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# Terrestrial Biological Studies In Southern Victoria Land, Antarctica.

A Thesis

submitted in partial fulfilment

of the requirements of the Degree

of

Master of Science in Biological Sciences

at

The University of Waikato

by

ANNE-MAREE J. SCHWARZ

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University of Waikato

1990

## Dedication

For Mike and Jan who have always provided stimulus and encouragement for my ideas.

**Abstract**

The biota, comprising the bryophyte flushes on continental Antarctica, are specialized organisms adapted to the rigorous conditions imposed on them by the environment. Ice free areas of continental Antarctica provide the few habitats suitable for colonization by plants and invertebrates. The presence of free water and certain climatic conditions are essential features. This report investigates bryophyte flushes in two ice free areas in Southern Victoria Land. The first is within the Lake Fryxell Site of Special Scientific Interest No.12 adjacent to the Canada Glacier in the Taylor Valley, one of the so called Dry Valleys. The second is at Granite Harbour approximately sixty kilometres north of the Taylor Valley site.

The purpose of this investigation was to ascertain plant and invertebrate species present at these sites and to obtain some measure of their distribution and abundance. Climatic data are presented for the period of the study.

At the Canada Glacier site, plant associations were mapped in detail and biomass and nutrient values were calculated. Numerous counts of invertebrates were recorded from cores of plant material.

On the main flush, sites which had been damaged by sampling in the past were located. These were mapped, and described, envisaging that these will be important reference sites to monitor the ability of these flushes to recover from physical damage.

At Granite Harbour a qualitative investigation of plants and invertebrates was carried out. Comprehensive plant species lists have been compiled from the Canada Glacier and Granite Harbour areas. The different prevailing conditions for plant growth at the two sites are emphasised by the differences in numbers of species found.

Biomass figures from the Taylor Valley compare favourably with figures presented for lower latitudes of the Antarctic region. The plant species list from Granite Harbour is exceptional in its extent for a site of this latitude.

Invertebrate groups have been recorded for both sites. Counts of individuals from the Taylor Valley provide estimates of abundance which compare in number to estimates from maritime Antarctic locations.

It is concluded that the bryophyte flushes at the Lake Fryxell Site of Special Scientific Interest (S.S.S.I) are areas of relatively high biomass, with community patterning closely linked to the water regime of the area. They are likely to have a low annual net production and a low capacity for recolonization.

This is the largest area of bryophyte growth reported for the Dry Valley region and as such should play an important role in consideration of future impacts and studies in the area. This summary of biota, present at the Canada Glacier bryophyte flushes stands as the only collective record of these parameters to date for this area. The production of these data is the first necessary step to enable further monitoring and conservation to be carried out.

## Acknowledgements

Thanks are due to Waikato University and Antarctic Division D.S.I.R. for making this opportunity available to me. VXE 6 squadron, U.S. Navy provided field transport in Antarctica.

Taupo Research Lab. D.S.I.R. Marine and Freshwater Division, Taupo allowed me time and facilities to complete my writing up.

Thanks to my supervisor Dr. Allan Green for involving me in this work, for the benefit of his experience in the area and for the many helpful discussions since.

For his advice and company in the field, and for the provision of specialized knowledge of Antarctic bryophytes, I thank Dr. Rod Seppelt, Australian Antarctic Research .

Drs Clive Howard-Williams and Warwick Vincent lent their experience to ideas in the early stages and commented on earlier versions of the manuscript. Dr. John Green helped with ideas on microscopy techniques. Jan Simmiss enlightened me as to some of the mysteries of 'Word Perfect' and Debbie Care and Mike Schwarz did essential proofreading.

Lastly but by no means least, thanks to my family and good friends for their encouragement and their interest all the way and for their tolerance in the later stages.

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# Chapter I: INTRODUCTION AND OBJECTIVES

## I:I Introduction

The ecosystems of Antarctica are characterised by spatial discontinuity, harsh environmental conditions, low species diversity and slow growth rates. They are fragile in the sense that they have small capacity to absorb change without being profoundly altered and hence are potentially likely to suffer from impact (Report: IUCN/SCAR 1986). As the Antarctic is still less affected by human activities than other parts of the world, conservation programmes can start nearer the natural baseline than they would elsewhere. There is increased world interest in the expansion of tourism and exploitation of marine species and mineral resources. In order to avoid recurrences of uncontrolled exploitation that have repeatedly occurred elsewhere in the world, long-term conservation relying on effective base-line studies is essential (Report: IUCN/SCAR 1986).

The area of the Antarctic continent is about 14 000 000 square kilometres, comprising one tenth of the land surface of the earth. Of this, less than 3% is ever free of permanent snow and ice (Fig. 1.1). Over 50% of the continent is higher than 2000m with 25% being more than 3000 m.a.s.l. The 3% of ice free ground is made up of exposed nunataks, permanent ice free areas, and areas that become free of snow during the summer melt period (Laws 1984).

The ice free areas of continental Antarctica were described as oases by A. Stephenson in 1936 (Pickard 1986). The term was included in western literature during the United States Navy 'Operation Highjump' in 1947 (Byrd 1947). The current theory on the formation and maintenance of oases, as reviewed by Pickard (1986) is that they formed as a result of the unusual orography of the terrain, combined with climate changes toward a general warming. Two essential conditions are suggested for the formation of an oasis. There must be a relatively high block of land with a retreating or thinning ice sheet. As the ice sheet lowers, the outward flow of ice is no longer over the block but around it. Ice above the block continues to lower but as it is not replenished, the rock is exposed. The cause of the lowering of the ice sheet is linked to global phenomena and the general holocene trend to warmer temperatures.

Ice free areas are maintained by the low albedo of the exposed rock leading to a positive radiation balance. This warms the rocks which act as a heat source to melt any precipitation which is not blown away by wind. These oases then, are areas where temperatures can rise above freezing during the Antarctic summer, and consequently are places where plant and invertebrate life are to be found (Pickard 1986).

The general weather pattern for continental Antarctica is short cold summers followed by very long winters. Surface wind direction and strength is closely related to the direction and steepness of terrain. Katabatic winds draining the surface air of the interior are especially noticeable near the coast (Laws 1984).

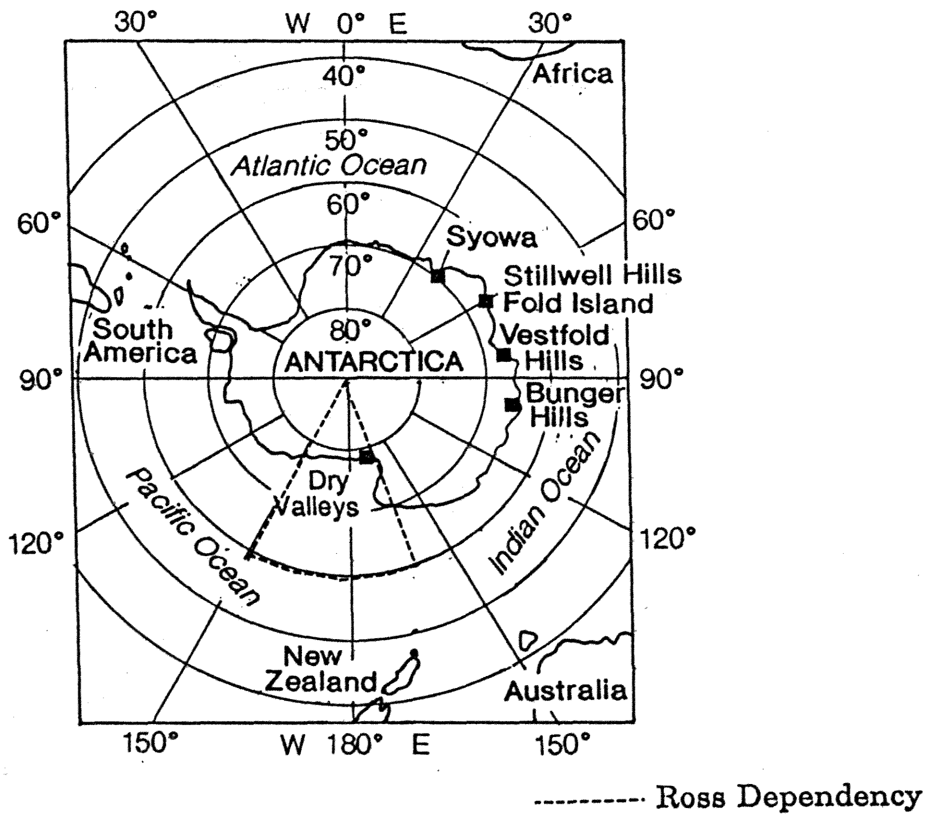



**Figure 1.1:** Map of the Antarctic continent with coastal oases highlighted.

Various zones with distinctive climatic and biotic features have been described for the Antarctic. Holdgate (1970) describes four zones, the southern cold temperate, subantarctic, maritime or oceanic Antarctic, and continental Antarctic. Continental Antarctic has no phanerogamic vegetation and is considered south of the limit of extensive closed cryptogam communities (Holdgate 1970). Laws (1984) reviews the zonations described in the literature from 1904 to 1982 and in conclusion presents the same divisions with similar descriptive criteria, based primarily on the vegetation. In Laws' (1984) classification continental Antarctica is further subdivided:

a. Coastal continental Antarctica is described as semi-desert with moss and algal vegetation present on ahumic soil but restricted in species and extent. Lichens are numerous and locally form extensive stands. Liverworts are very rare and invertebrates are locally abundant and diverse. This definition includes the coastal fringes of the continent and the ice free areas such as the Dry Valleys, of southern Victoria Land (Vincent 1988).

b. Slope continental Antarctica is desert with mainly open, discontinuous lichen vegetation with occasional moss patches near rare snow. Some invertebrates are found.

c. Ice plateau continental Antarctica is described as having no life besides micro-organisms and stray birds (Laws 1984, Longton 1988).

**I:II Antarctic Terrestrial Flora**

Mosses and lichens dominate the Antarctic terrestrial macroflora (Laws 1984). Until recently taxonomic confusion has clouded the biogeographical status of many cryptogamic taxa. This is especially so on continental Antarctica where collection by specialists has been restricted to comparatively few areas.

The bryophyte flora of Antarctica is comprised of some 70 mosses and 10 hepatic species. The majority of these are confined to the maritime Antarctic compared to which continental Antarctica is impoverished, with only six genera of mosses having been confirmed. These are *Bryum, Ceratadon, Grimmia, Plagiothecium* (one aquatic record), *Pottia* and *Sarconeurum* (Seppelt 1984). *Bryum* is the most widespread and abundant genus in the flora and arguably the most variable in morphology. More species have been reported in this than any other genus (Seppelt and Kanda 1986).

As latitude increases, the vegetation becomes sparser with fewer species and a comparatively smaller range of community types in a given area (Holdgate 1970, Laws 1984). Sporadic occurrences have been noted on some of the most southerly rock exposures 84° 35' S and 86° 09' S respectively (Laws 1984, Wise and Gressit 1965).

An important factor determining bryophyte distribution in the Antarctic is adaptation to low temperature conditions. Mosses and lichens show stress resistance to temperature extremes and water deficiency, and have an ability for rapid reactivation of photosynthesis without a lag phase when conditions are suitable (Kallio and Kärenlampi 1975). These characteristics are especially relevant to Antarctic bryophytes which are effectively freeze dried during the winter period. Two other important factors have an effect on the terrestrial biota of all south polar regions. Geographical isolation from potential source of propagules and cool summers, reduce the survival potential of species which do manage to achieve the necessary ocean crossing (Laws 1984).

The distribution of plants in the severe climatic regime of the Antarctic has been summarised by Holdgate (1970) as being dependant on a degree of shelter, a northerly aspect, adequate water supply in the growing season, direct solar radiation and a stable substratum. Pickard (1986) suggests the distribution of plants on continental Antarctica is limited by the suitability of ice free niches and the availability of liquid water for growth during summer. The poikilohydric water economy of mosses restricts the season of photosynthetic activity, and therefore productivity. Because of these constraints, in continental Antarctica, mosses are only very locally abundant by lakes, streams, glaciers and snow banks which melt gradually throughout the summer. They occur less extensively in hollows where blowing snow accumulates (Longton 1988). Steam warmed ground on Mt. Melbourne has also been recorded as supporting moss growth (Broady 1984, Broady et al. 1987a).

It is claimed that these discrete plant communities have low reproductive capacities and slow recovery rates. Consequently their ability to recolonise is small. For these reasons the habitats and their inhabitants are highly susceptible to the activities of humans (Greene et al. 1967).

Broadscale mapping and description of vegetation has been carried out for a few locations in continental Antarctica. Sites where more detailed studies have occurred are listed by Given (1988). These are Yule Bay and Lillie Glacier, Cape Hallet, Terra Nova Bay and Wood Bay, Ross Island, Dry Valleys, Blue Glacier and Garwood Valley. In addition Given (1988) suggests reasons why the Ross Dependency may hold particular botanical interest. These include the unique habitats of the Dry Valleys, the development of vegetation on geothermally heated soils, the wide range of rock types and suitable plant sites, and the relative accessibility of the dependency.

**I:III Antarctic Terrestrial fauna**

There are no true terrestrial vertebrates in Antarctica and the macroscopic fauna is therefore dominated by arthropods. Microscopic invertebrates dominate in areas which are seasonally free of snow cover (Laws 1984).

Dougherty and Harris (1963),in one of the earliest modern investigations into freshwater microfauna, describe the multicellular microfauna in freshwater bodies of Ross Island and the nearby continental coast of Victoria Land as having thriving populations of rotifera, nematoda, tardigrada and turbelleria (platyhelminthes). Laws (1984) reviews relevant literature up to 1982 on terrestrial invertebrates in Antarctica. He lists the main groups of species which have been identified from continental Antarctica as protozoa, rotifera, nematoda, tardigrada and arthropoda. Not included in this list are platyhelminthes which do not appear to have been reported in continental Antarctica since Dougherty and Harris (1963).

Since these earliest reports the focus of terrestrial invertebrate studies has been on the arthropods, particularly in the maritime Antarctic. The interactions between arthropods and plants has been investigated in the maritime Antarctic zone (Block 1985, Booth and Usher 1984, Usher and Booth 1984, 1986), but similar investigations on continental Antarctica are fewer in number. Pickard (1986), reviews recent developments in terrestrial invertebrate studies in the Vestfold Hills and Miller et al. (1988) studied the terrestrial tardigrada inhabiting algae, lichens and mosses in the Vestfold Hills. Everitt (1981) noted rotifers, tardigrades, nematodes, protozoans and bacteria associated with algal mats in Deep Lake Tarn in the Vestfold Hills. Suren (1989) studied microfauna associated with meltpools of the Ross Ice Shelf.

Corresponding maritime studies for freshwater ecosystems are reported by McInnes and Ellis-Evans (1987, 1988). Nematode species have been described from the McMurdo Sound region (Timm 1971, Wharton and Brown 1989).

**I:IV Coastal oases**

Ice free areas of coastal continental Antarctica are not only the areas where relatively abundant plants and invertebrates are found but are also the regions which receive the major attention in terms of tourism, exploration and modern scientific expeditions.

Two oases in coastal, continental East Antarctica, which have been the focus of biological studies, are the Vestfold Hills in Princess Elizabeth Land, and the Dry Valleys in southern Victoria Land, Ross dependency (Fig. 1.1).

The Dry Valleys encompass an area of about 5000 square kilometres with a maximum elevation of greater than 2000 m. The valleys are large features in the Transantarctic Mountains, one of the largest mountain ranges on earth. In contrast the Vestfold Hills, at a latitude of around 68° 35'S, are a smaller area of lower lying ground, termed a low coastal oasis (Pickard 1986).

A substantial amount of biological research has been completed in the Dry Valley area and the Vestfold Hills. While the topography and the latitude of the Vestfold Hills vary markedly from the Dry Valleys it is convenient to make comparisons between these two oases.

The importance of free water associated with warmer temperatures for plant growth has been emphasised (Pickard 1986, Laws 1984) and this condition is met in the Dry Valleys by melt water streams which are characterized by a highly variable flow regime at diel, seasonal and annual timescales (Vincent and Howard-Williams 1986).

In winter, plants in the Dry Valleys become 'freeze-dried' and therefore only poikilohydric plants such as mosses, lichens and terrestrial algae form the Dry Valley communities. Thompson (1980) listed the type of plant growth that could be found in the Dry Valleys. He classified them as edaphics (mainly algae), sublithics (including *Bryum antarcticum* and *Buellia frigida*), epilithic, chasmolithic and endolithic lichens.

Cryptoendolithic lichens have been described as the dominant form of life in the Dry Valley region by Friedmann (1982) who suggests that algae and lichens are the only terrestrial plants found in the Dry Valleys. In contrast Green (1986) states that bryophytes are the most abundant terrestrial plants where water is available. Although it is widely known to scientists who have visited the area, that mosses can be locally abundant, literature on the presence and distribution of mosses in the Dry Valleys is scarce.

Mosses have been reported from the Taylor Valley (Greenfield and Wilson 1981, Green 1986), and from a variety of places in the Garwood Valley near the Howchin and Joyce glaciers (Broady et al.1987b). Water flushed areas on valley slopes, channels of melt streams and areas below glacier ice cliffs supported these growths.

## I:V Sites of Special Scientific Interest

Within the Ross Dependency a number of Sites of Special Scientific Interest (S.S.S.I.) have been designated. These are in place to provide a measure of protection to certain areas, while permitting research to be carried out under specific management plans. Hence associated ecosystems and organisms are actively conserved and/or other forms of research where permitted by the management plans are facilitated. There are three such areas within the Dry Valleys. These are in the Asgaard Range, Barwick Valley and the Taylor Valley.

