greeff	–	–	+	–	–	+	+	+	–	–	–	–	–	+	–
Corythion dubium Taranek	+	+	–	–	–	–	+	+	+	–	–	–	+	+	+
Difflugiella sp. Cash	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Euglypha rotunda Wailes and Penard	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Euglypha strigosa (Ehrenberg) Leidy	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Phryganella acropodia (Hertwig and Lesser) Hopkinson	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pseudodifflugia gracilis Schlumberger	+	–	+	–	–	–	–	+	–	–	–	–	–	–	–
Trinema enchelys (Ehrenberg) Leidy	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Trinema lineare Penard	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–
Number of species (total 13)	4	1	4	0	2	1	3	3	2	1	0	0	4	4	1

TABLE VI. COMPOSITION OF THE FAUNA: CILIATA

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Enchelys sp. Hill	–	+	–	+	–	–	–	–	–	+	–	–	–	+	+
Holophrya sp. Ehrenberg	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+
Lagynophrya sp. Kahl	+	–	–	+	+	–	–	–	–	–	–	–	–	–	–
Litonotus sp. Wresniowski	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Urotricha agilis Stokes	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–
Leptopharynx sphagnetorum (Levander) Mermod	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+
Cryptochilium nigricans (Muller) Maupas	+	–	–	–	–	–	+	–	+	–	–	+	+	+	–
Cyclidium glaucoma Muller	+	+	–	–	–	–	+	+	+	–	–	–	–	–	–
Glaucoma pyriformis Ehrenberg	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Gonostomum affine Stein	–	–	–	–	–	–	+	–	+	–	–	–	–	–	+
Oxytricha fallax Stein	+	+	–	+	+	–	+	–	+	+	+	–	–	–	–
Oxytricha pellionella (Muller) Ehrenberg	+	+	–	+	–	–	+	–	–	–	–	–	–	–	–
Oxytricha setigera Stokes	–	+	–	+	+	–	–	–	–	–	–	–	–	–	–
Pleurotricha lanceolata (Ehrenberg) Stein	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Uroleptus sp. Ehrenberg	+	–	–	–	–	–	–	–	+	–	–	–	–	–	+
Vorticella striata Dujardin	–	–	–	–	–	–	–	–	–	+	–	–	+	+	+
NUMBER OF SPECIES (total 16)	6	5	0	5	4	0	7	1	6	3	1	3	3	4	6

TABLE VII. NUMBERS OF TESTACIDA IN *Drepanocladus* MOSS-CARPET PEAT

Site number	*Mean numbers of Testacida per g. peat fresh weight ±95 per cent confidence limits*
1	1,170±920
2	830±720
3	580±370
4	<300
5	<300
6	400±330
7	550±310
8	<300
9	500±380
10	<300
11	<300
12	<300
13	<300
14	350±290
15	350±290

are probably no more representative of the South Orkney Islands as a whole than are Signy Island's. However, comparison of the temperature data for the two stations (Table VIII) shows that between 1948 and 1971 annual mean temperatures at Orcadas were on average 0·23° C lower than those on Signy Island, while the 4 monthly means for December–March (the summer months to which most terrestrial biological activity is restricted) were on average 0·36° C lower. It seems probable therefore that the exposed peninsulas of Coronation and Laurie Islands and the small islands on which the sites were located would have still colder temperatures.

Comparison of sites within the South Orkney Islands—association analysis

In spite of all the sites in the present study being located on stands of the same moss species within the same island group, they revealed considerable heterogeneity in the species composition of their fauna, as shown by the histogram in Fig. 2. Only one species, *Oikomonas termo*, occurred in all 15 sites, while 33 out of 40 species observed occurred in five sites or less and 14 of those occurred in only one site. There is therefore still too much variability in the faunal data to detect simple correlations between the distribution of species and environmental factors. In order to make the results more compact and comprehensible, the data, constituting a presence-and-absence matrix of 40 species in 15 sites, were subjected to association analysis. This involved grouping the sites together on the basis of their tending to have similar fauna. The 15 sites were divided on a hierarchical system, at each stage being divided dichotomously into those with and those without the "best" species. The "best" species was the one carrying the "maximum total χ^2" calculated by the method of Williams and Lambert (1959). The analysis ran to five stages and divided the sites into six groups each containing between one and four sites; the results are plotted as a dendrogram (Fig. 3). This shows that the sites in groups 1 and 6 are nearly all located in areas of greywacke-shale on Laurie and Fredriksen Islands

