THE SIGNY ISLAND TERRESTRIAL REFERENCE SITES: I. AN INTRODUCTION

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ABSTRACT. Two contrasting terrestrial sites have been established at Signy Island, South Orkney Islands, so that future work may be concentrated and data more readily compared. They are referred to as the Signy Island reference sites (SIRS). One is a well-drained *Polytrichum–Chorisodontium* turf, the surface of which has been heavily colonized by lichens, and the other is an almost pure *Calliergidium–Calliergon–Drepanocladus* carpet on wet ground. Background information on these vegetation types is given by reference to relevant past work, and the actual sites are described in detail to provide an introduction to a series of papers discussing their ecology.

IN terms of the number of groups and component species, the terrestrial ecosystem of the Antarctic is a relatively simple one and, coupled with its isolation and relative freedom from human interference, it offers considerable advantages for a total functional analysis study. Signy Island, and the South Orkney Islands of which it is part, lie within the *maritime Antarctic*,* that area, almost entirely restricted to the west coast of the Antarctic Peninsula and islands of the Scotia Ridge, where the oceanic climate and lower latitudes create milder conditions. In the *maritime Antarctic* the biota is more extensive and diverse than that of the *continental Antarctic** and there are several months during each year when lowland ground is free of snow, and temperatures and water availability permit growth and activity.

Between 1961 and 1970 a considerable amount of biological research was carried out into the terrestrial environment and biota of Signy Island. These investigations provided essential preliminary information on the composition and ecology of the flora and fauna, but the broad and isolated approach of each project precluded any detailed integration of the results. Consequently, it was decided to select a number of sites at which future work would be concentrated, so permitting the accumulation of interrelatable data. In this way, an appraisal of the functional relationships of the various components of the system will be possible, leading it is hoped to a total ecosystem analysis.

It was decided that the first two sites should be examples of a *Polytrichum–Chorisodontium* turf and a *Calliergidium–Calliergon–Drepanocladus* swamp community (previously referred to as *Brachythecium–Calliergon–Drepanocladus*). These two vegetation types, which are typical of the *maritime Antarctic* (Gimingham and Smith, 1970), are widespread on Signy Island and are convenient for study, providing fairly extensive areas with sufficient peat depth to permit sampling by conventional coring methods. Furthermore, they are contrasting habitats and many of the earlier research programmes were concerned with them so a good deal of background information is available. The sites are referred to as the Signy Island reference sites (SIRS) 1 and 2.

This paper reviews relevant past work at Signy Island, gives a brief account of the establishment of the first two sites and describes each in detail. In so doing, it serves as an introduction to a series of papers dealing with individual aspects of the ecology of these sites.

PAST WORK

Much of the earlier work carried out at Signy Island is relevant to this project and is briefly reviewed here particularly in relation to the vegetation types of SIRS 1 and 2.

The chemical composition of Signy Island soils was first described from samples collected by M. W. Holdgate in February 1962 (Allen and others, 1967; Holdgate and others, 1967). It appears that an adequate supply of most of the principal nutrient elements for plant growth exists within the soils of the island. The large concentrations of birds and seals around the coast

* In this paper the terms *maritime Antarctic* and *continental Antarctic* refer to specific zones, defined according to climatic and vegetational criteria (Holdgate, 1964).