The Taylor Valley (Fig. 1.2), generally lies in an east-west direction. The Taylor Glacier enters the head of the valley and numerous other glaciers flow over the north and south facing slopes. The S.S.S.I. in the valley encompasses an area of 1km sq between the tongue of the Canada glacier and the shoreline of Lake Fryxell (Fig. 1:3) and is termed S.S.S.I. number 12 (New Zealand Antarctic Operations Manual 1989). During the summer months small meltwater streams drain from the glacier to the lake creating an extensive area of flushes. Much of the meltwater first drains into the Canada Pond adjacent to a low lying area of the glacier edge. The pond is frozen to the bottom in winter but thaws completely during the summer of most years. The S.S.S.I. was designated to protect an area of some of the richest algal and moss growth so far found in the Dry Valleys. The site is considered the centre for terrestrial and freshwater biological research and a reference site for other Dry Valley biological ecosystems (New Zealand Antarctic Operations Manual 1989). The area encompassed by the S.S.S.I. has come under review during the summer of 1989/90. The New Zealand Antarctic ResearchProgramme hut was sited within the S.S.S.I. and Antarctic Division D.S.I.R. requested that comment be made, by our expedition, on the huts relocation. The result was that the hut was moved during November 1989, and new boundaries were proposed to include a

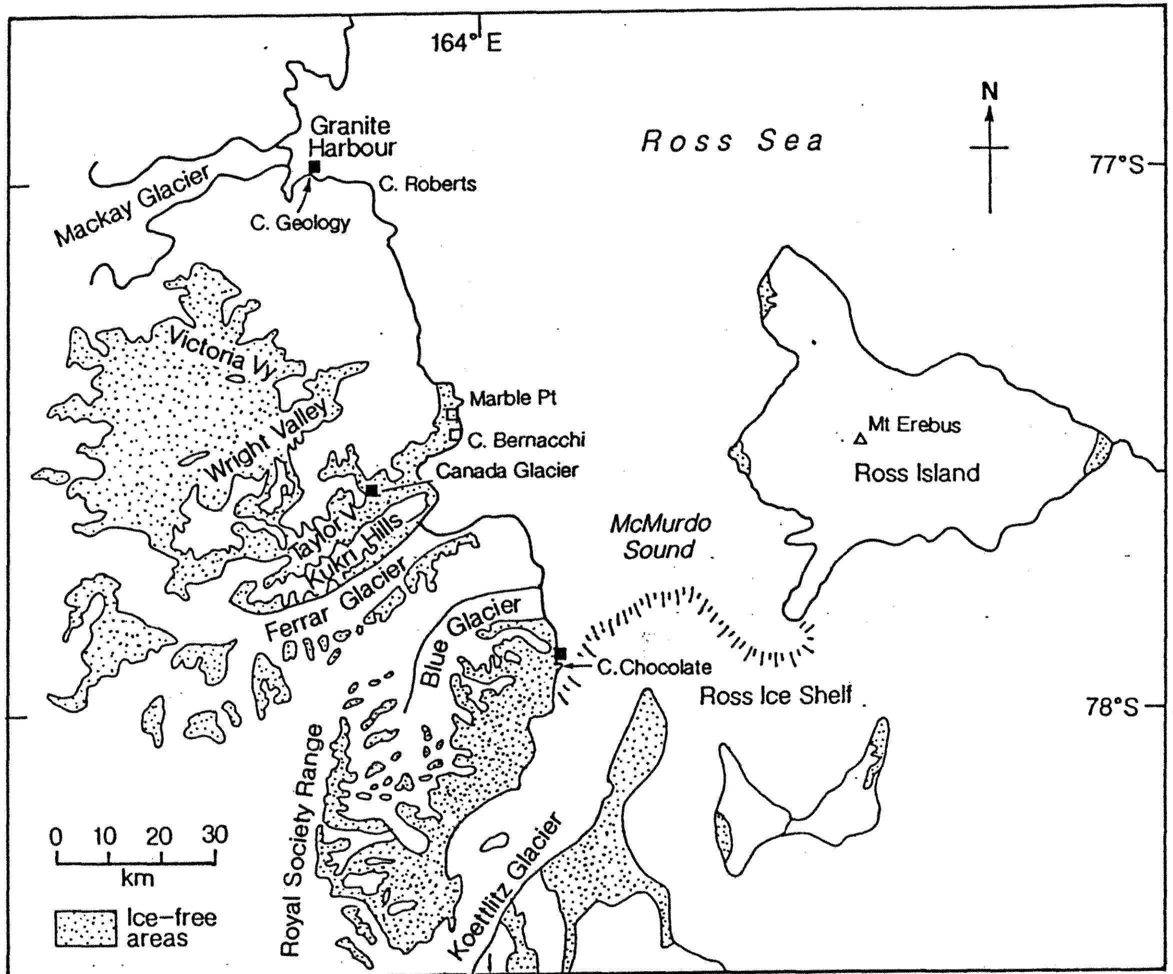



**Figure 1.2:** McMurdo Sound region of Southern Victoria Land, Antarctica, showing both the Taylor Valley and Granite Harbour.

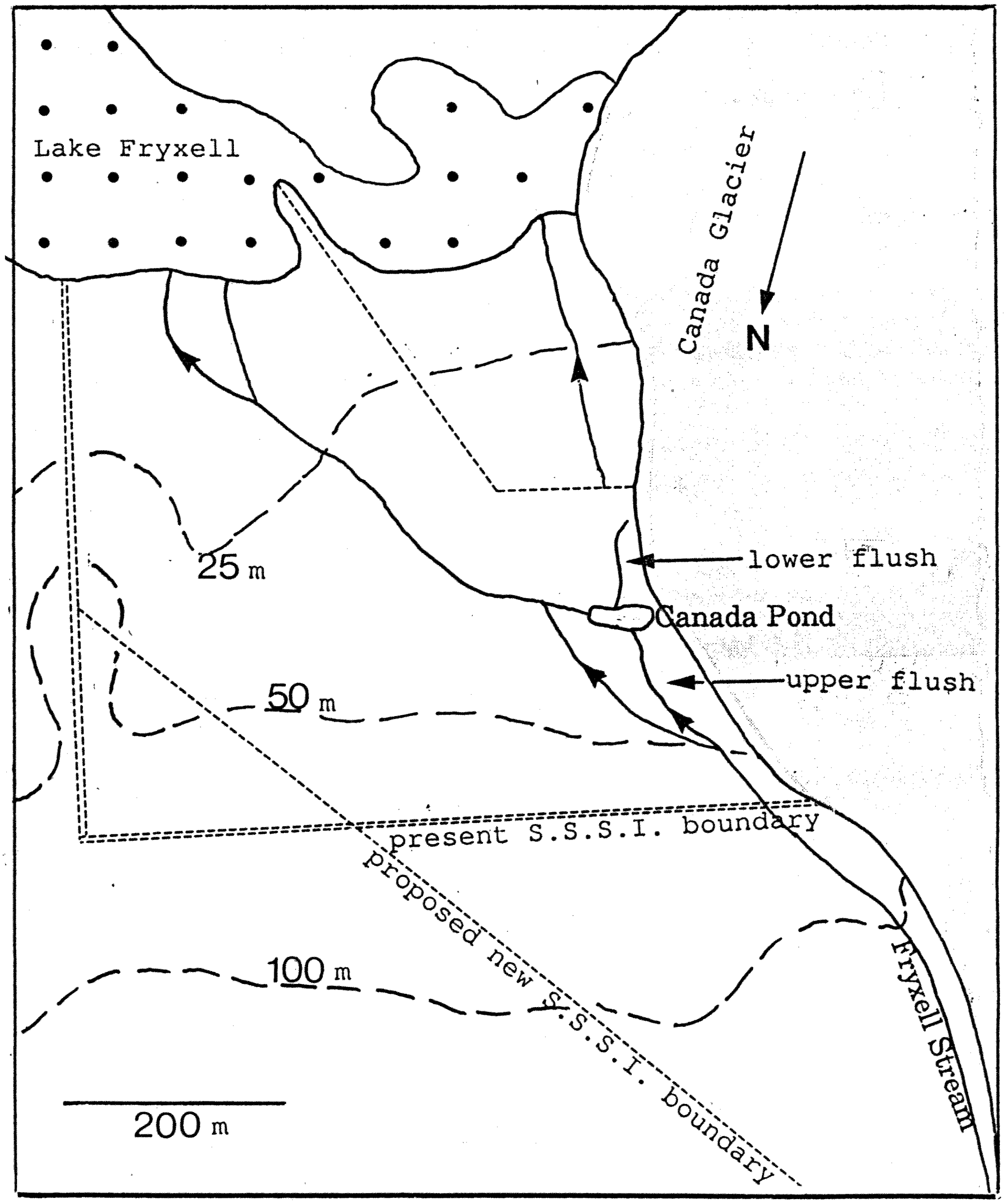



**Figure 1.3:** S.S.S.I. No. 12 showing the location of study sites in relation to the Canada Glacier.

larger area of plant growth and the headwaters of the Fryxell Stream (Fig. 1:3 ) in S.S.S.I. No.12.

## I:VI Objectives of the study

The fieldwork for this study was carried out in the Antarctic from 14.11.89 to 11.12.89. In view of the fragility of these ecosystems care was taken to minimise our impact by keeping sampling to a minimum, and to restrict movement within the area to strictly defined paths.

Subsequent laboratory analysis of samples was conducted at Waikato University in the early part of 1990. The study was completed at the Taupo Research Laboratory, D.S.I.R., Taupo, New Zealand.

The areas investigated were the Canada Glacier / Lake Fryxell bryophyte flushes in the Taylor Valley and the area of Cape Geology, Botany Bay and the Flatiron at Granite Harbour (Fig. 1.2). The first was the major focus of the study and therefore received greater attention to detail (objectives 1 to 4). The observations at Granite Harbour are a result of a qualitative survey of the area spanning two and a half days (objective 5).

The objectives of the study were:

1. To determine the locations of the plant communities, their community structure, floristic composition, biomass and nutrient status.

   The 1989 study of plants in S.S.S.I. No.12 focused on obtaining a definitive species list as identifications have not been confirmed from the location before.

2. To determine the invertebrate groups present, their abundance and to ascertain how invertebrate occurrence was related to vegetation community types.

3. To determine relationships between community composition (plants and invertebrates) and environmental factors, in particular topography and water.

4. To assess the capacity of these ecosystems to recover from external disturbances.

5. To compile a plant species list from Granite Harbour and to describe how the composition of communities at this site compared to that of the Canada Glacier/ Lake Fryxell S.S.S.I. flushes.

# Chapter II: Study Sites, Materials and methods.

## II:I Taylor Valley: Site Description and Climate.

The areas of bryophyte growth, which were the focus of the majority of this thesis, were located in S.S.S.I. No. 12 adjacent to the eastern face of the Canada Glacier (77° 38' S,163° 00' E), in the Taylor Valley approximately 12 km from the sea .

The Canada Glacier is a local alpine glacier as distinct from the large outlet glaciers draining the polar ice sheet, or a coastal piedmont glacier lying along the coastline. The smaller alpine glaciers are all dry based. These dry based glaciers are effectively incapable of basal erosion and flow slowly as there is no basal sliding. Chinn (1986) presented evidence that the Canada glacier had been advancing over the previous five or six years.

There are 3 main flow directions of water off the Canada Glacier during the Antarctic summer and it is associated with these flows that the main plant growth is found. The occurrence of wet algal-rich spongy flushes adjacent to the foot of a glacier where streams form is a frequent occurrence in the Dry Valley area (Howard-Williams and Vincent 1986).

The flush areas at the Canada Glacier can be described as 'short turf'. These are systems formed by sparingly branched acrocarpous mosses with main shoots erect and parallel. The colonies may be loose or more frequently compact, greater than 2cm tall and often composed of *Bryum* and *Pottia* (Longton 1988).

Two main areas of plant growth were identified for this study and were termed the 'upper' and 'lower' flush (Fig. 2.1). The lower flush is included in the present boundaries of the S.S.S.I.. Its source stream runs in a north east direction off the face of the glacier toward the Canada Pond and contributes to the Fryxell stream.

The area we termed the lower flush was that delimited by the extent of plant growth. It was approximately 130 metres long and 55 metres wide. The main stream flowing on to the flush divided in two, 45 metres downstream from the glacier, and rejoined 30 metres further down narrowing to a 10 metre wide strip draining into the Canada Pond (Photograph 1). In the summer of 1989/90 the amount of water flowing over the plants increased as the melt progressed, and eventually many of the bryophytes in lower lying areas were completely submerged (Photograph 2).

The upper flush is included in the revised S.S.S.I. boundaries. Water is supplied to this area from a few hundred metres length of the upper north facing edge of the Canada Glacier. This is the beginning of the Fryxell stream which rapidly increases in size along the first kilometre as streams contribute from various portions of the glacier (Howard-Williams et al. 1986). The Fryxell stream is one of three which dominate the hydraulic budget of the receiving waters of Lake Fryxell (Green et al. 1989).

Water which is sourced from the glacier and flows over the plants in the flushes, is likely to be the major source of nutrients to the system (Downes et al. 1986).

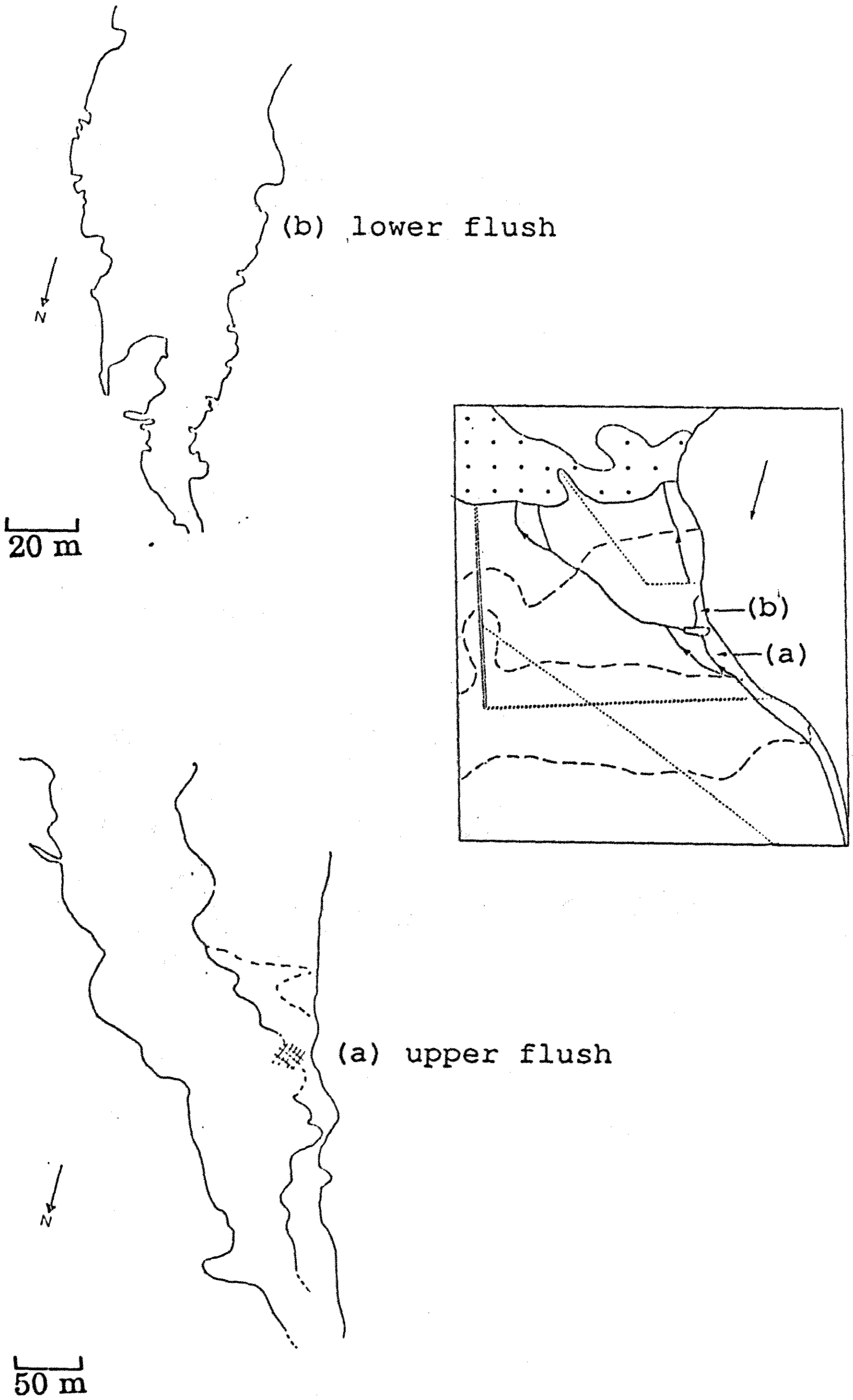



**Figure 2.1:** Expanded view of upper and lower flushes. The outlines are determined by the limits of visible plant growth.

**Photograph 1.** Overall view of the lower flush looking south.

**Photograph 2.** Submerged *Pottia heimii*

Howard-Williams et al. (1986) measured nutrients in the upper and lower part of the Fryxell stream during January 1984, and noted that inorganic nitrogen and phosphorus concentrations decreased markedly downstream. It was concluded that the significant algal growths in the area stripped nutrients from the water flowing over them.

The Dry Valleys' warm temperatures and persistent up and down valley winds help keep the area substantially free of snow in summer. The winters are characterised by long periods of cool calm weather interspersed with periods of warm, westerly katabatic gales (Vincent 1988). Polar microclimates are greatly affected by wind and the paucity of shelter for plants and animals limits their distribution. There are three primary wind effects. These are disturbance of local temperature and humidity profiles, abrasion damage by transport of ice and mineral particles, and transport of living propagules (Laws 1984).

In the Antarctic all terrestrial plants and micro-organisms live close to the ground. The special microclimate at this level in relationship to air temperature at higher levels is illustrated in Figure 2.2. An overall higher temperature for moss and lichen surfaces is evident compared to air temperatures at 0.6 metres and 1.5 metres. At S.S.S.I. No.12 a number of factors combine to provide a suitable microclimate for plant growth. The glacier provides protection from strong katabatic westerly winds and thereby

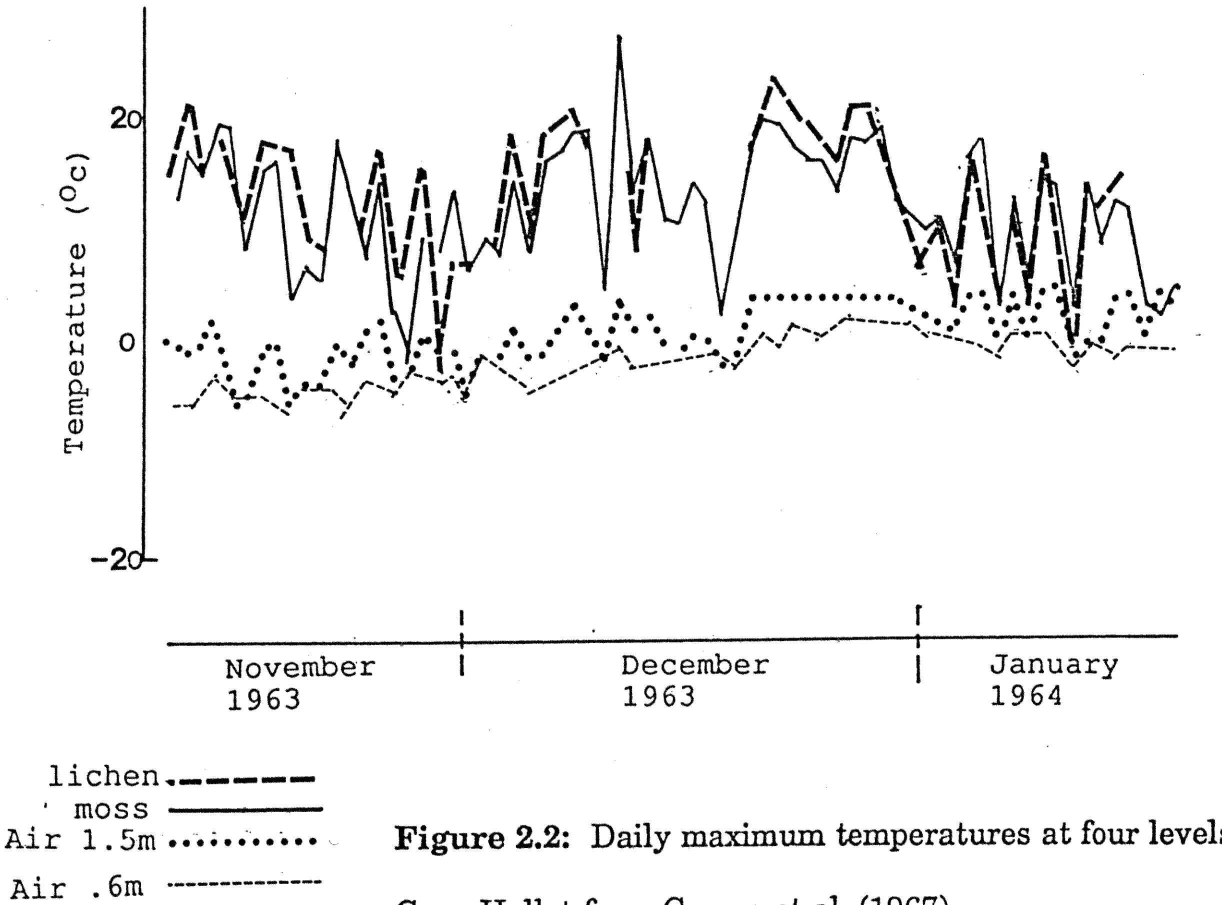



**Figure 2.2:** Daily maximum temperatures at four levels at Cape Hallet from Greene et al. (1967).

reduces abrasion of the plants, warm summer temperatures are attained at moss level and water is available from glacial melt. Extreme cold is the major feature of Antarctic environments. Even throughout the summer air temperatures at the margin of the continent lie between -10 and 15° celsius (Vincent 1988). Since 1985 continuous records of meterological data have been collected from within five kilometres of the study site at the Canada glacier. The meterological station is situated at Lake Hoare on the edge of a small peninsula 300m west of the Canada Glacier (Clow et al. 1988). In the year preceding this study daily average temperatures were above zero only within December 1988 and January 1989. They fell to below -40° celsius at times between May and August 1989 (Fig. 2.3). Relative humidity showed little change in overall trend throughout the year, fluctuating between extremes of approximately 30 and 80% (Fig. 2.4).