TABLE VIII. COMPARISON OF ANNUAL AND SUMMER TEMPERATURES AT SIGNY ISLAND AND ORCADAS METEOROLOGICAL STATIONS, SOUTH ORKNEY ISLANDS

Annual mean temperature (°C)			
Year	*Signy Island*	*Orcadas*	*Difference*
1948	−4·6	−4·9	+0·3
1949	−5·9	−6·0	+0·1
1950	−4·7	−4·8	+0·1
1951	−3·1	−3·3	+0·2
1952	−3·9	−4·0	+0·1
1953	−3·7	−3·9	+0·2
1954	−4·0	−4·2	+0·2
1955	−1·9	−2·1	+0·2
1956	−1·2	−1·5	+0·3
1957	−3·6	−3·5	+0·1
1958	−4·8	−5·0	+0·2
1959	−5·3	−5·4	+0·1
1960	−3·1	−2·9	+0·2
1961	−4·1	−4·3	+0·2
1962	−2·0	−2·3	+0·3
1963	−3·3	−3·6	+0·3
1964	−3·7	−4·0	+0·3
1965	−2·1	−3·0	+0·9
1966	−4·2	−4·3	+0·1
1967	−3·8	−4·0	+0·2
1968	−2·6	−2·9	+0·3
1969	−4·0	−4·0	0·0
1970	−2·8	−3·2	+0·4
		MEAN DIFFERENCE:	+0·23

December–March mean temperature (°C)			
Year	*Signy Island*	*Orcadas*	*Difference*
1948–49	−0·6	−0·8	+0·2
1949–50	0·0	−0·3	+0·7
1950–51	+0·9	+0·6	+0·3
1951–52	+0·6	+0·3	+0·3
1952–53	−0·5	−0·3	+0·2
1953–54	+0·7	+0·2	+0·4
1954–55	+1·0	+0·7	+0·3
1955–56	+0·6	+0·4	+0·2
1956–57	+0·7	+0·7	0·0
1957–58	−0·8	−0·6	−0·2
1958–59	−0·1	0·0	−0·1
1959–60	+0·7	+0·9	−0·2
1960–61	+0·6	+0·3	+0·3
1961–62	+0·6	+0·3	+0·3
1962–63	+1·3	+0·7	+0·6
1963–64	+0·7	+0·3	+0·4
1964–65	+1·8	+1·2	+0·6
1965–66	+0·4	−0·3	+0·7
1966–67	+0·3	−0·1	+0·4
1967–68	+0·4	+0·3	+0·1
1968–69	+0·6	+0·4	+0·2
1969–70	−0·1	−0·6	+0·5
1970–71	+1·0	−0·5	+1·5
		MEAN DIFFERENCE:	+0·36

Sources of data: Servicio Meteorológico Nacional, Argentina (1951); Pepper (1954); meteorological records at Signy Island station, 1947–71; meteorological records at Meteorological Office, London Road, Bracknell, Berkshire.