provide one important reservoir of nutrients, particularly phosphorus and nitrogen, which are disseminated by various agencies. The frequent high winds, for example, probably distribute organic and inorganic particles over the island. As a result, all of the soils exhibit relatively high values for phosphorus and inorganic nitrogen. The high precipitation is also an important source of nutrients, being strongly influenced by sea spray which provides sodium, magnesium and chloride, and solution of gaseous inorganic nitrogen emanating from the vertebrate concentrations. Random droppings from overflying birds are also important, and the elements from these, together with those from the other sources mentioned, are often concentrated by a build-up in the snow cover before being made available to the soil and vegetation as run-off. There appears to be little seasonal fluctuation in extractable nutrients, although in *Polytrichum–Chorisodontium* peat the phosphate ion showed greatest seasonal change (Northover and Allen, 1967; Northover and Grimshaw, 1967). This was attributed to a gradual build-up from faunal origins. The depth of peat below the *Polytrichum–Chorisodontium* community raises the living surface clear of most drainage water. As a result, the turf is low in potassium as this is mainly derived from the break-down of the underlying schistose rock and transported by drainage water. Precipitation is probably the dominant source of nutrient supply to these semi-ombrogenous deep peat mosses. In contrast, the *Calliergidium–Calliergon–Drepanocladus* community may be described as a soligenous mire, permeated by drainage water. The peat soils here are, however, broadly similar in composition to those below the *Polytrichum–Chorisodontium* community, although they are much thinner and may have a yellowish basal layer smelling of H_2S. The moss and underlying peat are similar in nutrient composition, although the concentrations are highest just below the living vegetation and fall off down the profile. Of all the Signy Island vegetation, the *Polytrichum–Chorisodontium* turves have the highest C/N ratios and the lowest ash contents, while *Drepanocladus*, in contrast, has a lower C/N ratio and higher ash weight.

There is very little interaction between the vegetation, peat and basal soil layers in these bryophytes. Decomposition of organic matter is slow and the lower layers of the deeper banks are permanently frozen. Also, the lack of a root system and the absence of invertebrates such as earthworms and myriapods further prevents mixing.

Various programmes at Signy Island have involved measurements of moss and soil temperatures, the most detailed being that of Chambers (1966) as part of a study of patterned ground on the island. Most of his data concerned mineral soil but they illustrate the frequency and extent of freeze-thaw cycles in the active layer. The high chemical content of the ground water at Signy Island was found to lower the freezing point to $-0\cdot1^\circ$ C. 3 hourly readings from a thermistor probe inserted at a depth of 2·5 cm. in a *Chorisodontium aciphyllum* bank provided valuable data over nearly 2 years. In 1963, the annual mean was $-0\cdot95^\circ$ C with a mean monthly minimum of $-5\cdot8^\circ$ C (August) and a maximum of $+4\cdot1^\circ$ C (January). Chambers (1966) commented on the effect of diurnal and shorter-term temperature fluctuations and their rapidity was emphasized by Longton and Holdgate (1967), who quoted a rise from 0° to 19° C during 2 hr. at 2–3 mm. depth in *P. alpestre* at Signy Island. Absorbed solar radiation is responsible for these sudden temperature increases in summer and, together with the insulating effect of the snow cover in winter, it is clear that Antarctic vegetation and its associated fauna exists in a relatively favourable micro-climate.

Holdgate (1964) erected the first classification of Signy Island vegetation, and this was subsequently developed and extended by Longton (1967) and more recently by Gimingham and Smith (1970) and Smith (1972). Banks formed by *Polytrichum alpestre* and *Chorisodontium aciphyllum* are one of the most prominent floristic features of the South Orkney Islands and *maritime Antarctic* localities as far south as the Argentine Islands. They are found on well-drained slopes or gravelly porous ground near sea-level to about 165 m. with small patches up to 250 m. In the South Orkney Islands, banks of 1–2 m. depth have developed and on Signy Island the base of one, 190 cm. below the present surface, has been dated at A.D. 147± (Godwin and Switsur, 1966). Mosses of the genera *Calliergidium*, *Calliergon* and *Drepanocladus* form the most extensive closed bryophyte communities to be found in the *maritime Antarctic*. They occur in wet depressions and around melt pools, and are generally restricted to coastal lowlands. There is a scarcity of associated moss species and an almost total absence of lichens within these swamp communities. Although they are common vegetation types, detailed field sketch mapping of the vegetation by Holdgate in 1962–64 indicated that at Signy Island the *Polytrichum–Chorisodontium* moss turf only covers about 6 per cent and the moss carpet less than 12 per cent of the total snow-free surface (Tilbrook, 1970).