For approximately four months of the year the site is subject to continual darkness (Fig. 2.5). With the return of sunlight during the summer months a diurnal cycle in photosynthetic quantum flux is evident. Throughout the year air temperature closely follows incident sunlight. Meltwater stream ecosystems in the Dry Valleys are fundamentally linked to radiation and temperature. There is a strong correlation between mean daily discharge and the seasonal radiation cycle. Many streams show pronounced diel variations that depend on the position of the sun relative to the melting glacier face

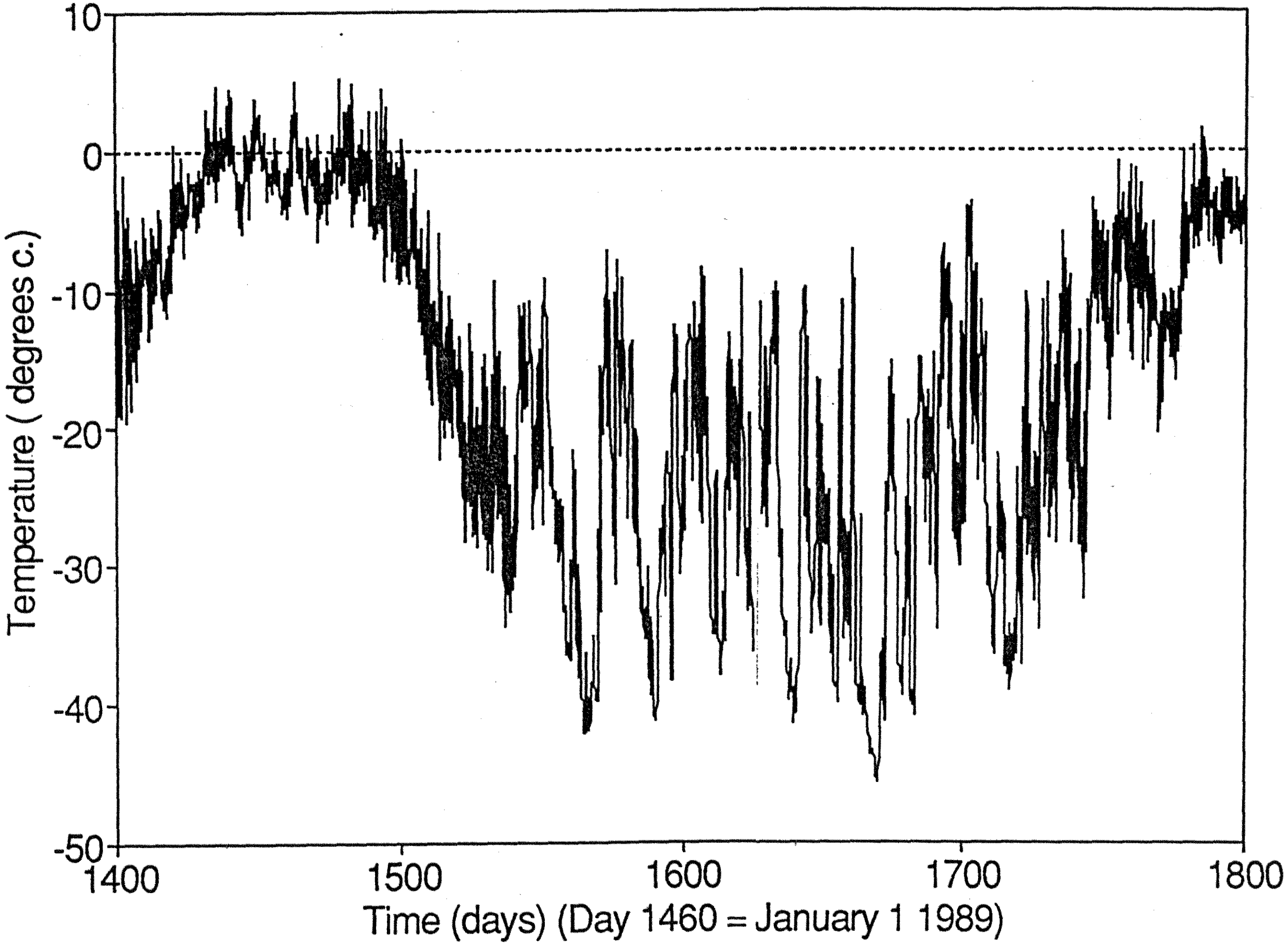



**Figure 2.3:** Daily average temperatures at Lake Hoare from December 1988 to December 1989 (McKay, unpublished data).

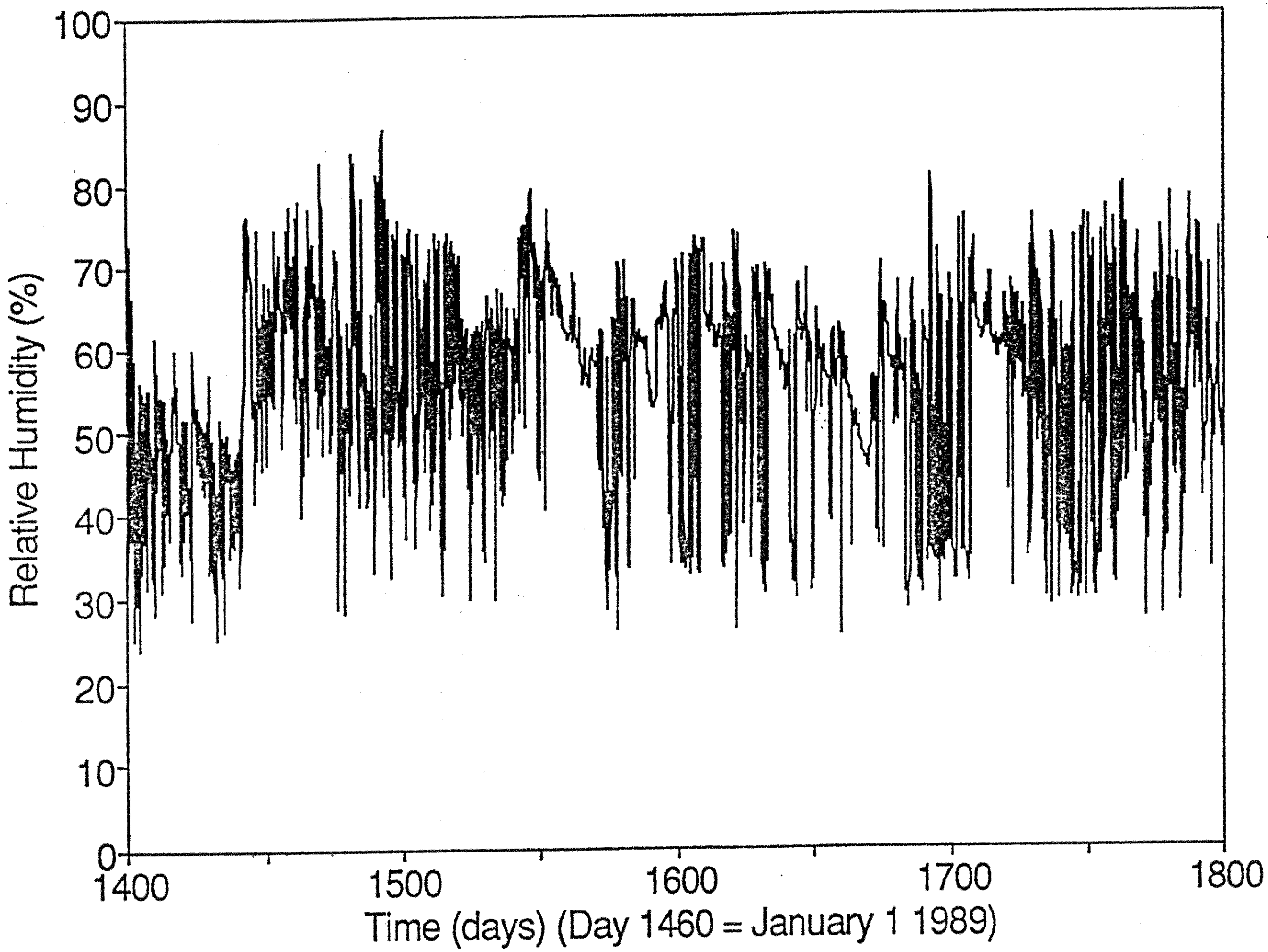



**Figure 2.4:** Daily average relative humidity at Lake Hoare from December 1988 to December 1989 (McKay, unpublished data).

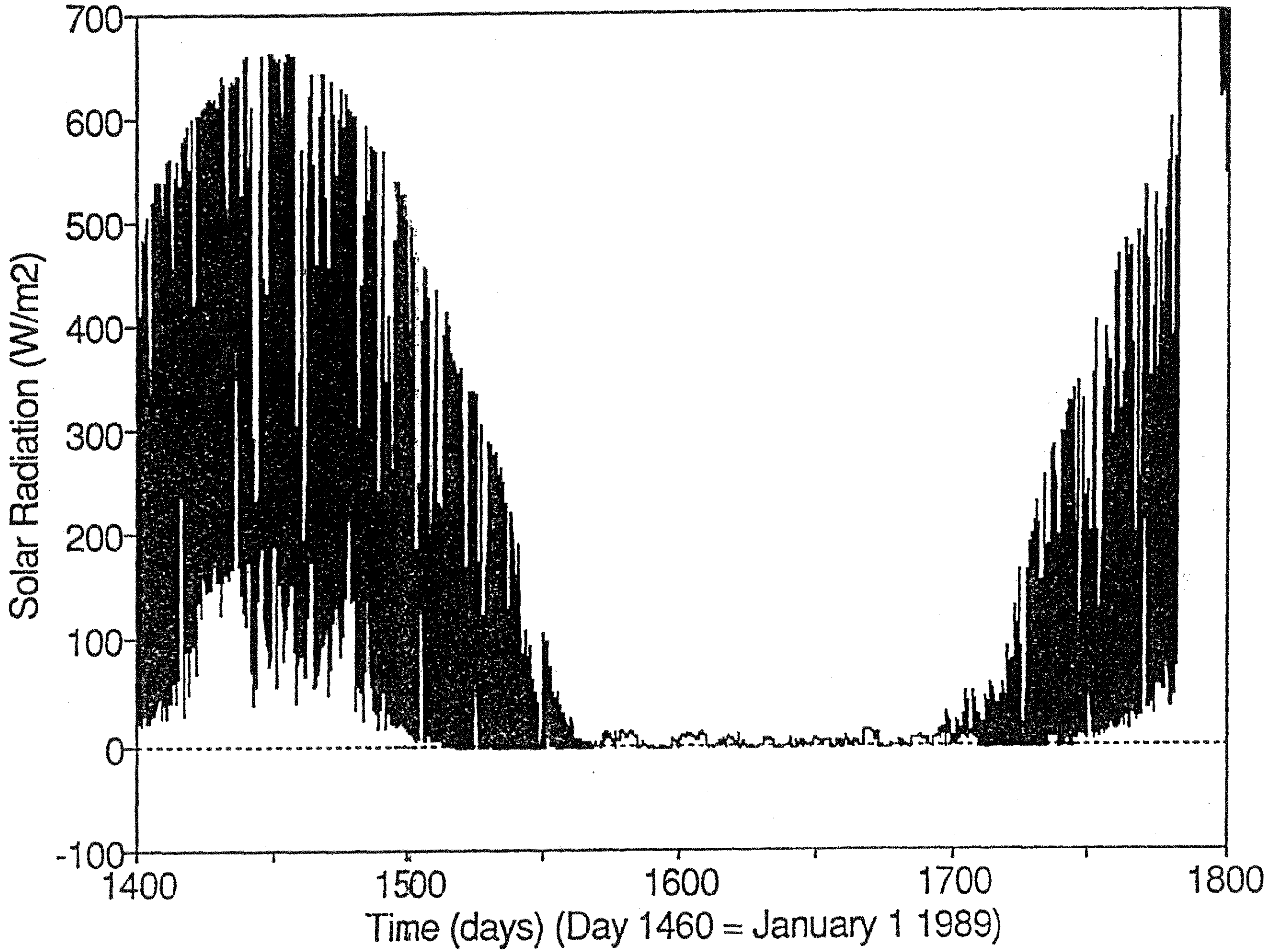
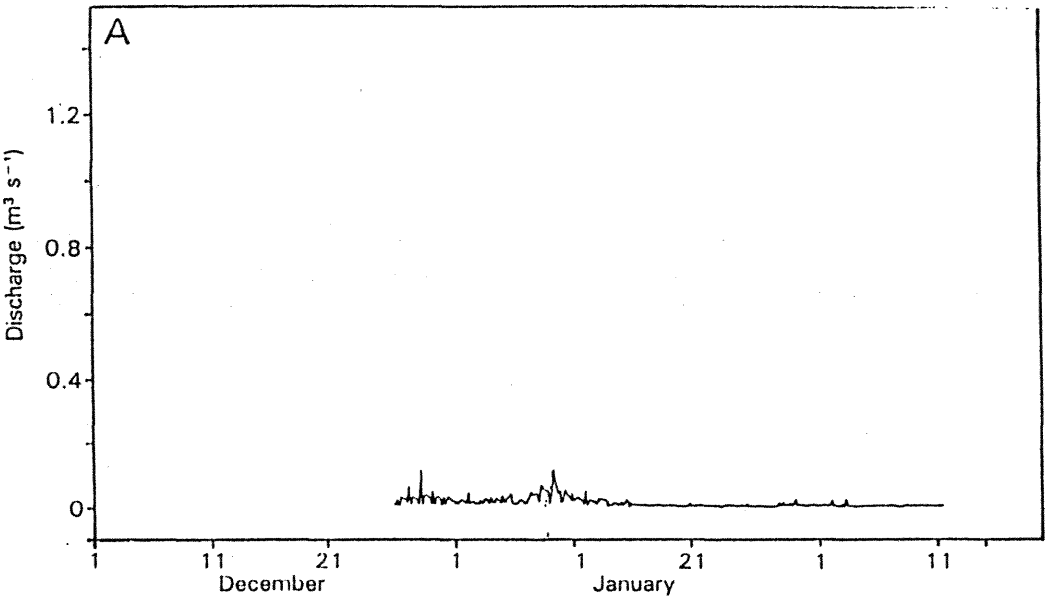



**Figure 2.5:** Daily solar flux at Lake Hoare from December 1988 to December 1989 (McKay, unpublished data).



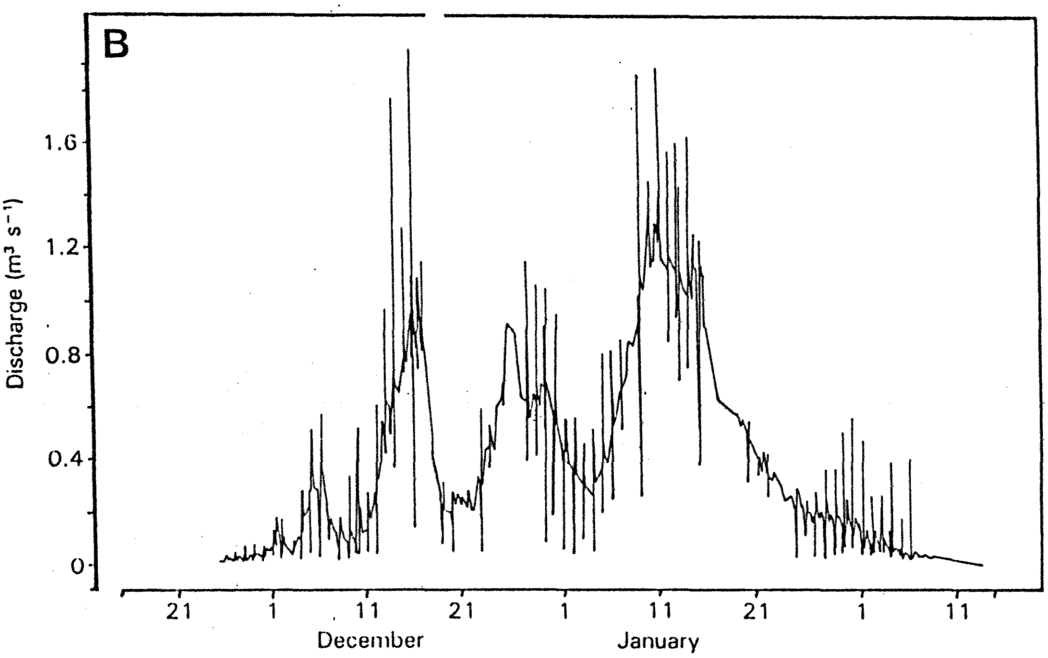




**Figure 2.6:** Discharge of the Onyx River A) 1977/78 (Chinn 1983), B) 1979/80 (Chinn and Cumming 1983)

(Vincent 1988). As a consequence small shifts in energy balance at glacier ice faces may markedly alter the availability of water for biota in these ecosystems.

As water flow off the glacier is affected by changes in incident radiation, it is consequently extremely variable on all scales from hours to years. Figures from the Onyx River in the Wright Valley illustrate variations in discharge related to changes in the radiation balance at the glacier face and emphasise the variability in annual discharge between years (Fig. 2.6). It follows that plant communities might provide an integrated assessment of water reliability and volume in an area, because of their reliance on this water for growth.

## II:II Site Description and climate, Granite Harbour

Granite Harbour is located at 77° 00' S, 162° 50' E (Fig. 1.2). Ice free areas on the coast provide suitable habitats for plants and invertebrate colonisation (Fig. 2.7).

Granite Harbour was named by Scotts party in January 1902. The area was noted as being well protected from the wind and enclosed by much bare rock capable of absorbing the suns' rays. Small streams of water were described as meandering over stones with banks of almost luxurious mosses in their sheltered courses (Murray 1929). Coloured lichens, 'good sized' clumps of 'real' green moss, and plentiful collembola were noted in Edward Wilsons' diary (Savours 1966).

On November 30, 1911, the western geological party from the Terra Nova came to a small sheltered beach east of Cape Geology.