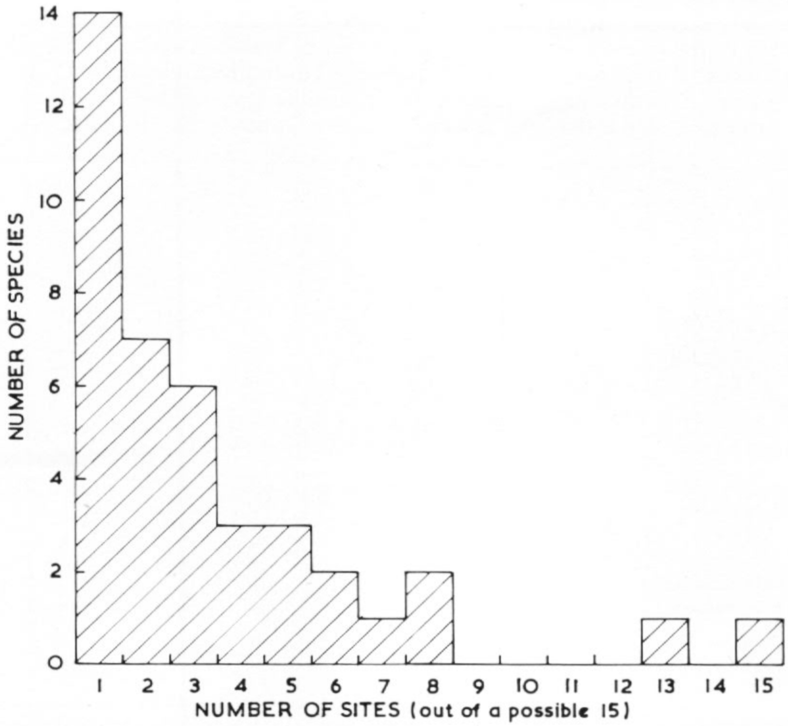

Fig. 2. Histogram showing the frequency of occurrence of 40 species of Protozoa in 15 sites in the South Orkney Islands.

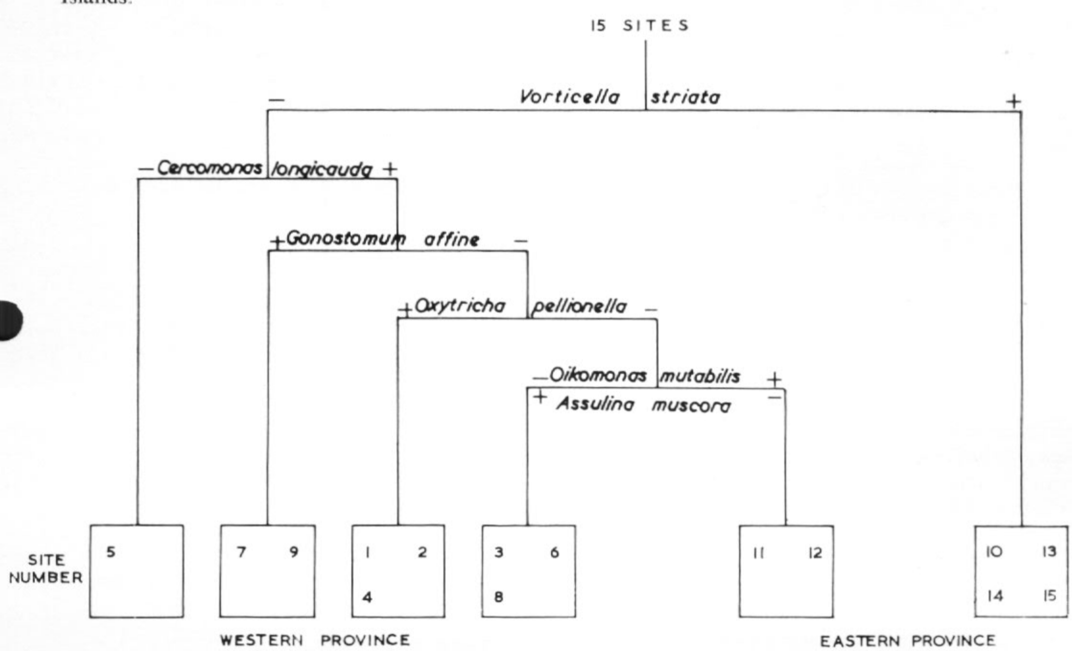

Fig. 3. Dendrogram: association analysis of 15 sites of *Drepanocladus* moss carpet in the South Orkney Islands on the basis of their protozoan fauna.

(Tilley, 1935; Dalziel, 1971), while the sites in groups 2, 3, 4 and 5 are nearly all located in areas of mica-schist or conglomerate on Monroe, Coronation, Matthews, Christoffersen and Powell Islands (West, 1968; Thomson, 1971, 1973; personal communication from D. H. Matthews). The South Orkney Islands may therefore be considered as consisting of two protozoan faunistic "provinces", which may be labelled "eastern" and "western" (Fig. 4), the division between them coinciding substantially with a major division in the islands' geology. The coincidence is not exact: the inclusion of Davis Point (site 9) in the western province and of Olivine Point in the eastern province is anomalous. The fauna recorded from Signy Island (Smith, 1973*a*) is so different from the rest of the South Orkney Islands that Signy Island, though geologically part of the western province (Matthews and Maling, 1967), cannot be included in this division at all.