The importance of the water supply in the distribution of the mosses and its relationship to growth form has been investigated by Gimingham (1967) and Gimingham and Smith (1971). While both *P. alpestre* and *C. aciphyllum* possess the ability to pass water upwards from a source below and conserve it in the dense colony of growing shoots, the latter can also draw it into the turf from rain or melting snow on the surface. *Calliergon* sp. was very susceptible to drying out and though able to re-hydrate very rapidly it is limited to areas of abundant ground water. *Drepanocladus uncinatus*, however, was more versatile, displaying a variation of growth form from a compact mat in drier habitats to a looser carpet on swampy ground. The water relations are clearly important to many invertebrate groups.

The timing and efficiency of sexual reproduction in *P. alpestre* and other Polytrichaceae (Longton, 1972) is probably controlled by temperature and, in this part of their geographical range, vegetative propagation is an essential means of survival. Stem elongation and leaf production in *P. alpestre* occur mainly during a period of about 3 months at the warmest time of the year, normally commencing after the clearance of winter snow and ending in February (Longton, 1970). Annual net production of this species at Signy Island was calculated as 342 g./m.^{2}. Baker (1972) obtained a figure of 436 g./m.^{2} for the annual net production of *C. aciphyllum* at Signy Island. Whilst more recent work by N. J. Collins (personal communication) indicates similar values for the peat-bank species, the carpet-forming moss species may have an appreciably greater net annual production.

The only data so far available on decomposition are those of Baker (1972) which suggest a rate of about 2 per cent per year for *C. aciphyllum* peat. Some work has, however, been carried out on the main decomposer groups and other micro-organisms at Signy Island. The total numbers of species of both Fungi and Bacteria on Signy Island are restricted and consist of cold-tolerant cosmopolitan types (Heal and others, 1967; Latter and Heal, 1971). Out of a total of 119 strains of Bacteria from three depths in a *C. aciphyllum* peat, 52 per cent belonged to the genus *Brevibacterium* and 12 other genera were represented (Baker and Smith, 1972). Psychrophiles formed 62 per cent of the collection but only four strains were obligate psychrophiles. No pattern could be established for the various genera from different depths and the 17 chromogenic isolates found were distributed evenly down the profile. Bacterial abundance was found to be of the same order as that recorded in similar temperate peats, whereas the number of yeasts was exceptionally high (Baker, 1970*a*, *b*). For the 1–2 cm. layer, the number of Bacteria was 118×10^7/m.^{2} and the yeasts 706×10^7/m.^{2} but, while yeasts, like filamentous Fungi, decreased down the peat profile to only 10×10^7/m.^{2} at 11–12 cm., the Bacteria increased giving a figure of 594×10^7/m.^{2} at the same depth. The Bacteria in the surface layer showed a marked seasonal variation which was correlated with total peat respiration measurements. Fogg and Stewart (1968) and Horne (1972) found that nitrogen fixation was common at Signy Island and was mainly associated with the blue-green alga *Nostoc commune*, either free-living or as a phycobiont with the lichens *Collema pulposum* and *Stereocaulon* sp. The more favourable sites for fixation, however, were bare wet solifluction areas influenced by basic rocks. Some preliminary work on the testate Amoebae of various Signy Island soils, including *Polytrichum* and *Chorisodontium* peat, was done by Heal (1965).