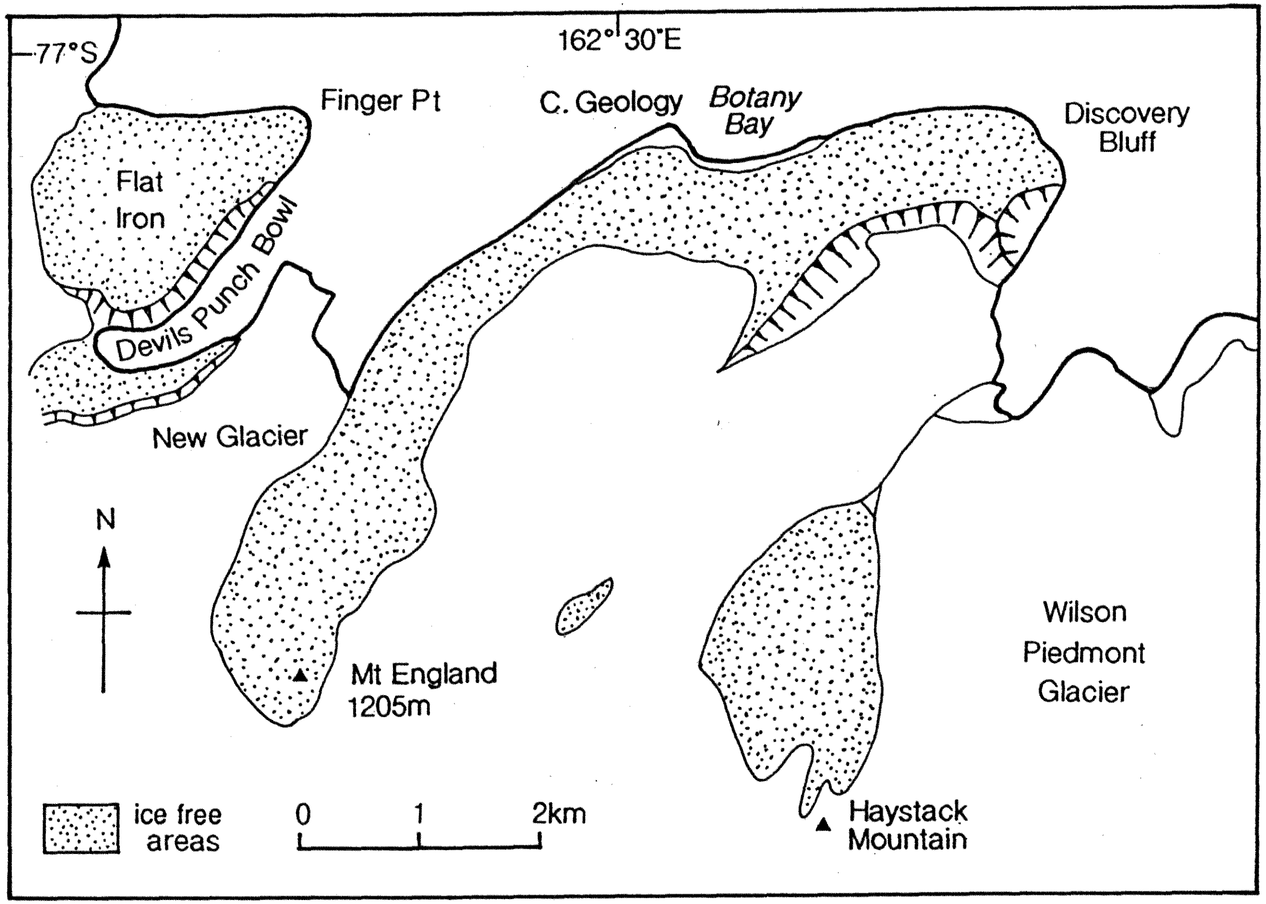



**Figure 2.7:** Map showing location of Cape Geology and Botany Bay at Granite Harbour.

Because of the lichens and moss which they found growing here in 'some abundance' they named it Botany Bay (Quartermain 1967). During this expedition they constructed a kitchen of granite blocks roofed with a sledge, biscuit boxes and sealskins. Much of this (including the sealskins) remains today (photograph 3).

During our visit in 1989 we noted that the north facing sites of Cape Geology and Botany Bay are fed by numerous streams running down the steep granite faces. The streams are fed by part of the Wilson-Piedmont glacier above and are possibly enriched by the presence of a skua rookery. Ryan and Watkins (1989) concluded that nutrients in ornithogenic products had direct causal effects on the abundance and dispersion of the biota of inland Antarctic nunataks. Plant growth at this site contrasted with that at the Canada Glacier in that there was no well defined flush area and the plants grew amongst granite boulders. On Cape Geology most plant growth was found in the narrow catchments of the streams or on granite ledges where snowmelt and windblown deposits provided the water and substrate necessary for growth. In Botany Bay a comparatively wider area of less steep slope next to the sea allowed water from the streams to spread out amongst the boulders creating an expanse of suitable habitats extending approximately 50 to 100 metres along the beach.

Mosses and lichens have been collected in the past from the Granite Harbour region. These have been identified as *Bryum argenteum* Hedw. , *B. antarcticum* Hook.f et Wils., *Sarconeurum glaciale* (C. Mull.) Card. et Bryhn,

**Photograph 3.** Scotts kitchen at Granite Harbour.

*Lecanora griseomarginata, Rinodina frigida* and *Usnea antarctica.* Algae of the genera *Prasiola, Zygnema, Navicula, Nostoc* and *Phormidium* have also been reported (Ugolini 1977).

Climatic conditions in the Granite Harbour region have been inferred from meteorological stations at other sites in the McMurdo region. Ugolini (1977) estimated from isotherms delineating the area, that the mean annual temperature for the Kar Plateau on the north side of Granite Harbour is probably between -20.0 and - 25° celsius. He judged from the amount of snow on the ground in October 1969 that the precipitation is probably higher than for other ice free areas of Southern Victoria Land. The Kar Plateau has an average elevation of 600 metres and as such is substantially higher than our study site which was within 100 metres of sea level. Air temperatures for 19-24 November 1969 fluctuated between -8 and +2° celsius, and for 24-26 October 1969 from -10 to -30° celsius (Ugolini 1977).

Records kept by two New Zealand research parties in the Granite Harbour region over the summer of 1983/1984 note a range of temperatures from -14° celsius on October 11 to -2° celsius on December 4. These readings were usually taken between 0700 and 1000 hours. A maximum windspeed of 30 knots was recorded on one day in early October. Wind speeds were otherwise generally less than 10 knots (Pyne 1984).

## II:III Methods

### II:III:I Microclimate on the Canada Glacier Bryophyte flush.

A Campbell CR21 datalogger was set up on the lower bryophyte flush with three probes attached to it. These logged continuously at fifteen minute intervals for just over three weeks.

Photosynthetically active radiation (PAR 400-700nm) was measured with a LI 190sb quantum sensor to an accuracy of 0.1 uM $m^{-2}$/sec. The logger was programmed to record maximum, minimum and average P.A.R. over the preceding fifteen minutes. A combination temperature and humidity probe was placed at 4 cm above the moss bed and another temperature probe was pushed 1cm into the moss. Relative humidity was measured to 0.1% and temperature to 0.1° celsius. The response of the humidity sensor is such that only trends can be taken from the data. Absolute values can be several % in error.

Air temperature and moss temperatures were also measured using a hand held 'Fluke' digital thermometer over 4 diel periods at two hourly intervals during November and December 1989. The air temperature was measured at approximately 10 cm above the moss. The temperatures within a bed of *Bryum argenteum* (for sites see Fig. 2.8) were measured at depths of 5, 10 and 15 mm.

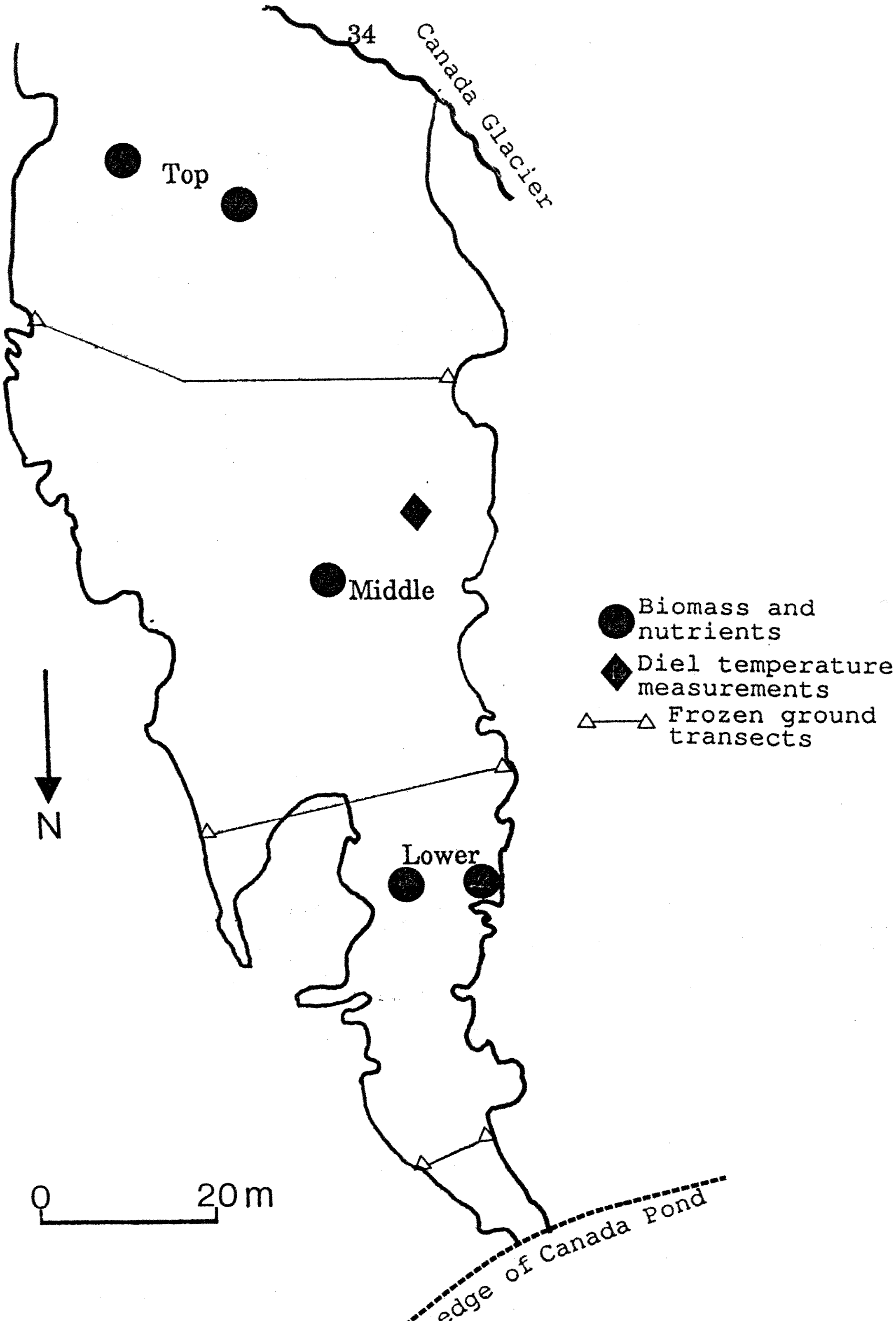



**Figure 2.8:** Lower flush map showing sites for nutrient and biomass samples, transects for measurement of frozen ground and sites for measurement of moss temperature.

### II:III:II Frozen ground.

On 3 days during November and December (17.11, 24.11, 8.12) the depth of frozen ground was estimated on three transects spanning the lower flush (Fig. 2.8). This was measured by pushing a steel measuring rod into the ground until it could be pushed no further. Care was taken to detect fake readings from buried rocks.

### II:III:III Plant Taxonomy

There is considerable confusion surrounding the taxonomy of the bryophytes of continental Antarctica. *Bryum* is both the largest genus and the one that raises the most taxonomic questions. It is considered that only through taxonomic revision and controlled environment growth studies will the number of moss species in continental Antarctica be clarified (Seppelt 1983). Previous records from the Canada Glacier bryophyte flushes reported *Bryum argenteum* and *Bryum antarcticum* (Green 1986) but recently the identification of *Bryum antarcticum* has come under review ( Kanda 1981, Seppelt and Kanda 1986). We were fortunate to have Rod Seppelt from the Australian Antarctic Division with us who has wide experience in the taxonomy of Antarctic bryophytes. His identification of bryophytes in the field enabled us to compile a species list in light of recent taxonomic reviews.

### II:III:IV Vegetation of the lower flush (Initial mapping).

Collections of representative plant specimens were made from both the lower and upper flushes. The lower flush was mapped by establishing a five metre grid. A survey line was established on the western side of the flush and measuring tapes run perpendicular to it, across the flush, at five metre intervals. The elevations along the survey line and across the flush were measured with a builders theodolite. This was also used to ensure that lateral tapes were at right angles to the main survey line. The boundaries of major plant associations were drawn and a visual estimation of cover made within these boundaries. An overall map was produced at a scale of 1:100.

### II:III:V Verification of cover estimates

To establish the accuracy of the visual cover estimates, point quadrats were examined at a number of areas over the flush. A quadrat 10cm x 20cm divided into 1cm squares was subjectively sited on the flush to cover the range of vegetation perceived to be present. At each cm intersect within the quadrat the plant species was noted. Within each community type between 2 and 10 quadrats were investigated. The % cover of each species in each quadrat, and the mean % cover within each plant community was derived from these figures.

Transects were laid across the main flow channel at five locations on the lower flush. The microtopography of these transects was mapped using a theodolite. The heights were not surveyed with regard to a standard reference point but their relationship to the overall contours of the flush is illustrated in the results section. The height of the ground and the plant species present were noted at five cm intervals along the transect. The data from the transects was subsequently divided into 20 cm intervals for the purpose of analysis. Each of these intervals was regarded as a site, and chi squared analysis was carried out to determine a degree of association between plant species. Each site was designated as a hummock or a hollow from the topographic survey data.

### II:III:VI Nutrients

For each of *Pottia, B. argenteum* and *Nostoc* associations, 5 x 1 cm diameter cores were taken from 3 different sites (Fig. 2.8) to be used for nutrient analysis. A stainless steel cork borer was used to core to the depth where the plant material met the substratum. This was to a depth of approximately 15 mm for the mosses but less for the algae. The cores were placed in glass vials and kept frozen until they were dried after return to New Zealand prior to analysis. To obtain the minimum required weight for this analysis, the 5 core samples were bulked. Nutrient analysis was carried out by the Plant Analysis Laboratory, M.A.F., Hamilton.

Nitrogen and phosphorus were analyzed using a Kjeldahl digest with selenium as a catalyst. Nitrogen was analyzed by a modified Gehrke-Wall automated method, while phosphorus was analyzed by an automated method using an ammonium molybdenate and amino napthal sulphuric acid reaction.

The remaining nutrients were analyzed using a nitricperchloric mixed acid, wet ashing procedure. The digests were diluted with strontium chloride solution to inhibit the formation of stable calcium and magnesium phosphates, sulphates and aluminates in the flame. These diluted solutions were then analyzed on a four channel flame spectrophotometer using atomic absorbtion for the magnesium channel and flame emission for sodium, potassium and calcium.

**II:III:VII Biomass**

To obtain an estimate of the biomass of the plants an additional set of cores was taken adjacent to the first set. Each individual core was dried for 1 week at 50° celsius and then weighed. Many of the samples had a high sand content so for all the samples ash free dry weights were calculated. The samples were placed in a furnace for 2 hours at 550° celsius. After cooling in a desiccator the material remaining after ashing was weighed on an OHAUS GT480 digital balance. This weight was subtracted from the initial dry weight to obtain an estimate of the above ground biomass. The results were extrapolated to biomass/unit area assuming continuous cover (Longton 1988). No distinction was made between green and decaying material.

**II:III:VIII Vegetation of the Upper flush**

The upper flush was mapped on a broad scale to compare the vegetation with that of the lower flush. 45 transects were placed across the flush at 10m intervals starting at the Canada pond and working northward. The major boundaries of plant groups were marked at each 10m interval. Percent covers were not estimated due to the great variability on this large scale.

**II:III:IX Epilithic Lichen Mapping**

At the outwash area of the Canada Pond, an area containing epilithic lichens was discovered. Lichen distribution was mapped in relation to water depth using a similar method to that used for the lower flush. Two parallel

30 m tapes were laid out in a line with the river flow and enclosing the entire outwash area. Two further 30 m tapes were then placed across the stream at a distance of one metre apart. The number of lichens could be counted in each one metre square by moving along the tapes. When each transect had been completed the upper tape was lifted and moved downstream, one metre below the remaining tape, and the assessment proceedure repeated. A total distance of 15 m was mapped along the stream. A microtopographic survey was also made. Lichens were recorded by an abundance index fully explained in the results section.

### II:III:X Recovery

To obtain a measure of the ability of the lower flush to recover from damage we relocated plant and animal sampling sites which were still recognizable after a period of 10 years. Damage was initially located by careful observations of the flush. Sites were marked on a site map and where possible, were then surveyed enabling a scale map to be produced.

A simple map available from 1980 allowed old paths to be relocated on the flush whilst small cairns indicated sampling sites. Excluding paths and footprints, a total of nineteen damaged sites were identified and, of these, nine were confirmed as to type and date of damage.

### II:III:XI Invertebrates

Samples for invertebrate enumeration were taken from the lower flush by the coring method described for the plant samples. These cores were placed in 'whirl-paks' (NASCO Ltd) and kept frozen until they were examined.

Invertebrate numbers were recorded from samples taken in November before the melt began. Animals were not active within the flush at this time and these counts are therefore an indication of the potential inoculum which would become active as soon as water was available. Numbers were also recorded from samples taken after meltwater had been on the flush for 14 days (8-10.12.89). Abundances per square metre were calculated from 27 pre-melt 1cm diameter cores and 17 post-melt cores. Most of the samples were counted in the field but some were retained frozen and transported back to New Zealand.

For invertebrate enumeration the cores were sectioned into 3 layers, 5 mm thick, wetted and left at approximately 2° celsius for 1 hour before counting. While in the field initial counts were made at intervals for a 24 hour period to establish a minimum time to leave the sample before counting. A time course plot of invertebrate numbers (Fig. 2.9) was used to determine the minimum period required to maintain a sample in the wetted state before counting the invertebrates in this and all subsequent experiments. One hour was decided on as there was little change in numbers of active invertebrates over the following time period up to 24 hours. In practice the time varied between one and two hours as some samples were more time consuming than others to count.

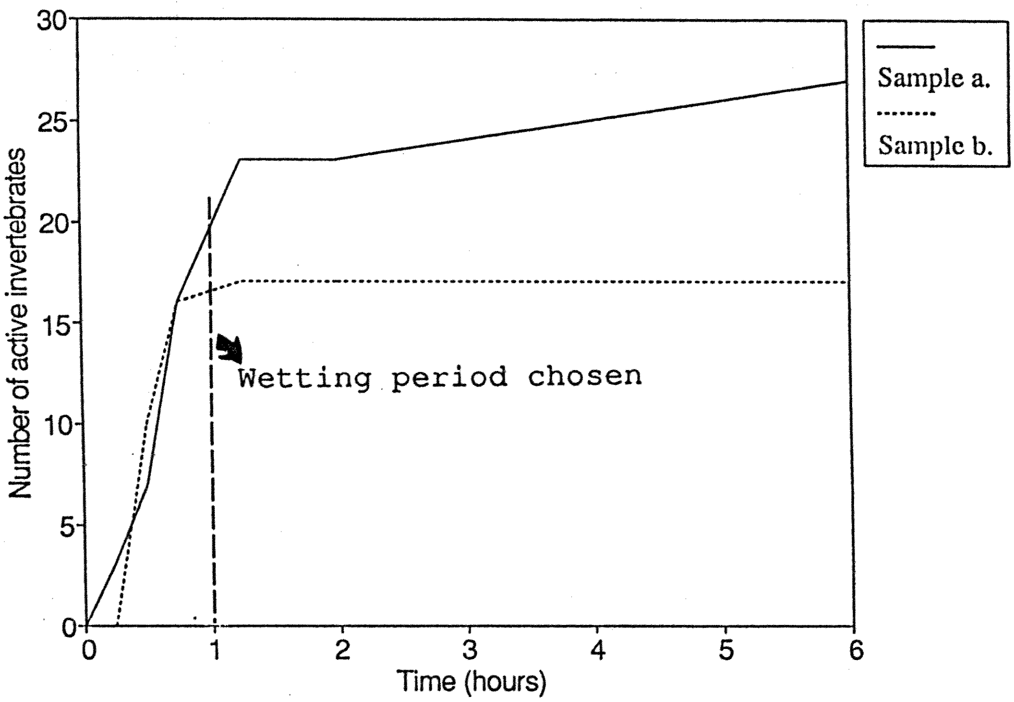



**Figure 2.9:** Invertebrate counts over time following wetting of a freeze dried moss core.

The small size of the samples made it possible to count the total number of animals in each core by teasing apart the plant material, in a thin layer of water. This was done in a channelled perspex counting tray (channel width 10 mm). Animals which were visibly moving were counted under a dissecting microscope (x50).