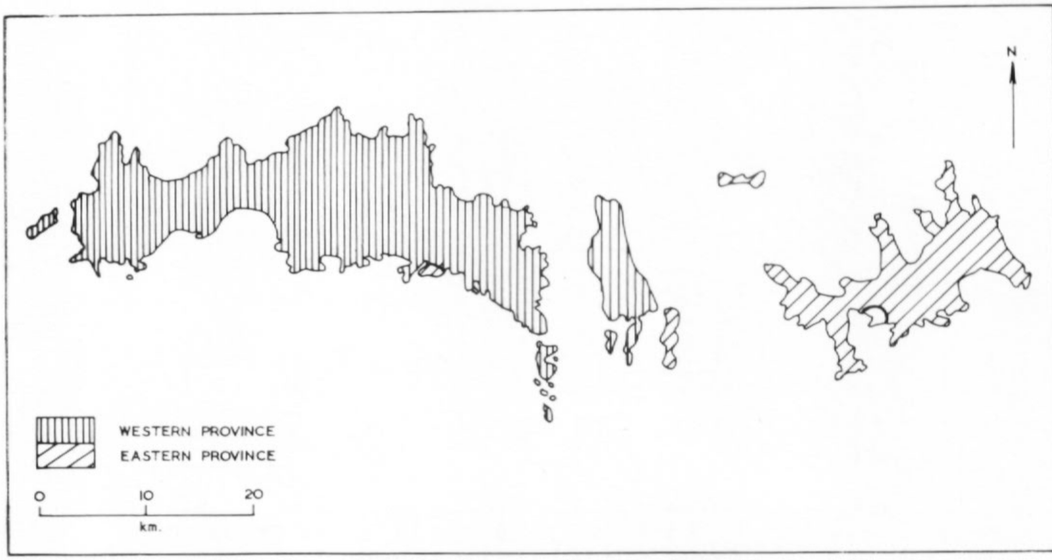

Fig. 4. Sketch map of the South Orkney Islands (except Signy Island) showing the division into eastern and western protozoan faunistic provinces.

On the basis of their occurrence in the two provinces, the protozoan species may be divided into three groups:

Protozoa specific to the western province

Spongomonas uvella
Mayorella sp.
Metachaos sp.
Difflugiella sp.
Euglypha rotunda
Euglypha strigosa
Phryganella acropodia
Pseudodifflugia gracilis
Lagynophrya sp.
Litonotus sp.
Cyclidium glaucoma
Oxytricha pellionella
Oxytricha setigera
Pleurotricha lanceolata
Uroleptus sp.

Protozoa specific to the eastern province

Polypseudopodius bacterioides
Petalomonas angusta
Allantion tachyploon
Cercomonas crassicauda
Heteromita lens
Hyalodiscus sp.
Valkampfia sp.
Trinema lineare
Trinema enchelys
Leptopharynx sphagnetorum
Glaucoma pyriformis
Vorticella striata

Protozoa common to both provinces

Oikomonas termo
Oikomonas mutabilis
Bodo saltans
Cercobodo vibrans
Cercomonas longicauda
Assulina muscora
Corythion dubium
Enchelys sp.
Holophrya sp.
Urotricha agilis
Cryptochilium nigricans
Gonostomum affine
Oxytricha fallax

All three groups contain some species belonging to each taxonomic class, but the western-specific group contains only one flagellate species, and the eastern-specific group only two testate amoeba species. Accordingly, flagellates are on average a smaller proportion of the fauna in the western province than in the eastern, whereas testate anoebae are a smaller proportion of the fauna in the eastern province than in the western. The mean taxonomic composition of the fauna of the sites in each province is shown by pie diagrams (Fig. 5).