A population study of the arthopods and nematodes in various habitats at Signy Island was carried out by Tilbrook (1967*a*, *b*). This included a 2 year investigation of *Polytrichum–Chorisodontium* turf, both pure and lichen-encrusted, and a shorter study of *Calliergidium–Calliergon–Drepanocladus* sites. The moss turf contained four common species of Acari and three species of Collembola, while in the carpet communities only one acarine and one collembolan were common. In terms of the numbers of individuals, the turf showed an annual mean of around 17×10^4/m.^{2} Acari and 3×10^4/m.^{2} Collembola, while a mean for two samples from two wet moss sites gave only about $0{\cdot}2 \times 10^4$/m.^{2} Acari but about 29×10^4/m.^{2} Collembola. The nematodes were not specifically identified but as a group they showed a marked preference for the wet moss communities with densities of about 101×10^2/m.^{2} compared with approximately 24×10^4/m.^{2} for the drier site. This preference for the wetter habitat was also shown by the tardigrades and rotifers.

Establishment of the Sites

A number of criteria were considered in selecting these sites, of which three were critical. It was decided that each site should have a minimum area of 500 m.^{2} to allow for intensive sampling pressure, should be as homogeneous in floristic composition as possible and as near to the British Antarctic Survey station as feasible without risking disturbance or contamination from it.

Signy Island was examined for suitable areas by H. G. Smith and N. J. Collins during the austral summer of 1969–70 and the first site (SIRS 1), a moss-turf community, was established on Gourlay Peninsula in the south-east corner of the island. A year later an adjacent wet moss community was selected by H. G. Smith and P. G. Jennings as SIRS 2. The author visited Signy Island during the 1971–72 summer when the establishment of these two sites was completed. A hut was erected between the sites to house a micro-climate recorder and serve as a field laboratory for the project.

Description of the Sites

The locations of SIRS 1 and 2 are shown on the map (Fig. 1) and the photograph (Fig. 2).

Geology

The solid geology of the Gourlay Peninsula area has been described by Matthews and Maling (1967) as consisting of quartz-mica-schists of the Moe Island Series, but much of the area, including the two sites, is overlain with superficial drift and scree deposits. The schists are composed of alternating laminae of quartz and quartzo-feldspathic material associated with chlorite, mica, epidote, garnet and variable amounts of accessory minerals.

Climate

No meteorological measurements have been made at the sites but they experience the general oceanic climate of Signy Island which has been summarized by Pepper (1954) and Holdgate and others (1967). It is characterized by relatively high temperatures with a small seasonal range, frequent precipitation and heavy cloud cover. The sites are particularly influenced by the predominant westerly and north-westerly winds which sweep across McLeod Glacier.

SIRS 1

Topography. This site is at a mean altitude of 53 m. on the north-west slope of the knoll about 500 m. south-west of Rethval Point. The slope has a mean gradient of 1 : 3·9 and supports a more or less continuous cover of vegetation. Areas of turf-forming bryophytes are broken up by small rock outcrops and deposits of drift and scree, most of which are covered with lichens (Fig. 3). The topography of the site area and the nature of the surface substrate are shown on the map (Fig. 4), prepared from an original survey made by N. J. Collins, O. H. S. Darling, H. G. Smith and V. W. Spaull in January 1970.

Vegetation. The site includes a number of sociations all assignable to the *Polytrichum alpestre–Chorisodontium aciphyllum* association of the moss-turf sub-formation (Gimingham and Smith, 1970). The sociations represent transitional stages in the cyclic changes that occur in this association.

P. alpestre and *C. aciphyllum* occur in varying proportions ranging from locally pure stands of either moss to areas in which they are co-dominant, with the hepatic *Cephaloziella varians* a common associate. Much of the moss surface has been colonized by epiphytic fruticose or crustose lichens which form a continuous cover in places, particularly on the steeper more exposed parts of the site. *Alectoria chalybeiformis*, *A. nigricans*, *Cornicularia aculeata* and *Usnea antarctica* are loosely attached to the moss, while other fruticose species such as *Sphaerophorus globosus*, *Stereocaulon alpinum* and species of *Cladonia* (*C. furcata*, *C. rangiferina*, *C. pyxidata* and *C. chlorophaea*), together with the encrusting *Ochrolechia frigida*, form a more dense and continuous cover. *Usnea fasciata* occurs on rocks protruding through, or just buried by, the moss turf.