### II:III:XII Granite Harbour

Investigations at Granite Harbour were carried out from 4.12.89 to 7.12.89. Representative plant samples were taken from Geology bay, Botany bay and from the Flatiron. The plants were identified to obtain a species list and invertebrates were extracted in the same manner as described for Fryxell samples. No quantitative analysis of invertebrate numbers was attempted here.

One stream catchment was surveyed in relative detail as to plant composition. The area lies on what could be termed the boundary between Geology bay and Botany bay. The catchment was drawn to scale and a visual impression of changing plant species composition was noted from the snow bank at the highest point down to the ocean. Physical characteristics were noted. Samples were taken at 6 sites in this area to be examined for the presence of invertebrates.

# Chapter III: Climate and microclimate: Lake Fryxell area.

## III:I Introduction:

It is accepted that in the Antarctic microclimate zones occur close to the ground which may be crucial to the existence of biota. It is considered that in S.S.S.I. No.12, a number of factors associated with the Canada Glacier combine to provide a favourable microclimate to enable the continuation of plant growth in the area.

In order to describe microclimate characteristics close to the ground on the lower flush, air temperature, relative humidity, and photosynthetically active radiation were measured over the entire study period. The depth of frozen ground was measured on three occasions and moss temperature was measured over four diel periods.

This chapter presents results from microclimate observations on the lower flush adjacent to the Canada Glacier during November and December 1989.

## III:II Results

### III:II:I Climate

Temperature recordings at 4 cm above the moss for a 15 day period from 24.11.89 to 10.12 89, are illustrated in Figure 3.1. An obvious diel variation is evident with a trend to increased average temperatures in December. The

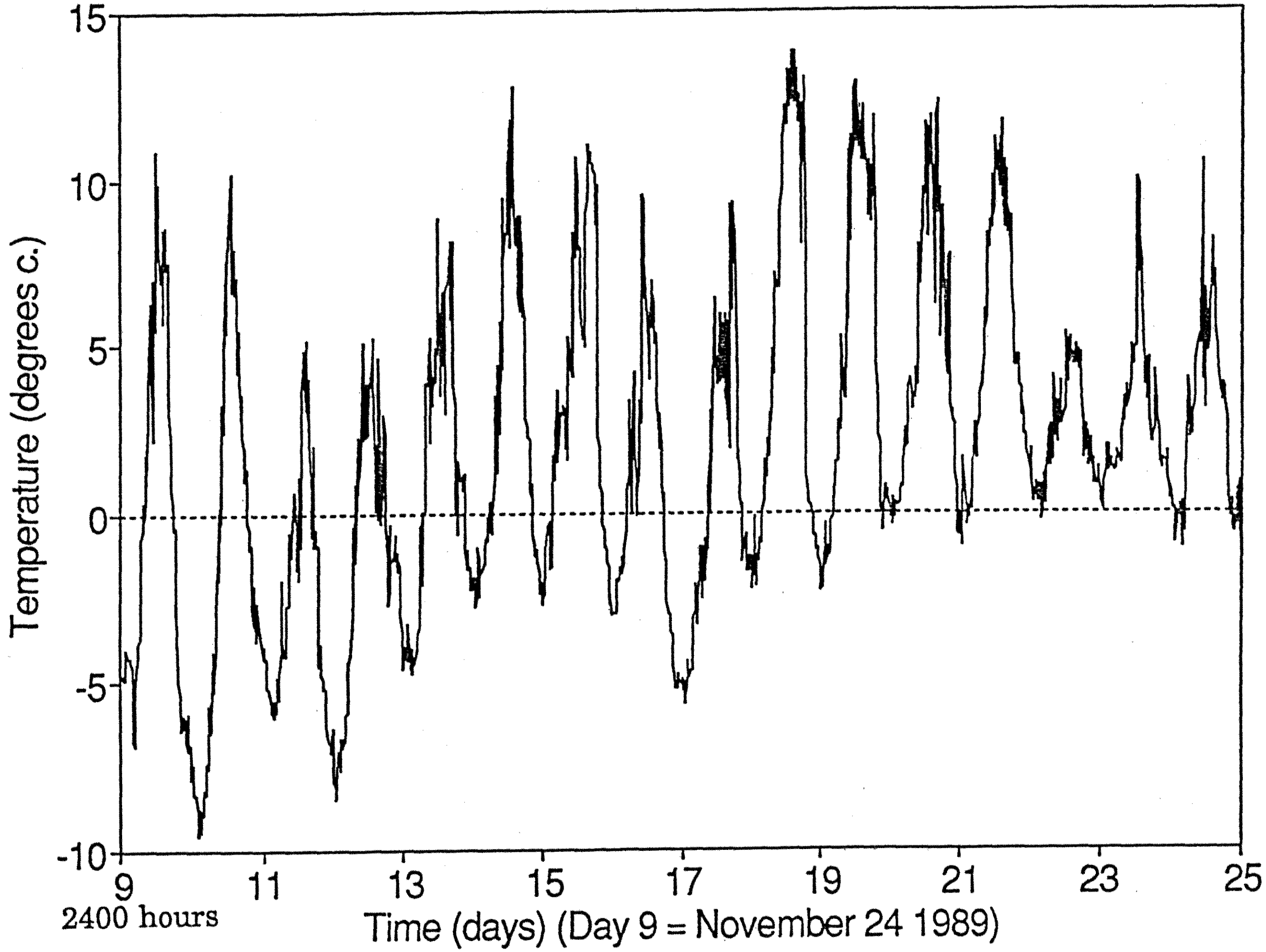



**Figure 3.1:** Air temperature at 4cm above the moss on the lower flush.

temperature experienced at this level over the monitored period was -9 ° celsius with a maximum of 13.5 ° celsius. Temperature fluctuations are illustrated in Figure 3.2 over four diel periods. A consistent diel fluctuation is evident with an obvious increase in average temperature as the summer progresses. During the hours of 2200 and 0400 when the air temperature drops to the lowest level of the diel period, moss temperature consistently remains higher than air temperature. The capacity of the moss to buffer against air temperature changes means that during these diel study periods the mosses had a higher average temperature overall than the air temperature. As the water flow increased over the flush, temperature differences which had been observed at different depths within the moss, ceased to be obvious.

Figure 3.3 shows the relative humidity (R.H.) at moss level for the period 24.11.89 to 10.12.89. While the moisture content of the air close to plant communities has been little studied, data in the literature all show increasing moisture gradients down toward the ground with R.H. maxima usually occurring at night (Laws 1984). R.H. maxima at night are evident from Figure 3.3. Higher R.H. due to lower temperatures is evident on comparison of Figures 3.1 and 3.3 around the 27th November (day 12) and the 7th December (day 22).

Figure 3.4 illustrates two diel periods of P.A.R. from the datalogger.

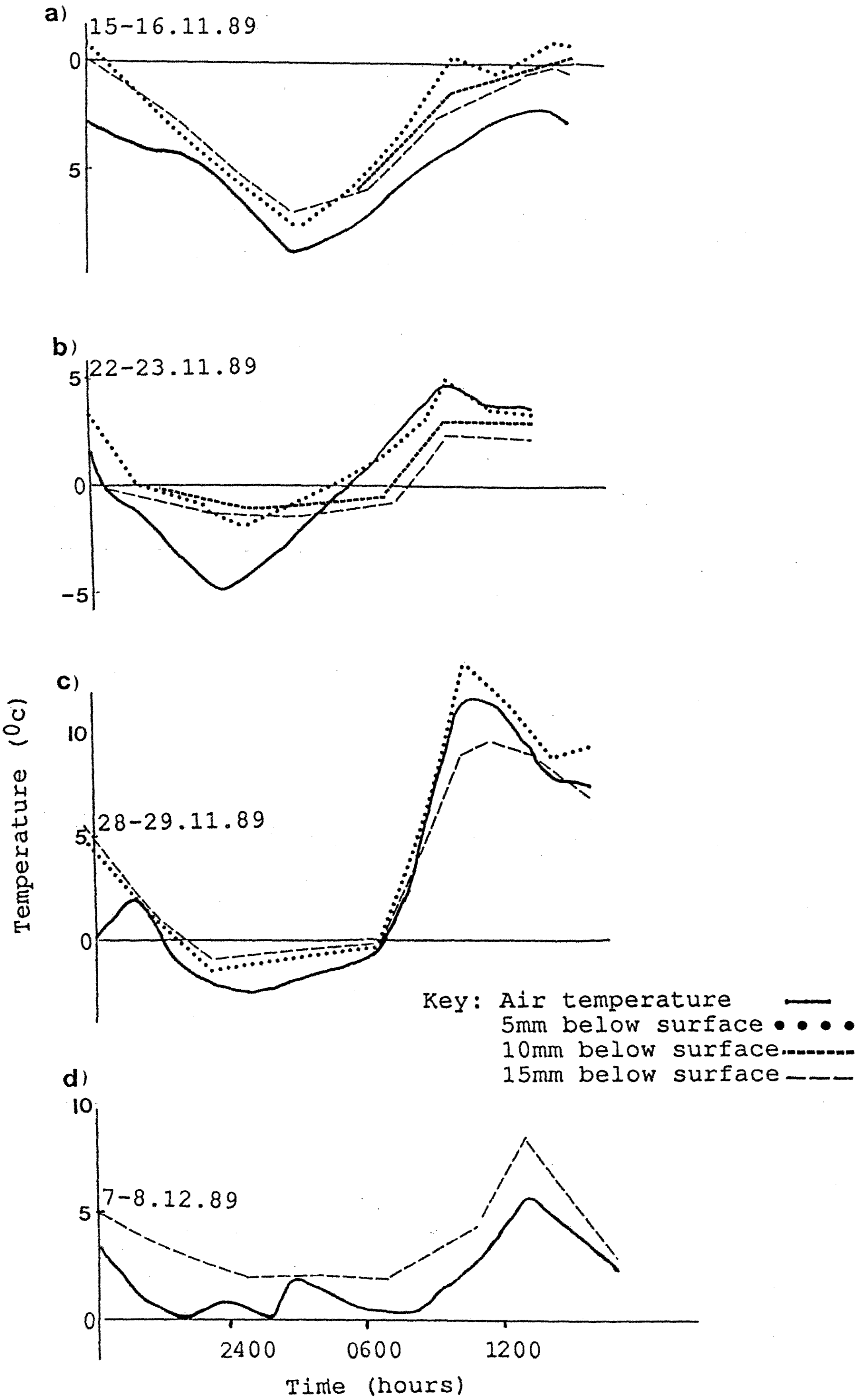



**Figure 3.2:** Temperature fluctuation within the moss and at the moss surface over 4 diel periods.

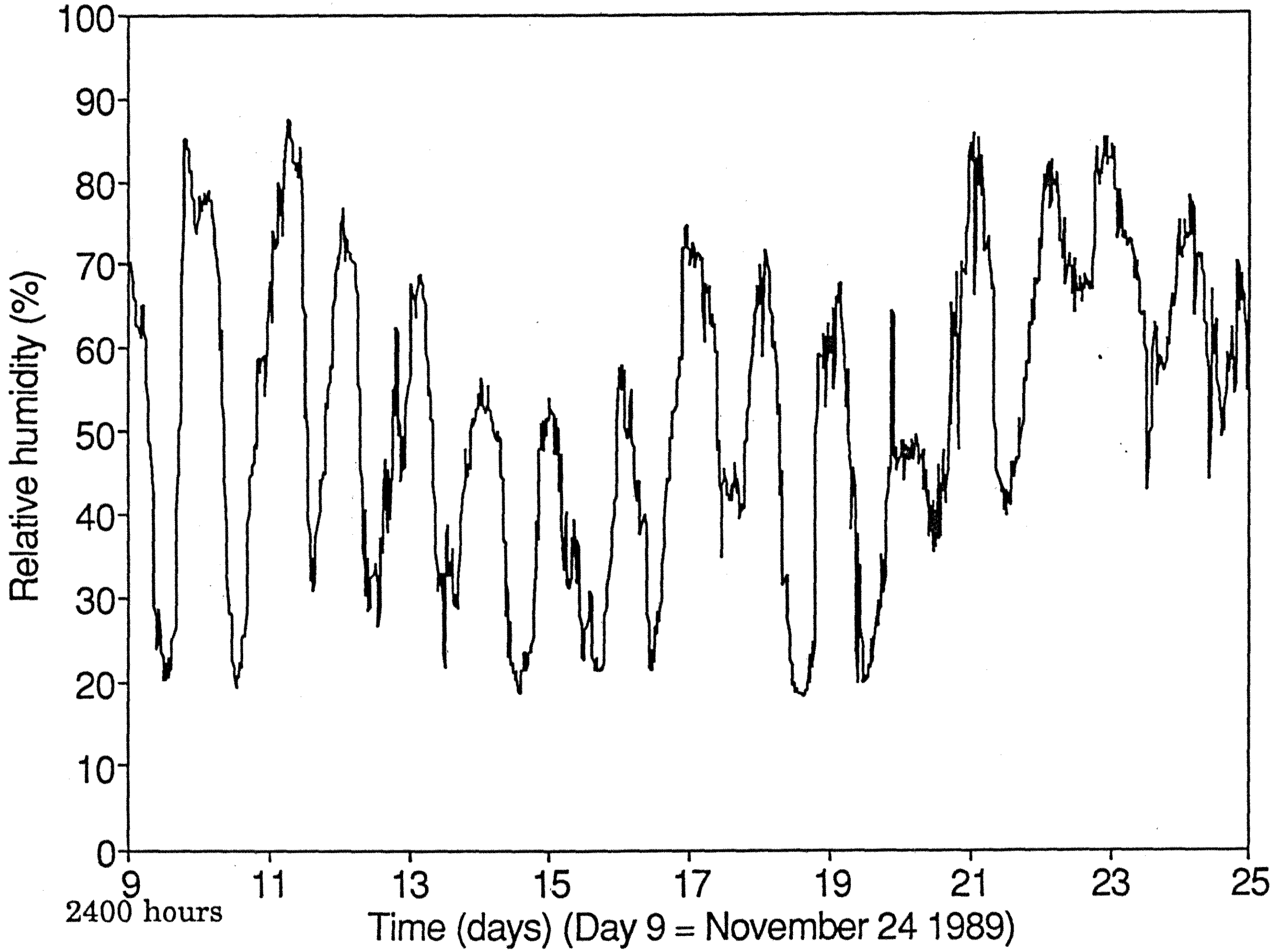



**Figure 3.3:** Relative humidity at moss level on the lower flush.

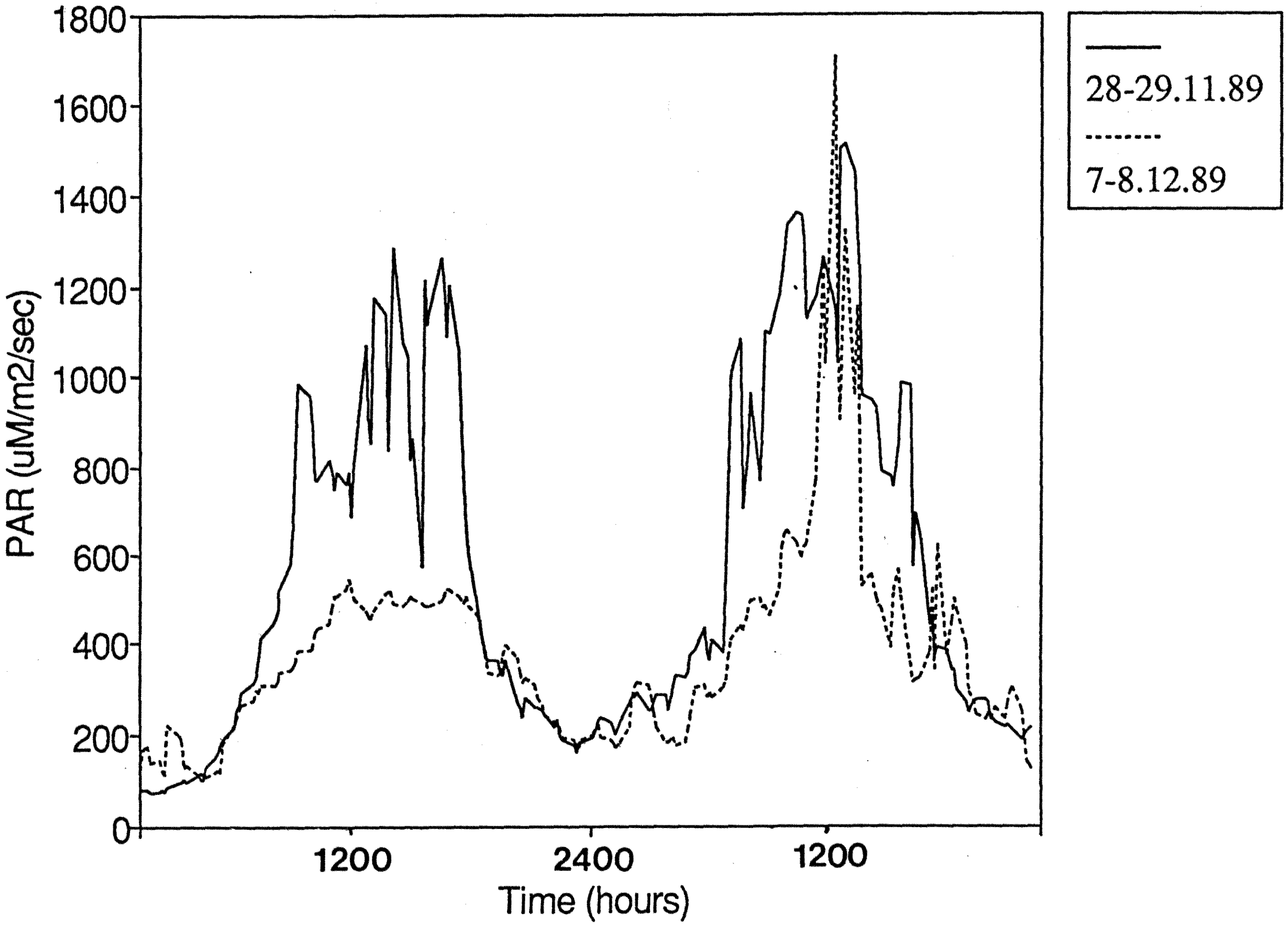



**Figure 3.4:** P.A.R. over two different diel periods at moss level on the lower flush.

These dates correspond to 2 diel periods when temperatures within the moss were measured. Comparison of Figure 3.4 (datalogger) and Figures 3.2 c and d (diels) illustrates the relationship between P.A.R. and temperature. The first period of 28/29 November was a clear day and although this was early in the summer before water was flowing over the whole flush, moss temperatures reached more than 12° celsius on the afternoon of the 29th (Fig. 3.2). P.A.R. levels reached a maximum of 1500 µM $m^{-2}$ s-1. In comparison the period of 7/8 December was a partially overcast day with a maximum P.A.R. of 1720 µM $m^{-2}$ s-1. By this part of the summer moss temperatures were often around 0 ° celsius and meltwater covered the flush for much of the day, but the lower overall light levels appear to have precluded the maximum temperature exceeding 9° celsius.

A significant increase in air and moss temperature over the course of the day can be seen between 15/16.11.89 and 22/23.11.89 (Fig. 3.2) at which stage meltwater became visible on the flush itself (Fig. 3.5 and photograph 4). Over the following week the amount of water flowing onto the flush waxed and waned as temperatures fluctuated above and below zero, and with cloudy and clear skies, but by the 7th of December water was flowing over the entire flush. This correlates to extended periods when the air temperature remained above zero. Water level at the site of transects 1, 2, 3 and 5 on the 10.12.89 is shown on the transect profiles illustrated in chapter IV.