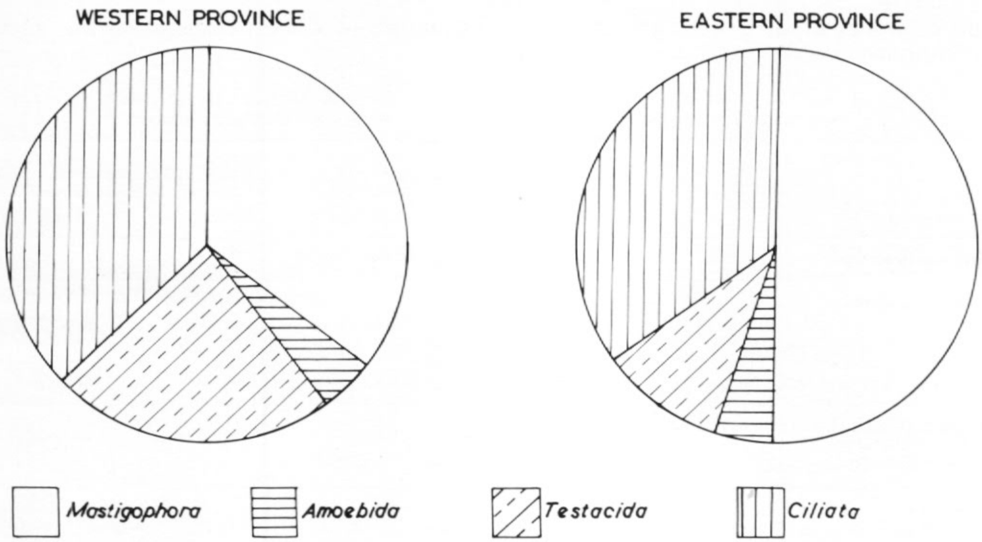

Fig. 5. Pie diagrams comparing the mean composition of the protozoan fauna, by taxonomic groups, in the eastern and western faunological provinces of the South Orkney Islands.

The western-specific group of Protozoa contains more species than the other groups, but this is a result of the greater number of sites in the western province, since the mean number of Protozoa per site in the western province (8·1) is lower than in the eastern province (9·5). However, the numbers of individuals of testate amoebae in the western province sites are greater than those in the eastern: only three out of nine sites in the western province had less than 300/g. fresh weight, while the others six sites had more than 500/g.; whereas four out of six sites in the eastern province had less than 300/g., and all had less than 500/g. (Table VII).

There is very little independent information in the literature on the habitat preferences of the protozoan species constituting the South Orkney Islands fauna which might explain the considerable differences in the fauna of the two provinces. However, 13 of the 40 species identified are included in species lists of saprobic classification (Kolkwitz and Marsson, 1909; Kolkwitz, 1950). Of these, the eight which occur in the eastern-specific and common groups are all listed as polysaprobic or α-mesosaprobic, while the other five, which occur in the western-specific group, are listed as α/β-mesosaprobic or oligosaprobic. This suggests that the eastern province provides habitats more saprobic and possibly more nutrient-rich than the western.

Discussion

In assessing, from the results, the significance of differences between the sites, it is important to distinguish between those parameters which represent permanent characteristics of the sites and those which are spot readings of variables which fluctuate with time within sites. Topography and geology are clearly permanent features, while peat moisture and temperature will fluctuate considerably. From the results of a study on moss turf (Smith, 1973*b*), it can be assumed that peat pH and loss on ignition, while showing spatial variation within sites, will show little variation with time in their mean values for particular sites.

To aid discussion of differences between the faunistic provinces, some comparative data are listed in Table IX. Using the available data, it is now possible to attempt to show that the distribution and abundance of Protozoa throughout the South Orkney Islands are influenced by environmental factors. To be satisfactory such an attempt must explain:

i. Why sites in the eastern province had in general more flagellate species and fewer testate species than those in the western province, and tended to have the more saprozoic species.
ii. Why sites in the eastern province had lower numbers of individuals of testates in mid-summer.

TABLE IX. COMPARISON OF SOME ENVIRONMENTAL FACTORS IN THE EASTERN AND WESTERN PROTOZOAN FAUNISTIC PROVINCES OF THE SOUTH ORKNEY ISLANDS

	Western province		*Eastern province*	
	Mean	*Range*	*Mean*	*Range*
Site altitude (m.)	22	5 to 60	57	30 to 110
Peat properties:				
pH	4·82	4·3 to 5·5	4·85	4·4 to 6·0
Moisture (per cent dry weight)	339	124 to 511	318	56 to 591
Loss on ignition (per cent dry weight)	79	56 to 87	81	54 to 90
Temperature interval above ambient:				
Moss surface (°C)	+6·6	+3·2 to +11·4	+3·0	+1·0 to +6·0
Peat at −20 mm. (°C)	+2·8	−0·8 to +6·3	+2·2	+0·7 to +4·6
Temperature gradient of moss-peat horizon 0–20 mm. (°C mm.$^{-1}$)	−0·15	−0·30 to −0·03	−0·05	−0·10 to −0·02