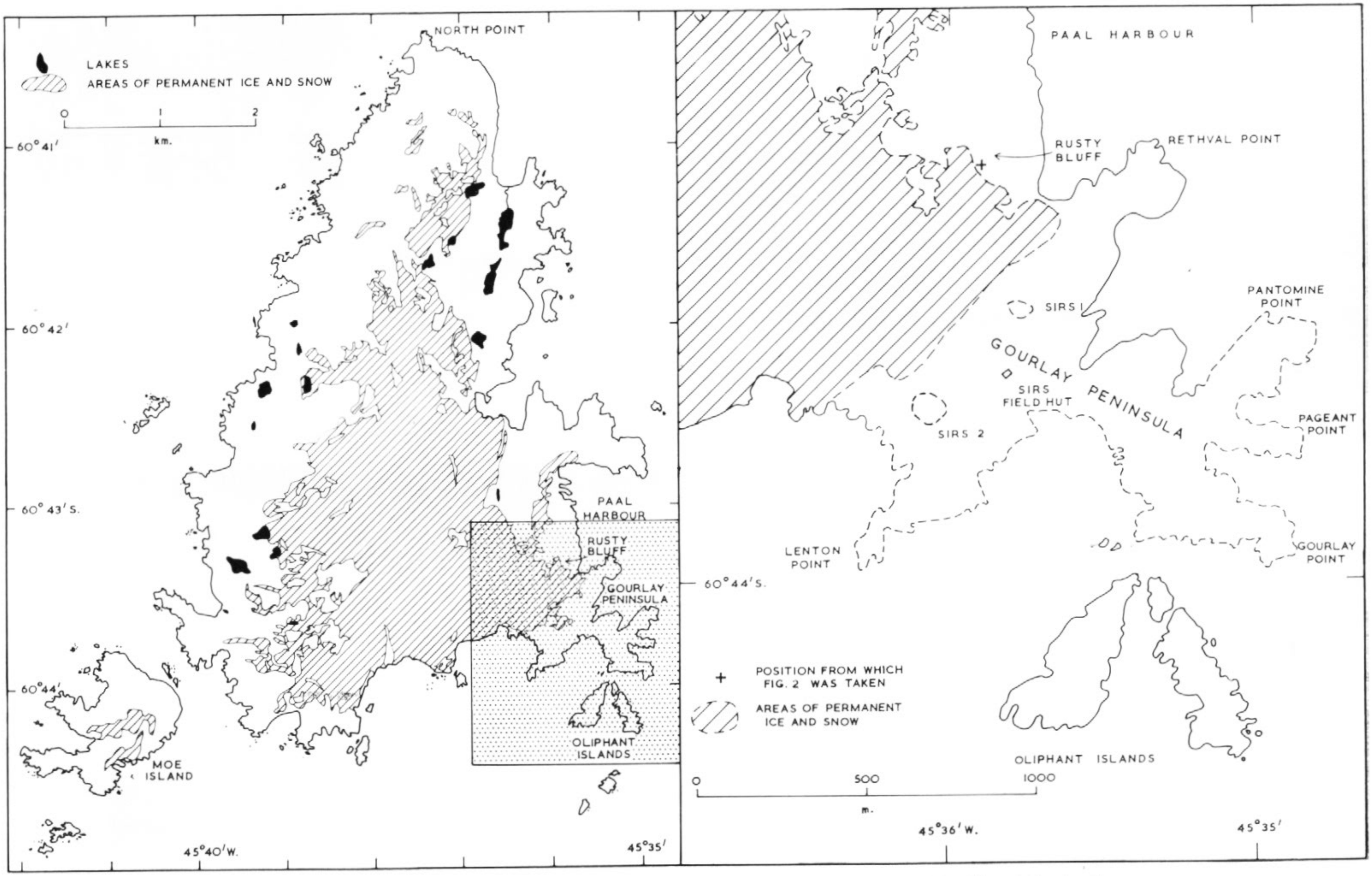

Fig. 1. Maps of Signy Island and the Gourlay Peninsula area showing the location of the Signy Island reference sites 1 and 2.