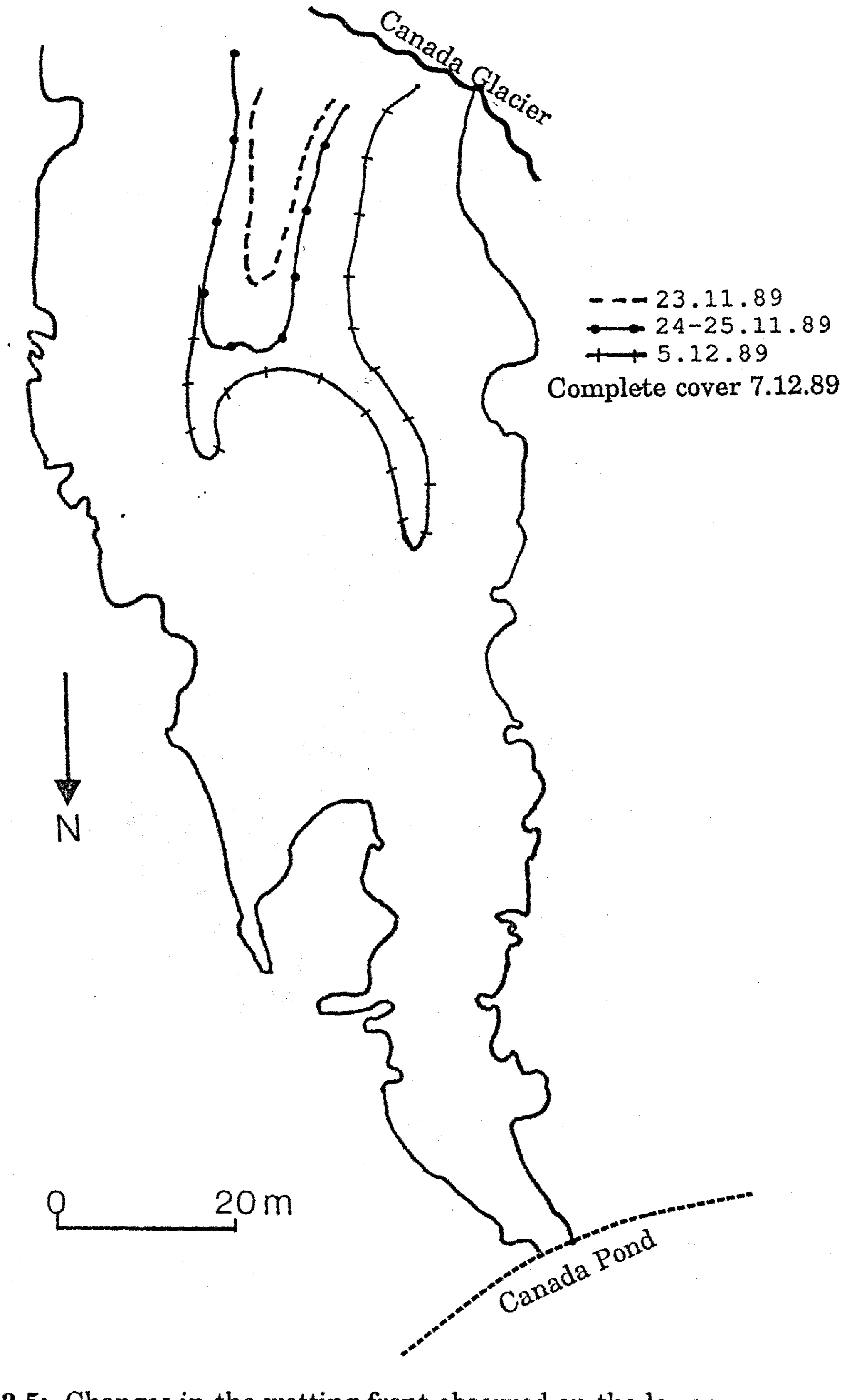



**Figure 3.5:** Changes in the wetting front observed on the lower flush in the early stages of glacial meltwater flow.

**Photograph 4.** Meltwater appearing on the lower flush (23.11.89).

### III:II:II Frozen ground

An effect of increasing soil temperature on the flush is the increase in depth of substrate to the frozen ground layer (Fig. 3.6). A general pattern of deepening of the frozen ground layer can be observed. This deepening of the frozen layer would imply an additional source of water being available to the plants as more water entered the liquid state. The large increase in depth between 24 .11 .89 and 8 .12 .89 (Fig. 3:6 ) corresponds to increasing air temperatures (Fig. 3:1) and the associated increased amount of free water flowing over the flush.

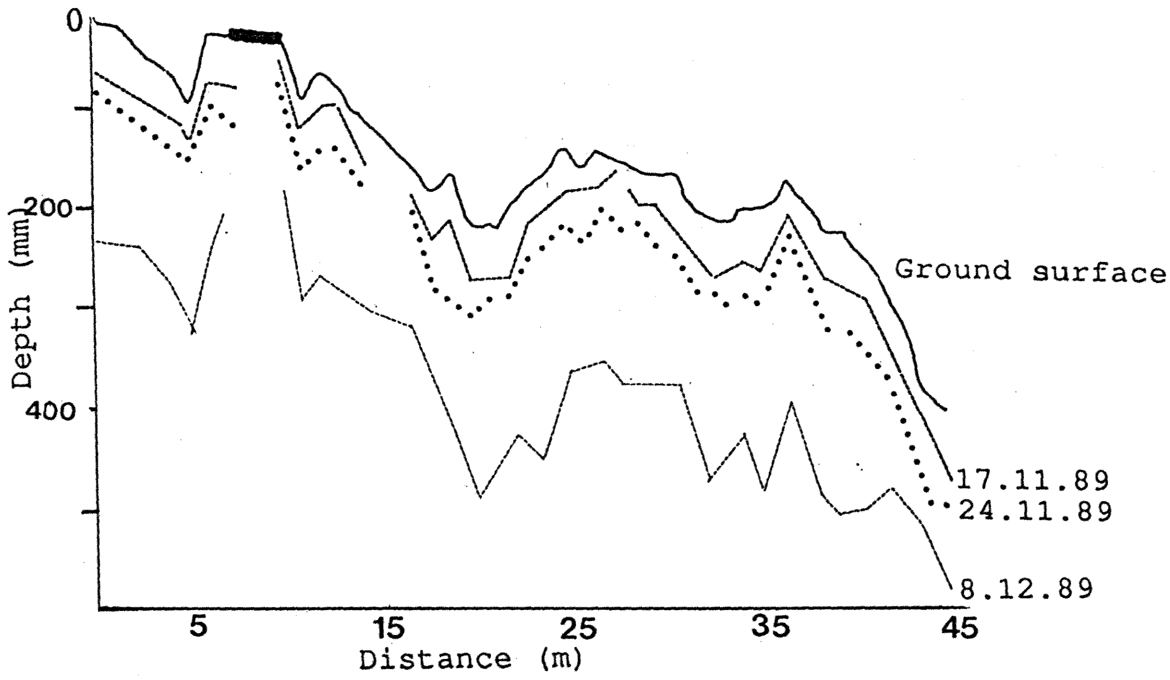



**Figure 3.6:** A representative transect illustrating the change in depth of frozen ground across the whole flush.

# Chapter IV: Vegetation: Lake Fryxell S.S.S.I./Canada Glacier

## IV:I Introduction

Two areas of plant growth adjacent to the Canada Glacier were investigated during this study. A bryophyte species list was compiled and the presence of algae was noted.

The distribution of plants in areas such as the Dry Valleys is highly dependent on the availability of water during the summer season. In light of this, the patterning of plant species in relation to water flow was analyzed in detail on the lower flush, and investigated on a broad scale on the upper flush. In this chapter vegetation maps of both areas are presented, accompanied by a detailed analysis of species composition and percent cover on the lower flush. Results from analysis of biomass and nutrient content are included.

The presence of lichens at this relatively low altitude site is noted with a description of their distribution in relation to water level in the Fryxell stream.

## IV:II Results

### IV:II:I Plant Species

This section outlines plant species described from flush areas adjacent to the eastern edge of the Canada Glacier.

## MOSSES

*Bryum argenteum* Hedw.

*Bryum pseudotriquetrum* (Hedw.) Gaertn.

*Pottia heimii* (Hedw.) Feurnr.

*B. argenteum* is one of the few truly cosmopolitan moss species. Seppelt (1984) notes that many Antarctic specimens tend to lack the characteristic silvery-green colour of the leaf tips, however achlorophyllous leaf tips were evident on the Fryxell specimens. It was noted that in the freeze dried state, patches of *B. argenteum* turf had lifted away from the substrate over the winter period.

This is the first record for *Bryum pseudotriqutrum* from this area although it is considered to be widespread in the Antarctic region (Seppelt and Kanda 1986). The plants occurred scattered amongst the *B. argenteum*. Seppelt (1986) notes that *B. pseudotriquetrum* is widely scattered in the eastern half of the Vestfold Hills but that extensive beds are uncommon. Seppelt (1984) considers *B. pseudotriquetrum* to be synonymous with *B. algens*.

*Pottia heimii* has been referred to in the past as *B. antarcticum.* Records of *B. antarcticum* are now considered to be synonymous with *P. heimii* (Kanda 1981). *P. heimii* can be divided into two growth forms. The first is healthy looking moss growing adjacent to channelled areas or where there is available seepage water. The second type is termed 'encrusted' *Pottia*. This has a dry unhealthy appearance due to salt precipitation on the surface. Vincent (1988) reports that Antarctic soils have an unusually high salt content which may include calcium sulphate which often occurs as surface encrustations. Greenfield and Wilson (1981) collected freeze dried mosses from Cape Bird which were encrusted with a white crystalline deposit. This was found, on analysis, to contain 35 % sodium, 0.4 % magnesium, 2.2 % potassium and 0.3 % calcium. They suggest this is probably wind blown salt, deposited on snow cover and further deposited on these mosses by evaporation. The accumulation of soluble salts is a feature of desert regions in which evaporation exceeds precipitation and where soils are not flushed by meltwater. This implies that these encrusted *Pottia* areas only receive water by percolation up from the sediment below .

LICHENS

*Sarcogyne* sp.

*Caloplaca citrina* (Hoffm.)Th. Fr.

*Carbonea capsulata* (Dodge and Baker) Hale comb.nov.

*Lecanora expectans* Darb.

These were noted in a small area near the outflow of the Canada Pond and identified by Dr. Rod Seppelt.

ALGAE

Broady (1981) has described the algal communities which are an important component of the flora of the study area. He labelled the algal growths within the flush as "hydroterrestrial" due to the alternating wet and dry moisture relations. Three general communities were recognised by us in mapping and analysis of plant communities.

These were

a) *Nostoc commune* which forms large macroscopic mucilaginous colonies in wetter areas of the flush. Oscillatorian algae are associated.

b) Red brown felt in the region of maximum and most frequent water flow. This is dominated by Oscillatorian algae.

c) Epiphytic algae over the surface of *Bryum argenteum* and *Pottia heimii.* These are dominated by *Nostoc* but include several Oscillatorian algae and *Calothrix* in wetter *Bryum argenteum* areas (Broady 1981).

### IV:II:II Initial mapping.

Patterning of plant species is easily seen visually on the flush. Within the main channels of water flow *Nostoc* communities and associated Oscillatorian sp. dominate (Broady 1981). *Bryum argenteum* is found in areas of flowing water and seepage areas. Where water is flowing a high proportion of this moss has epiphytic *Nostoc* communities associated with it. Moving out to the edges of the flowing water zones or to higher ground *Pottia heimii* dominates.

Figure 4.1 is the initial map of the lower flush showing obvious community boundaries. It was within these boundaries that estimates of % cover were made. Because subjective assessment of plant abundance contains a very large error, it will only give an approximate indication of abundance (Kershaw 1964). To avoid placing too much emphasis on this visual estimation the cover percentages were bulked into areas of >5 % cover to give a visual picture of distribution. Figure 4.2 illustrates the distribution of *Nostoc* colonies (not associated with bryophytes) (overlay 1), *Bryum argenteum* (>5 % cover) (overlay 2) and *Pottia heimii* (>5 % cover) (overlay 3). *Bryum pseudotriquetrum* is included with B. argenteum. The maps overlay a general contour map of the flush on which the main lines of water flow are indicated (Fig. 4.3). The relationship of transect positions to the overall contours of the flush are also marked on figure 4.3.

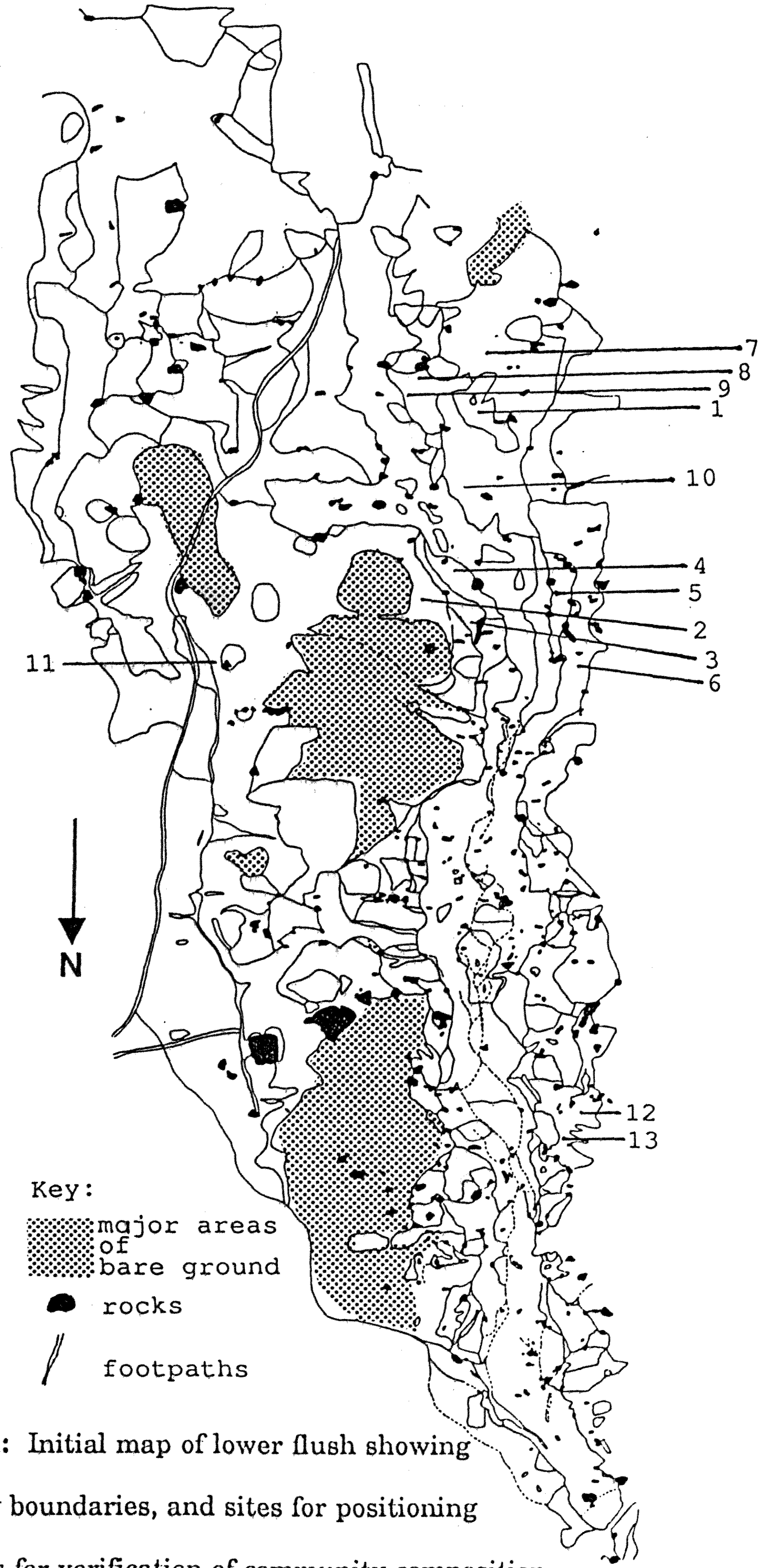



**Figure 4.1:** Initial map of lower flush showing community boundaries, and sites for positioning of quadrats for verification of community composition.