The following hypotheses provide possible answers to these questions:

1. It is suggested that the petrological differences between the eastern and the western provinces result in the moss peats of the eastern province having a nutrient status which supports greater microbial activity, so producing more saprobic conditions within the peat than is found in the moss peats of the western province. Accordingly, the moss peats of the eastern province would constitute habitats for a fauna richer in polysaprobic or α-mesosaprobic species (e.g. *Cercomonas longicauda*, *Hyalodiscus* sp. and *Trinema enchelys*). The available data on the geochemistry of the rock formations of the South Orkney Islands are insufficient to refute or substantiate this hypothesis. The mineralogy of the different formations is too similar for a distinction to be made on that basis; both the shales of the eastern province and the micas of the western province could be sources of clay minerals in soils formed. Since albite has been reported as occurring among the feldspars in the Fredriksen and Laurie Island greywackes (Tilley, 1935), it is possible that the peats in the eastern province are more sodium-rich than those in the western, but this cannot be confidently asserted without much more geochemical data.

   It is surprising that the distinction between the provinces is not reflected in the values for pH and loss on ignition of the peat, but there are no significant differences between the provinces in these variables (Table IX).

   It would be expected that the nutrient status of some sites would be influenced by enrichment from penguin colonies, and that this influence would cut across the geological division. This does not seem to have occurred except on Saddle Island where the presence of large numbers of chinstrap penguins is almost certainly responsible for the high pH (6·0) of the moss carpet there. Seals would be expected to have less influence on the moss fauna as they are mostly casual visitors to terrestrial sites. However, it seems significant that the four sites at which Weddell or fur seals were observed (Gosling Island, Matthews Island, Michelsen Island and Cape Geddes) remained together in the association analysis

until the last stage. The presence of seals at these sites is positively correlated with the occurrence of the polysaprobic flagellate species *Bodo saltans* in the moss-peat fauna (2×2 contingency table, Fisher's exact test: $P = 0{\cdot}005$).

2. It is suggested that the lower numbers of testate amoebae in the sites of the eastern province are a result of these sites experiencing harsher local climates than those of the western province. There are three lines of evidence for this:
   i. The sites in the eastern province are mostly at higher altitudes (Table IX).
   ii. Five out of the six sites in the eastern province face the east to south quadrant and so are more exposed to cold south-easterly winds off the Weddell Sea, whereas only four out of nine sites in the western province have this exposure.
   iii. At the time the sites were sampled, the temperature intervals above ambient of the moss at sites in the eastern province were smaller than those of moss at sites in the western province. Also the top 20 mm. of the moss carpet had shallower temperature gradients (Table IX). This indicates that the sites in the eastern province were receiving less heating by solar radiation than were those in the western. This is not entirely reliable as a guide to permanent differences in the local climates of the sites because the weather on 12 and 13 February 1971 (when the sites at Davis Point, Valavielle Point and Cape Geddes were sampled) was less sunny and windier (but not colder) than during the rest of the expedition; so on these days less radiant heating of the moss would be expected even in the absence of site factors. The comparison, however, holds good for sites on Saddle Island, Cape Dundas and Olivine Point which were sampled on days of calm sunny weather, similar to that prevailing when sites in the western province were sampled.

   It therefore seems likely that the sites in the eastern province are in general colder and more exposed than those of the western, so it is possible that differences in local climate are responsible for the lower numbers of testates in the sites of the eastern province. There is no evidence from the present study that testate numbers are limited by moisture in the eastern any more than in the western province, though this cannot be proved since moisture varies greatly within sites with time (Smith, 1973*b*). The data that are available (Table IX) suggest that the ranges of moisture conditions experienced by stands of *Drepanocladus* moss carpet are similar in the two provinces.

Acknowledgements

I wish to acknowledge with grateful thanks: J. J. Light, Dr. M. Macmanmon, and the Master and ship's company of R.R.S. *John Biscoe* for assistance with field work; N. J. Collins for supplying meteorological data and botanical advice; Dr. D. H. Matthews and Mrs. J. W. Thomson for geological advice; Dr. R. M. Laws and Dr. P. J. Tilbrook for reading and commenting on the manuscript; Professor F. T. Last for allowing me to work in the Department of Forestry and Natural Resources, University of Edinburgh.