Fig. 2. Photograph looking south from Rusty Bluff to show SIRS 1 (on the left) and SIRS 2 (on the right). The hut can be seen in the centre.

Fig. 3. A small part of SIRS 1 showing areas of moss turf broken up by rock outcrops. In places the moss surface is encrusted with lichen. A 1·5 m. snow stake and some examples of the strata are also shown.

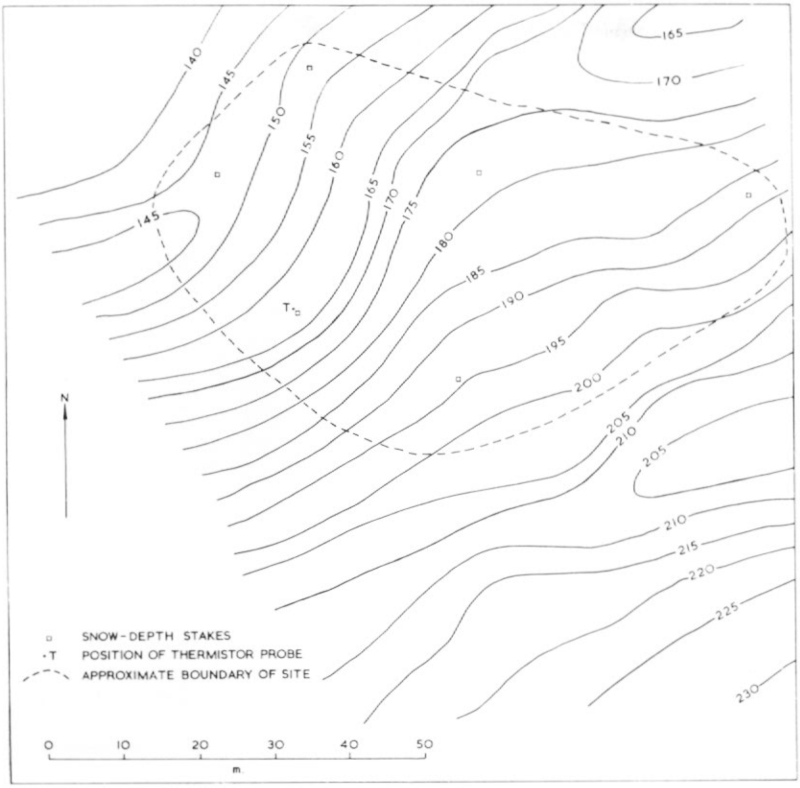

Fig. 4. Map showing the topography of SIRS 1. The contours are in feet.

Soil. An acid peat has developed beneath the *P. alpestre–C. aciphyllum* and this is fairly homogeneous with depth. Measurements made by H. G. Smith (personal communication) show that the peat depth varies between 13 and 32 cm., with a mean of 21 cm. No permafrost layer is found within the peat. The green apical portion of both mosses is about 1 cm. deep. The upper part of the peat consists of erect stems and is usually very cohesive due to the intertwining of a tomentum of rhizoids which is developed to within 1–2 cm. of the apex of *P. alpestre* stems. Below about 7–10 cm. the peat is less firm and consists of partially decomposed stems lying at various angles.

Although well drained, the moss and peat have a relatively high water content and this varies with depth and season. In summer the mean moisture content is approximately 400 per cent (of dry weight) in the 0–3 cm. layer and 500 per cent in the 3–6 cm. layer. In winter these figures rise to 700 and 800 per cent, respectively, owing to ice accumulation.

The upper 6 cm. give loss-on-ignition values of about 97 per cent and a pH of about 4·0.