**Figure 4.2:** Over lay maps of each species at 5 % cover.

overlay 1. *Nostoc*

overlay 2. *Bryum argenteum*

overlay 3. *Pottia heimii*

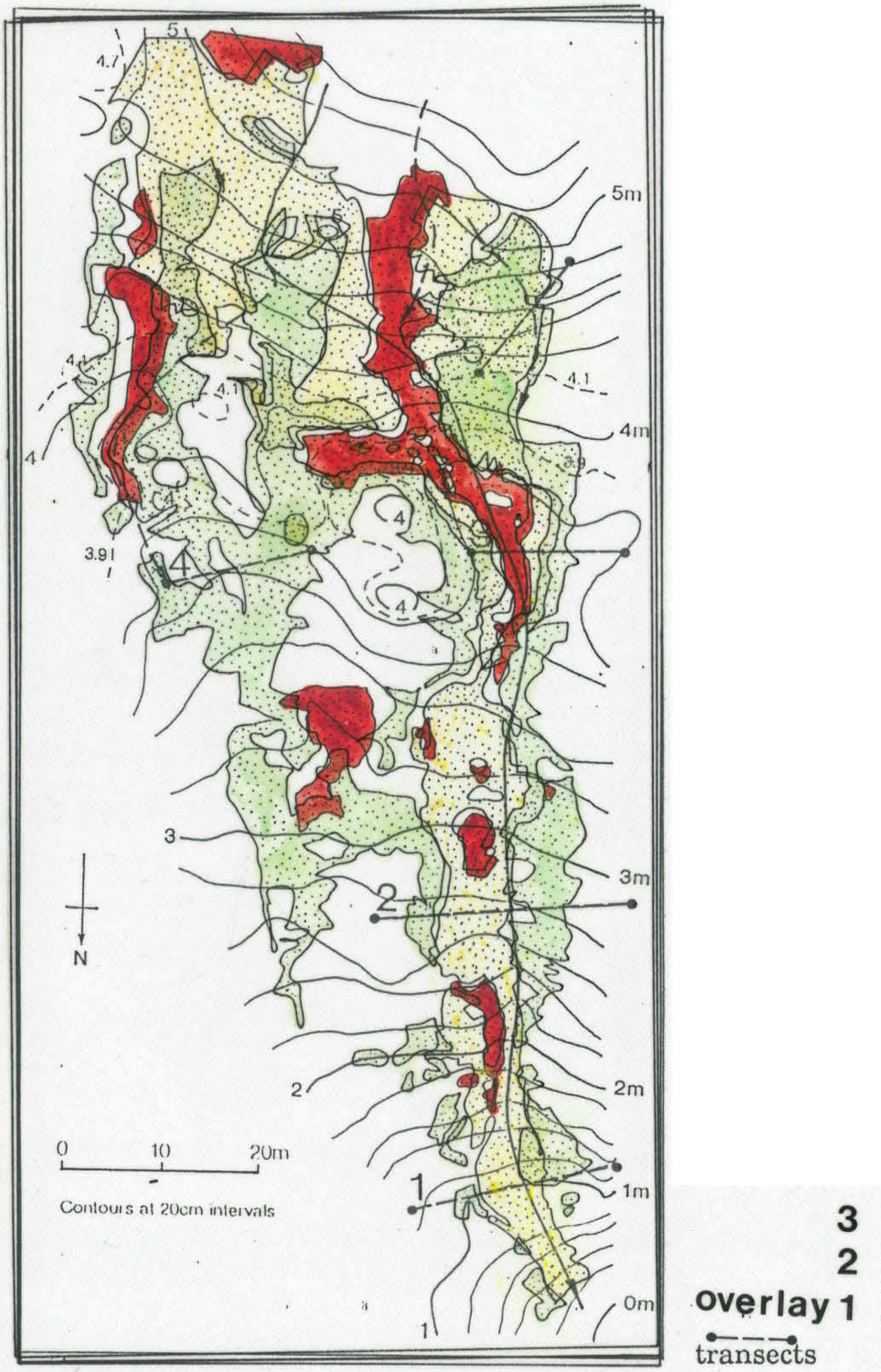
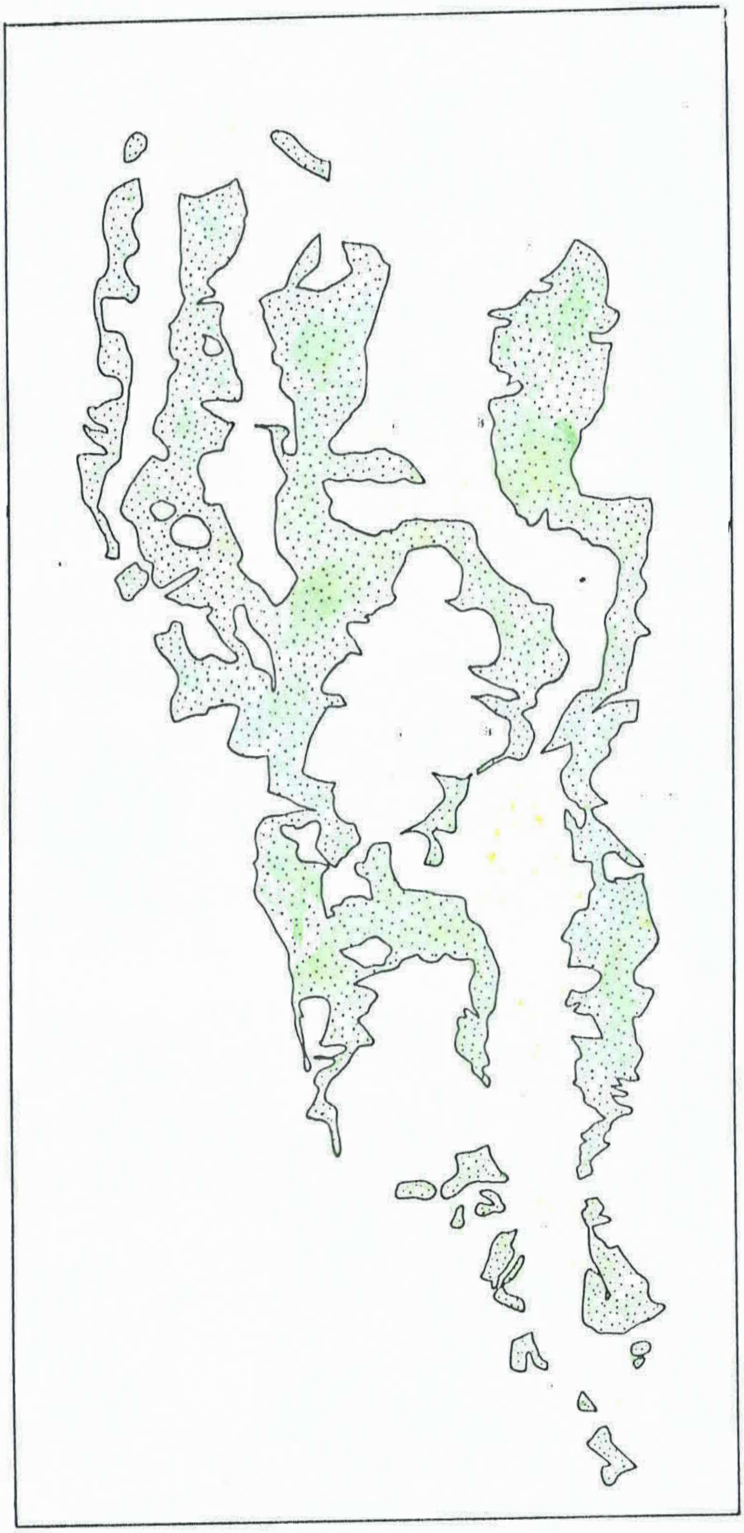
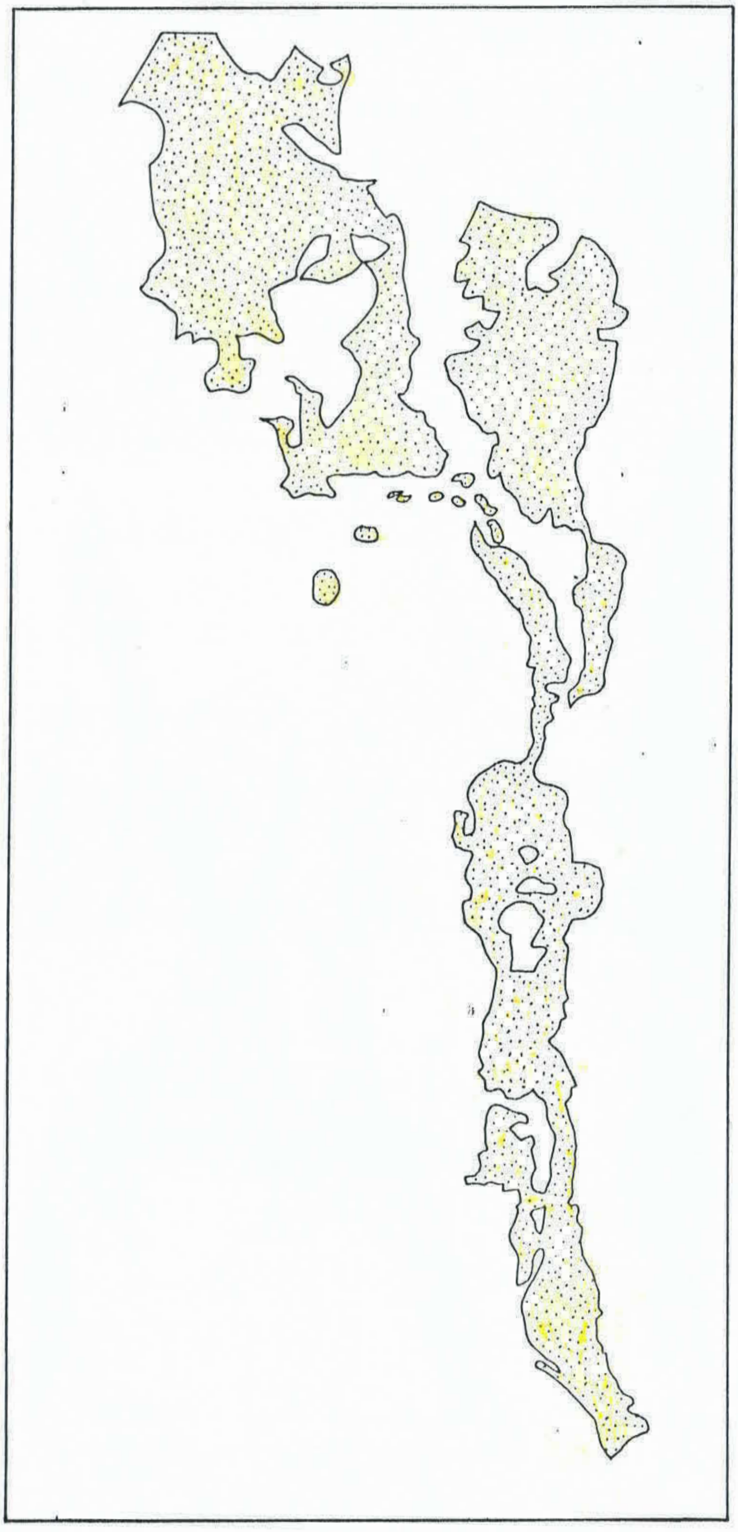


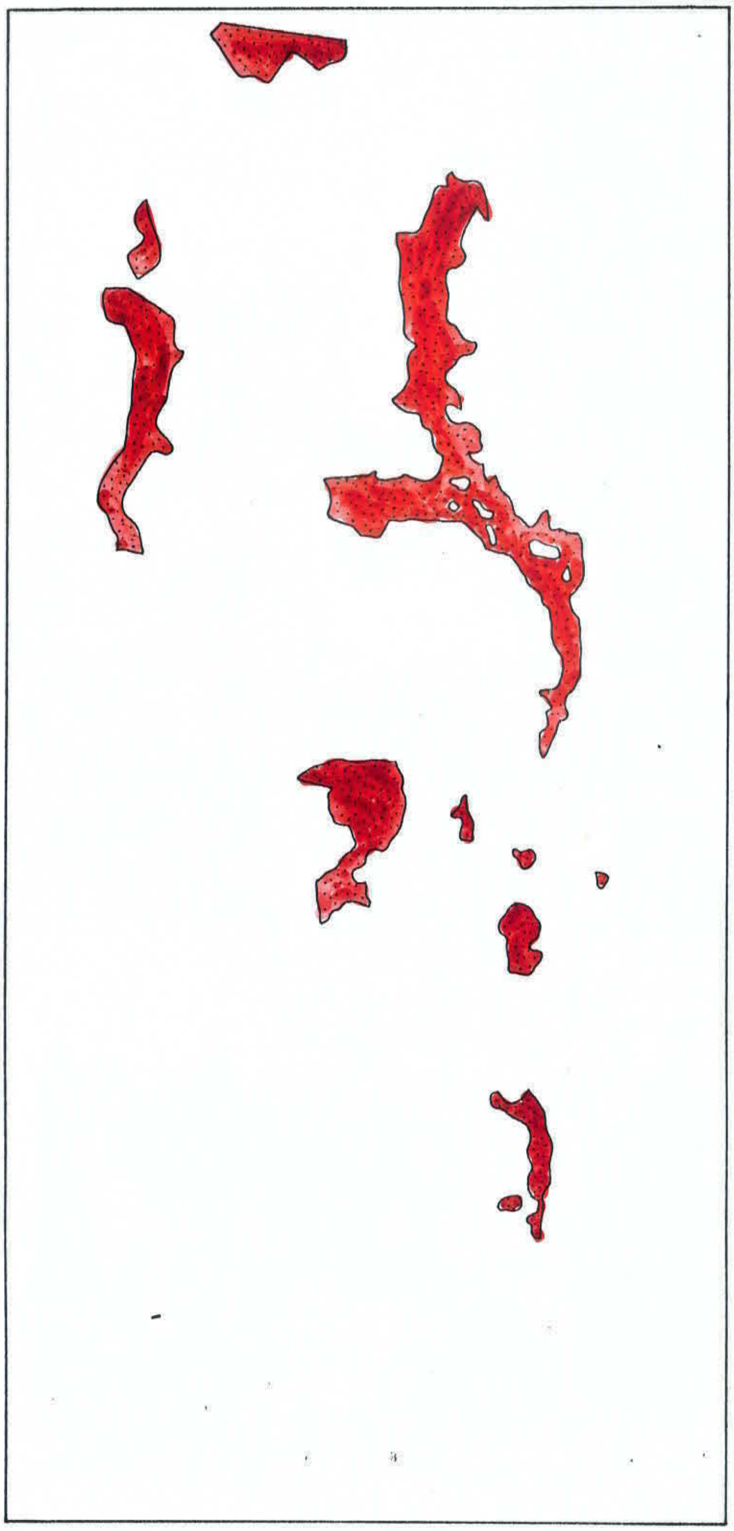

**Figure 4.3:** Contour map of the lower flush, showing transect positions



3



2



overlay 1

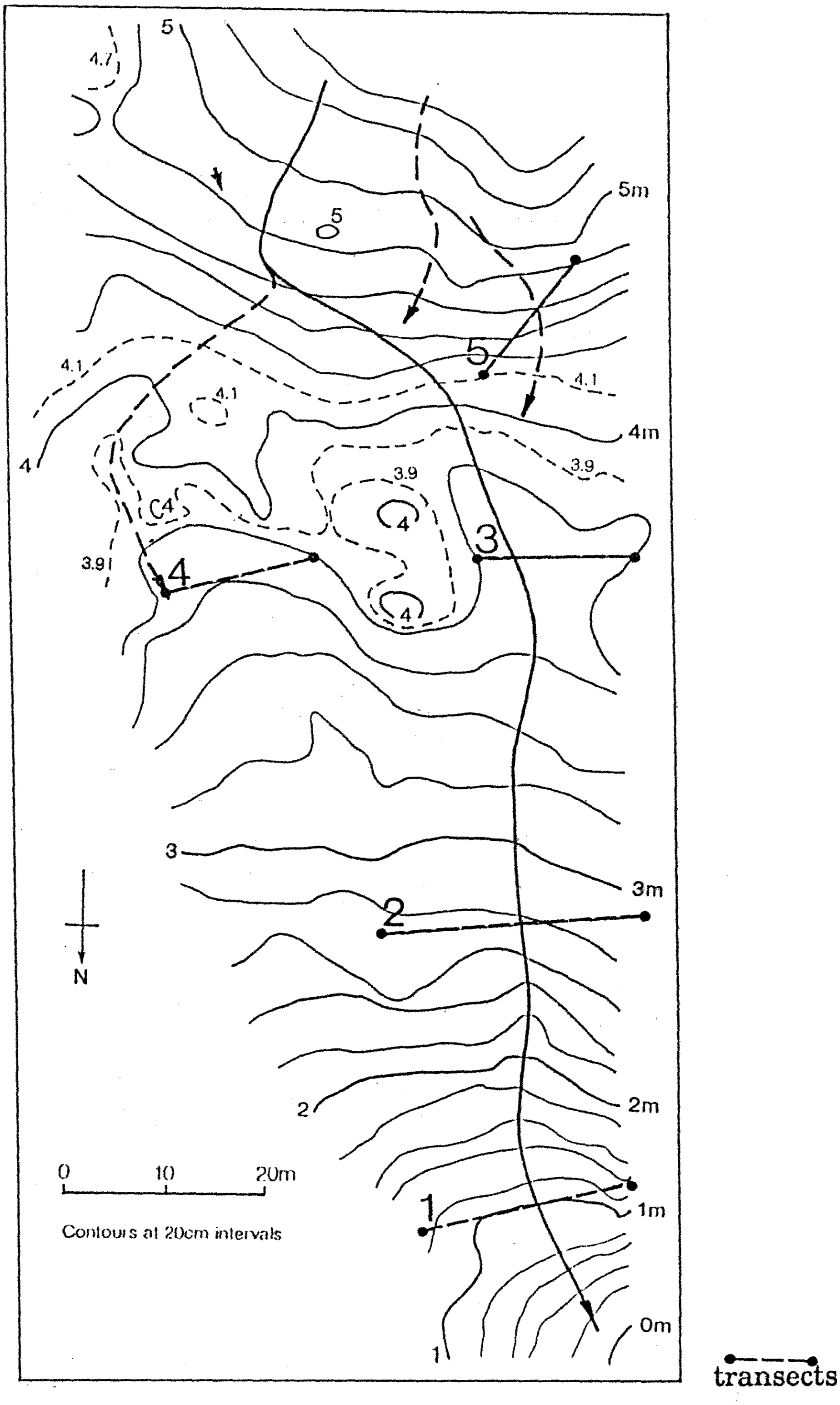



**Figure 4.3:** Contour map of the lower flush, showing transect positions

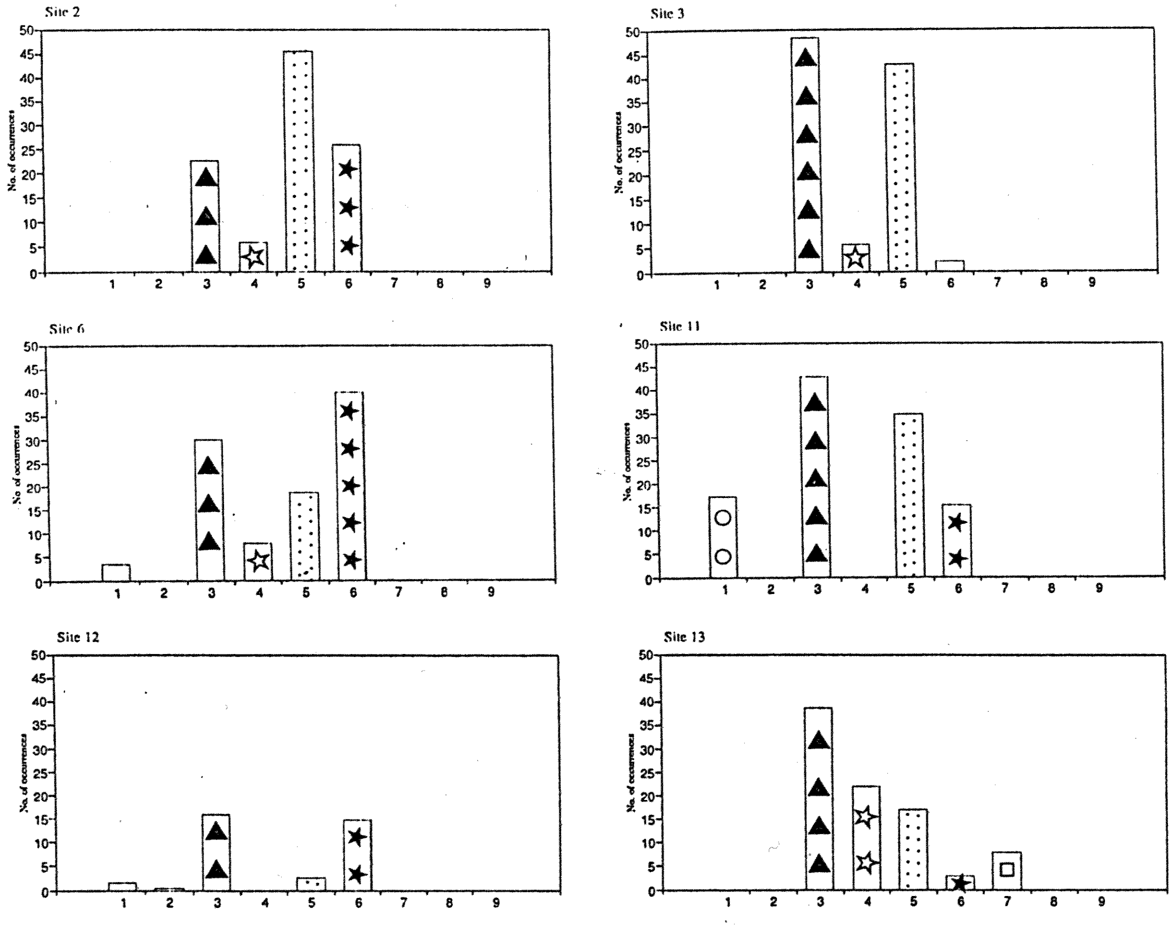
### IV:II:III Verification with quadrats

Histograms showing the frequency of occurrence of each species, were drawn from results obtained from the subjective siting of quadrats (for sites see Fig. 4.1). These give an indication of species composition within the broad cover estimates and suggest that the bulking of cover estimates into areas of >5% is an accurate indication of percent cover. The histograms drawn from *Pottia* areas of > 5 % cover (Fig. 4.4 a) indicate that *B. argenteum* was not prevalent at high % covers. Except for site 11 taken in an area of encrusted *Pottia*, epiphytic *Nostoc* was present at low percentages.

No *B. pseudotriquetrum* was present in these quadrats.