MS. received 26 October 1973

REFERENCES

Couteaux, M. M. 1967. Une technique d'observation des thecamoebiens du sol. *Revue Ecol. & Biol. Sol*, **4**, No. 4, 593–96.

Dalziel, I. W. D. 1971. Structural studies in the Scotia arc: the South Orkney Islands. R/V *Hero* cruise 71-1. *Antarct. Jnl U.S.*, **6**, No. 4, 124–26.

Decloitre, L. 1960. Thecamoebiens de la 8eme Expédition Antarctique Française. *Bull. Mus. natn. Hist. nat., Paris*, **32**, No. 3, 242–51.

————. 1964. Thecamoebiens de la XIIeme Expédition Antarctique Française. *Publs Expéd. polair. fr.*, No. 259, 47 pp.

Dillion, R. D., Walsh, G. L. *and* D. A. Bierle. 1968. A preliminary survey of Antarctic meltwater and soil amoeba. *Trans. Am. microsc. Soc.*, **87**, No. 4, 486–92.

Gimingham, C. H. *and* R. I. L. Smith. 1971. Growth form and water relations of mosses in the maritime Antarctic. *British Antarctic Survey Bulletin*, No. 25, 1–21.

Heal, O. W. 1965. Observations on testate Amoebae (Protozoa : Rhizopoda) from Signy Island, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 6, 43–47.

KOLKWITZ, R. 1950. Oekologie der Saprobien. *Ver. Wass., Boden u. Lufthyg.*, No. 4, 64 pp.

————. *and* M. MARSSON. 1909. Oekologie die tierschen Saprobie. *Int. Revue ges. Hydrobiol. Hydrogr.*, **2**, 126–52.

MATTHEWS, D. H. *and* D. H. MALING. 1967. The geology of the South Orkney Islands: I. Signy Island. *Falkland Islands Dependencies Survey Scientific Reports*, No. 25, 32 pp.

PEPPER, J. 1954. *The meteorology of the Falkland Islands and Dependencies, 1944–1950*. London, Falkland Islands and Dependencies Meteorological Service.

SERVICIO METEOROLÓGICO NACIONAL, ARGENTINA. 1951. *Datos climatologicos y geomagneticos Islas Orcadas del Sud, periodo 1903–1950*. Buenos Aires, Servicio Meteorológico Nacional, Ser. B, Secc. 1ª, Pt. 1ª, No. 11.

SMITH, H. G. 1972. The terrestrial Protozoa of Elephant Island, South Shetland Islands. *British Antarctic Survey Bulletin*, No. 31, 55–62.

————. 1973*a*. The Signy Island terrestrial reference sites: II. The Protozoa. *British Antarctic Survey Bulletin*, Nos. 33 and 34, 83–87.

————. 1973*b*. The Signy Island terrestrial reference sites: III. Population ecology of *Corythion dubium* (Rhizopoda : Testacida) in site 1. *British Antarctic Survey Bulletin*, Nos. 33 and 34, 123–35.

————. 1973*c*. The ecology of Protozoa in chinstrap penguin guano. *British Antarctic Survey Bulletin*, No. 35, 33–50.

SUDZUKI, M. 1964. On the microfauna of the Antarctic region. I. Moss-water community at Langhovde. *JARE sci. Rep.*, Ser. E, No. 19, 41 pp.

THOMSON, J. W. 1971. The geology of Matthews Island, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 26, 51–57.

————. 1973. The geology of Powell, Christoffersen and Michelsen Islands, South Orkney Islands. *British Antarctic Survey Bulletin*, Nos. 33 and 34, 137–67.

TILLEY, C. E. 1935. Report on rocks from the South Orkney Islands. '*Discovery*' *Rep.*, **10**, 383–90.

WEST, S. M. 1968. Petrography of metamorphic rocks from the Inaccessible and Larsen Islands, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 18, 45–57.

WILLIAMS, W. T. *and* J. M. LAMBERT. 1959. Multivariate methods in plant ecology: I. Association-analysis in plant communities. *J. Ecol.*, **47**, No. 1, 83–101.