A pair of brown skuas (*Catharacta skua*) nest adjacent to this site and their droppings, pellets and remains of prey food are common on the moss surface.

SIRS 2

Topography. This site (Fig. 5) is situated in a very shallow basin at an altitude of about 28 m. on the fairly flat area inland from Lenton Point and 360 m. south-west of SIRS 1. To the west and south, the ground rises gently and there is a small knoll north-north-east of the site. The flat central area is covered by a carpet of bryophytes broken by isolated small rocks and a small pool which appears to be permanent but whose size and shape varies depending on the amount of precipitation and run-off. The map (Fig. 6) has been drawn from a survey made by P. A. Broady, P. G. Jennings and I. B. Collinge in March 1972.

Fig. 5. The major part of SIRS 2 showing the shallow basin with its cover of carpet-forming mosses bordered by more rocky ground and the lighter-coloured turf-forming species. Several non-breeding skuas can be seen around the pool.

Vegetation. The vegetation of this site falls within the *Calliergidium austro-stramineum–Calliergon sarmentosum–Drepanocladus uncinatus* association of the moss-carpet sub-formation (Gimingham and Smith, 1970). It consists of a fairly uniform carpet of these pleurocarpous mosses, either in small pure stands or mixed together. *Cephaloziella varians* is found amongst the mosses and occasionally as a dense mat on the surface. At the beginning of the 1971–72 summer, large areas of the surface had a black appearance and the moss seemed to be moribund. By the end of the summer, however, these areas were much reduced due to the development of new green shoots. Around the edges of the basin there is a well-defined junction between the moss carpet and a turf formed by *P. alpestre* and *C. aciphyllum*. These latter species are also colonizing small areas within the site particularly where the underlying rocks are near to or break the surface, so providing better drainage conditions. Also associated with such locations are two crustose lichens, *Ochrolechia frigida* and *Psoroma hypnorum*, and a gelatinous green alga.

Soil. This consists of a peat which has developed to a mean depth of 12 cm. but it is very variable (range 4–20 cm.). The moss species exhibit an erect growth form of sparingly branched closely packed shoots. Although dense, however, the stems of these hydrophytic mosses lack the cohesive rhizoids common to the turf-forming species. Consequently, the moss has a spongy texture and the stems are easily separated one from another. The green portions of the shoots are about 0·5 cm. in length and beneath this discrete stems are visible down to 3 or 4 cm. though they frequently lose their upright form. Below 4 cm. the peat becomes more amorphous and compressed, and in places there is a yellowish basal layer.

The site is always very wet and occasionally waterlogged. In summer the mean moisture content is approximately 1,700 per cent (of dry weight) in the 0–3 cm. layer and 1,200 in the 3–6 cm. layer. In winter these figures are 2,000 and 1,300 per cent, respectively. The smaller percentage in the lower layer reflects the slightly higher mineral content towards the base of the shallower peat (loss on ignition for 0–6 cm. approximately 90 per cent). The carpet is slightly less acid than that of the *Polytrichum–Chorisodontium* turf with a value for the upper 6 cm. of about pH 5.

The site is frequently traversed by groups of penguins in summer and up to 25 non-breeding brown skuas were commonly present, particularly around the pool, during the latter part of the 1971–72 summer.

Fig. 6. Map showing the topography of SIRS 2. The contours are in feet.

Microbial and faunal composition

Table I shows the groups which are known to occur at the sites and gives an indication of the species diversity. Where available, the numbers of species at each site and those common to both are given and other figures are included from work on similar vegetation at Signy Island.

Sampling Procedure

It was clear that intensive study of these relatively small sites would inevitably result in considerable mechanical damage to the substrate by trampling, particularly at SIRS 2. To minimize this damage and in order that population studies of individual groups could utilize a stratified random-sampling method it was necessary to subdivide the sites. Neither site is

TABLE I. MICROBIAL AND FAUNAL COMPOSITION OF SIRS 1 AND 2

	Number of species SIRS 1	SIRS 2	Common to both	*Authority*
Bacteria	13*†	+	—	Baker and Smith (1972)
Fungi: Yeasts	7*	+	—	Personal communication from J. H. Baker
Filamentous Fungi	11*	+	—	Personal communication from A. D. Bailey
Algae	8	20	2	Personal communication from P. A. Broady
Protozoa: Mastigophora	14	10	8	Smith (1973)
Rhizopoda	14	10	7	Smith (1973)
Ciliata	11	10	4	Smith (1973)
Rotifera	+	+	—	Personal communication from P. G. Jennings
Nematoda	12	11	6	Personal communication from V. W. Spaull
Tardigrada	3	4	3	Personal communication from P. G. Jennings
Arthropoda: Acari	6	4	3	Personal communication from D. G. Goddard
Collembola	3	1	1	P. J. Tilbrook

\+ Present.
* Estimate based on data from other similar vegetation at Signy Island.
† Genera.

uniform in cover, however, so it was not appropriate to do this by a simple division of the total area. It was decided to delimit selected areas of typical vegetation within the site from which cores could be taken without entering them. 1 m. squares were therefore measured out in strips spaced apart to allow free movement around them. 150 of these squares were marked out on each site and these will be kept solely for the removal of cores. It was found that in summer the actual procedure of coring was possible without standing within the strata but winter conditions may pose problems.

MONITORING OF ENVIRONMENTAL FACTORS

Temperature and solar radiation

A long-term programme of micro-climate monitoring has been initiated. This will facilitate the comparison and integration of results from different studies taking place over many years as well as providing data for individual studies and for contrast between the two sites. Grant type D 20 channel recorders were chosen and initially temperature and total incoming radiation are being measured. Five Grant type C thermistor probes were positioned at different depths in one area of typical vegetation on each site (see Figs. 4 and 6). The depths are 0, 1·5, 4·5, 7·5 and 10·5 cm. as these coincide with the mid point of each 3 cm. layer—the division chosen for invertebrate studies. A Kipp and Zonen CM5 solarimeter was fixed on the roof of the hut for direct total radiation measurement. The instrument cycles every hour and data recording commenced on 1 January 1972.

Snow cover

Six stakes have been positioned on each site (Figs. 4 and 6) to obtain a measure of snow depth. One of these has been placed next to the thermistor probes to assist the interpretation of the temperature data.

Surface Vegetation

Ten 50 cm. square quadrats were marked out on each site to enable detailed photographic monitoring of changes in vegetation cover. The areas were chosen to represent typical vegetation and particularly boundaries between species or types where changes might be more marked. Within the quadrat three glass markers with white tops were positioned as indicators for close-up pictures. Both whole quadrat and close-up photographs will be taken in colour and black and white at the beginning and end of each summer using standard film and equipment.

Current Work

Several research projects directly concerned with one or both of the SIRS are currently in progress. One study is concerned with the composition of the vegetation of SIRS 1 and the production of the major bryophytes. An assessment of the autotrophic micro-organisms has commenced with a basic qualitative and quantitative survey of the Algae at both sites. The remaining studies concern heterotrophic groups, though as yet little positive information is available concerning their feeding habits and so knowledge of their links with the primary producers is still tenuous. The composition of the protozoan fauna at each site has been examined, together with the population ecology of a common testacean species at SIRS 1. Detailed population studies of the tardigrades, Acari and Collembola are taking place at both sites, as well as general surveys of their nematode and rotifer faunas.

Of necessity, these initial projects are broad ecological surveys of plant and animal groups to determine the biotic composition at the sites. They will be followed by more intensive autecological and physiological studies to assess the interrelationships of populations and the flow of energy within and between them. Respiratory and preliminary feeding studies of the more important arthropods are already in progress.

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