The histograms for the areas of *B. argenteum* >5 % (Fig. 4.4 b) show a greater mix of species. From the results *B. argenteum* appeared to have a broader range of habitats that it could occupy often overlapping the zones to which *Pottia* was restricted. Epiphytic *Nostoc* was more common on *Bryum* than on *Pottia.*

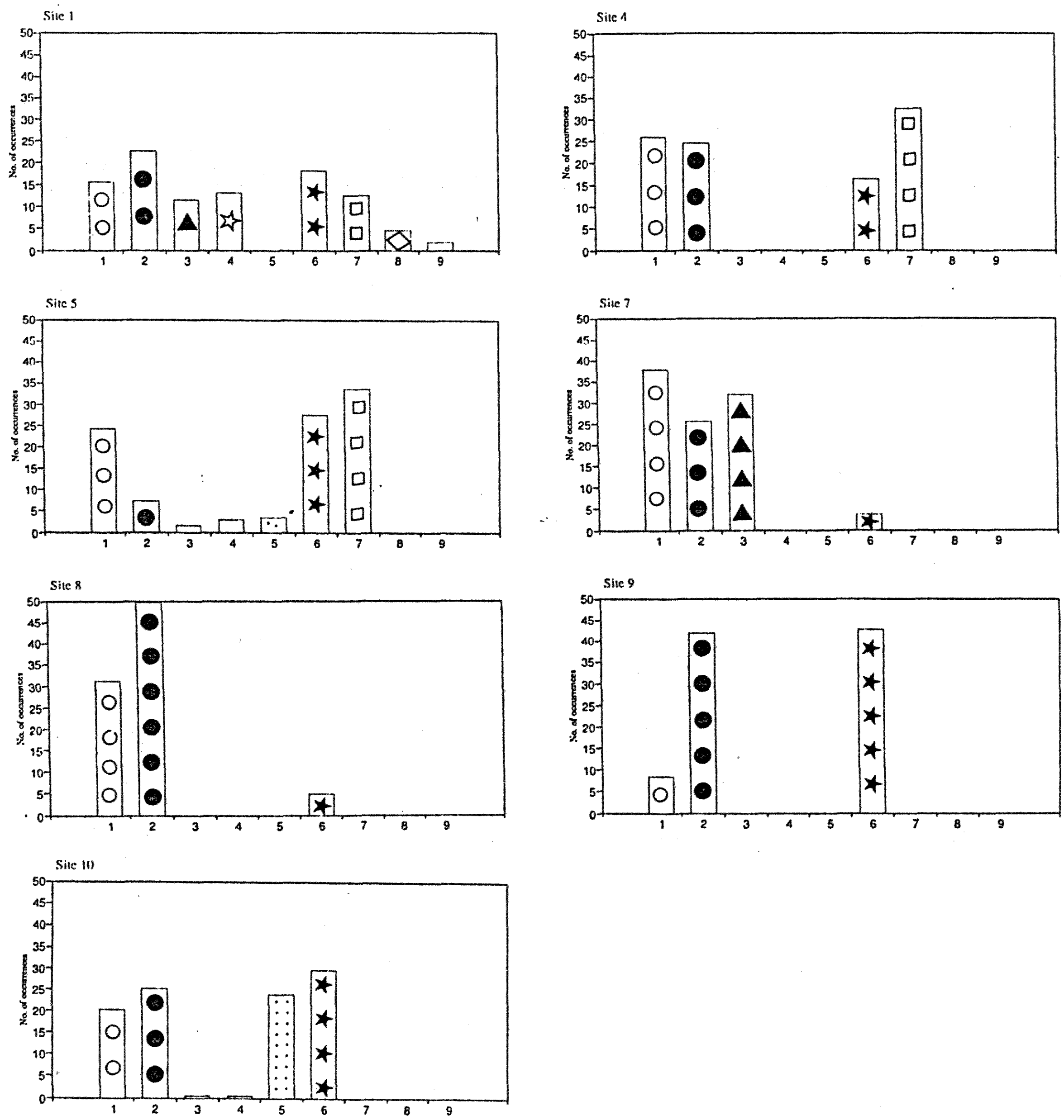
Often the demarcation between communities was quite marked. By comparing histograms 3 and 4, which represent communities immediately adjacent to each other it can be seen that the species composition was completely different. This phenomenon was especially evident close to the main channel, where there were large differences in the amount of water available to the plants.




Key: ○1. *Nostoc*
●2. *Bryum argenteum*
▲3. *Pottia*
☆4. Epiphytic *Nostoc* on *Pottia*
∷5. Encrusted *Pottia*
✶6. Rocks and sand
□7. Epiphytic *Nostoc* on *B.argenteum*
◇8. *B.pseudotriquetrum*
9. Epiphytic *Nostoc* on *B.pseudotriquetrum*

**Figure 4.4:** Histograms from subjective siting of quadrats.

a) from areas of *P. heimii* > 5% cover




b) from areas of *B. argenteum* >5% cover

### IV:II:IV Transects

The species present on 5 transects across the lower flush (Fig. 4.3) are illustrated in relation to microtopography in Figure 4.5. Chi squared analysis on the degree of association between plant species and between higher and lower ground gave the relationship illustrated in Table 4.1.

**Table 4.1:** Chi squared values, showing positive and negative relationships between plant species on five transects.

| Comparison | Chi sq. value | trend | p-value |
|---|---|---|---|
| *B.argenteum* and *P.heimii* | 16.297 | -ve | <0.01 |
| *B. argenteum* and *Nostoc* | 14.971 | +ve | <0.001 |
| *P. heimii* and *Nostoc* | 55.119 | -ve | <0.001 |
| *P. heimii* and hummocks | 10.639 | +ve | 0.001 - 0.005 |
| *B. argenteum* and hummocks | 0.621 | +ve | 0.6 - 0.95 |
| *Nostoc* and Hummocks | 3.584 | -ve | 0.05 - 0.10 |

The designated hollows are the first areas that receive running water in the early part of the summer season as can be seen by the water level marked on the transects (Fig. 4.5). The apparent uneven water flow over the area is the result of the contouring of the ground adjacent to these transects,

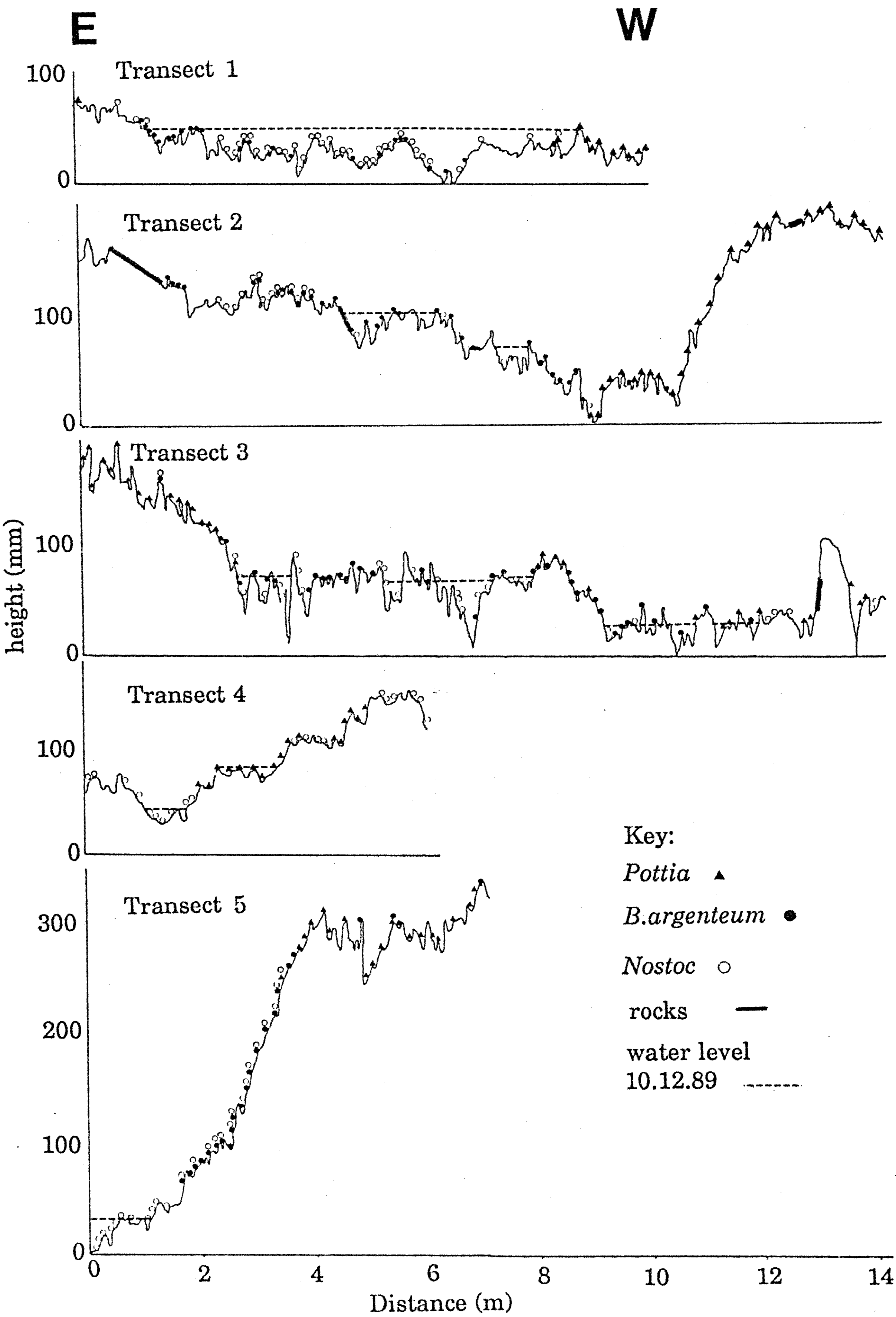



**Figure 4.5:** Microtopographical profiles across the lower flush.

with the water following well defined channels at this early stage of the melt.

*Pottia* shows significant positive correlation with hummocks which reflects the apparrent restriction of *Pottia* to relatively drier ground. Correspondingly the negative association between *Pottia* and the 2 other plant groups is a consequence of the drier areas being unsuitable for algal growth and apparently less suitable for *B. argenteum.*

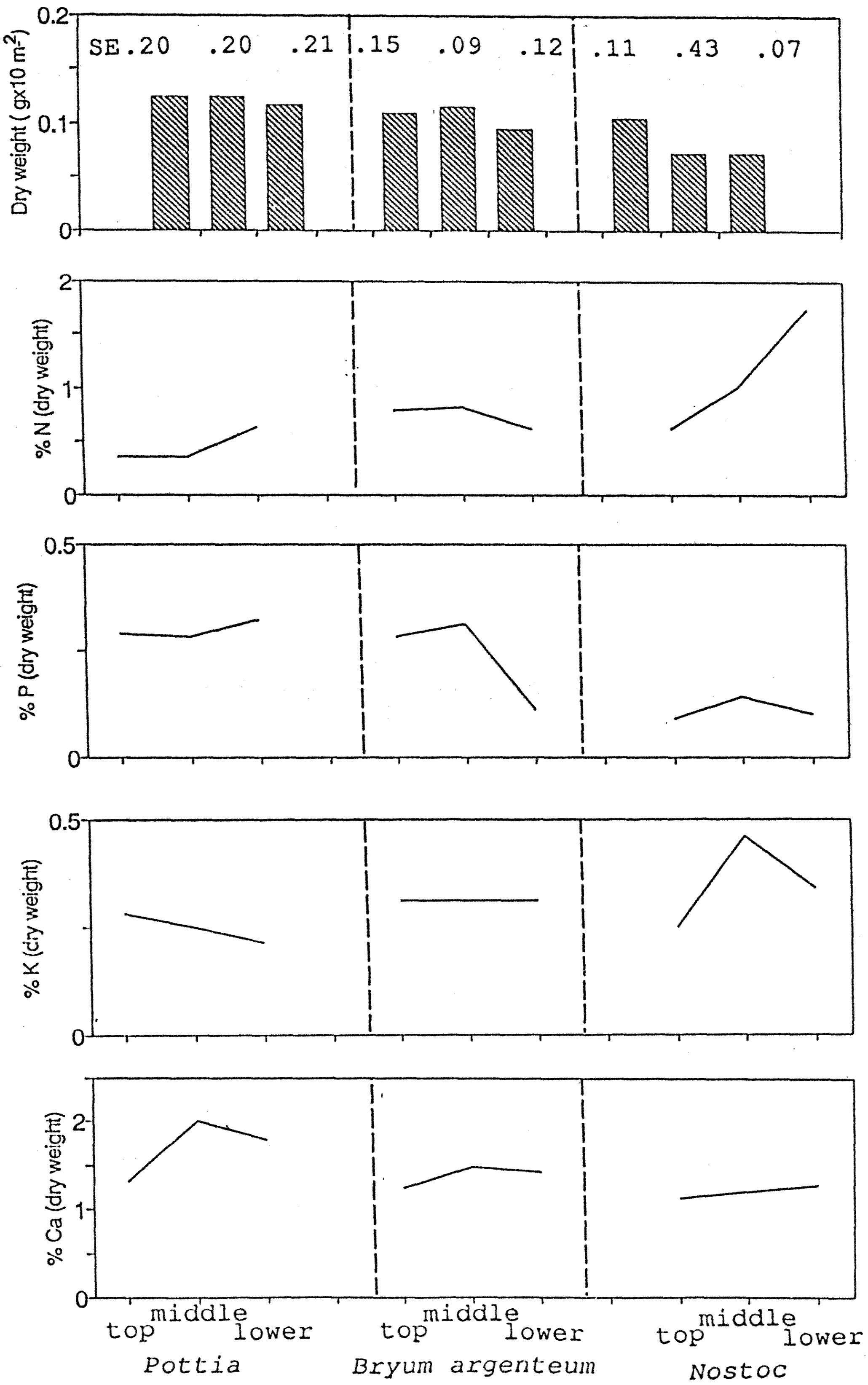
The association indicated between *Nostoc* and *B. argenteum* is to be expected and correlates with two factors already mentioned. These are the epiphytic nature of *Nostoc* in the flush and the wide range of habitats that *B. argenteum* appears to be able to cover.

### IV:II:V Biomass and nutrients on the lower flush

The ash free dry weights and percent nutrient composition of each of *Pottia*, *Bryum* and *Nostoc* from the lower flush are illustrated in Figure 4.6. *Pottia* has a significantly higher biomass (5 % level, t test) than *Nostoc* overall but there is no significant difference between the three sites (top, and middle, lower) on the lower flush.

The values presented for percent composition of nutrients at each position on the flush are based on one sample only (five, 1 cm cores were bulked to obtain sufficient dry matter) and therefore any perceivable trends are not statistically significant.

**Figure 4.6:** Biomass and nutrient content of plants on the lower flush.



Following arcsin transformation of the percent values (Snedecor and Cochran 1967), a t-test was carried out to ascertain any significant differences in elemental composition between plant species. While it appears from the graphs that the nitrogen content of *Nostoc* is higher than that of the two bryophytes this is not significant at the 5 % level. The levels of potassium are greatest in *Nostoc* and least in *Pottia*. Phosphorus and calcium are generally higher in the two bryophyte species than in *Nostoc* . The only significant difference (5 % level) between species is for phosphorus where *Pottia* has a significantly higher level than Nostoc.

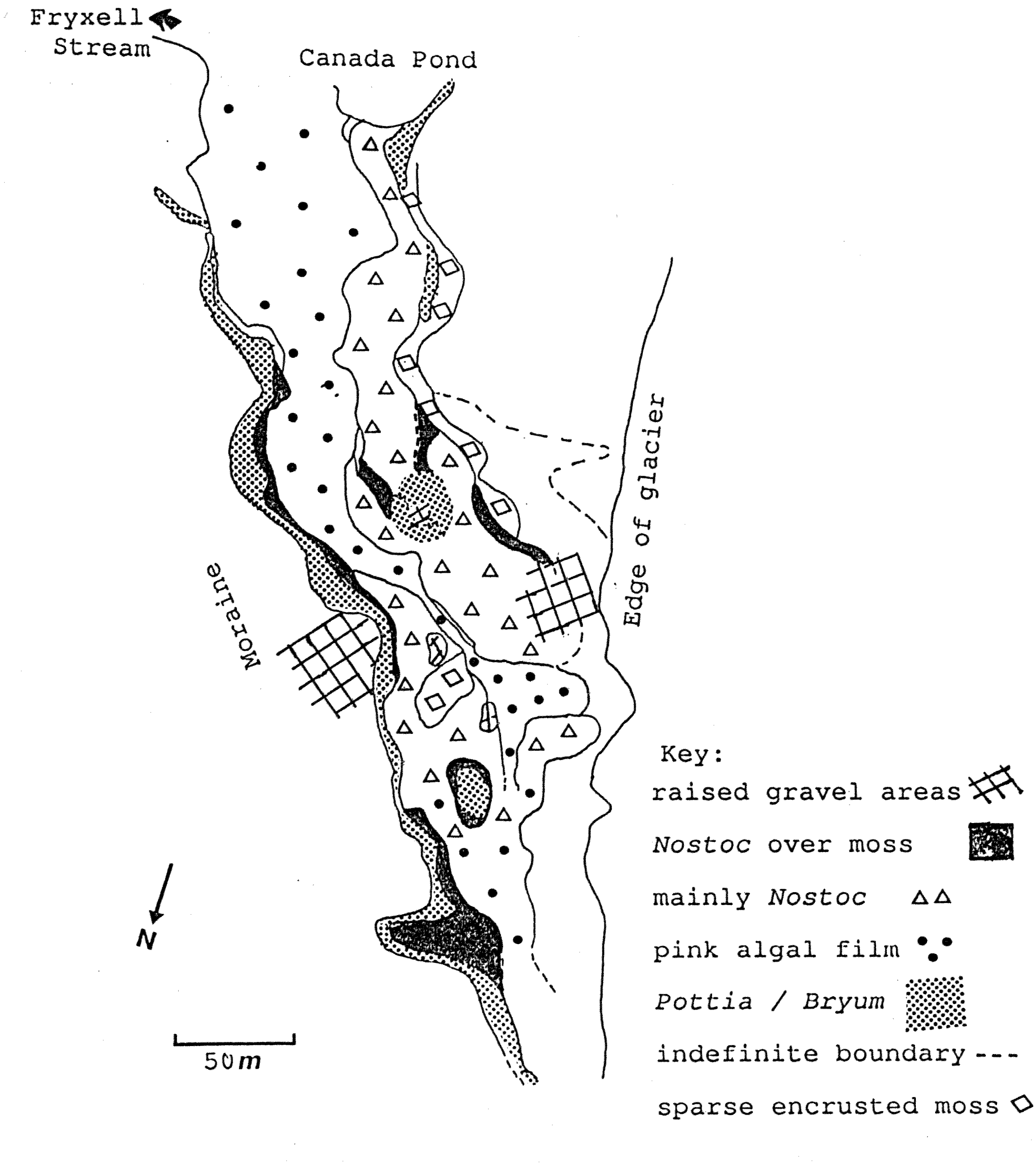
### IV:II:VI Sporophytes

In relation to the declining number of bryophyte species toward continental Antarctica, there is a similar decline with increasing latitude in the reported occurrence of fruiting mosses. Capsules are rare in continental Antarctica. During this study numerous *Pottia heimii* sporophytes were found on both the upper and lower flushes. Their occurrence appeared to be related to microtopography and to the degree of shelter. This is reported in Seppelt et al. (1990) (appendix A).

### IV:II:VII Vegetation of the Upper flush

The area of the upper flush was mapped from the low lying ground at the margin of the Canada pond, in a north west direction, toward the top of the Canada Glacier (Fig. 4.7). There is a wide outflow area at the base of the

**Figure 4.7:** Vegetation map of the upper flush.



flush where meltwater from the Canada Glacier either flows into the Canada pond, or down the Fryxell Stream. The meltwater is flowing through moraine from the glacier and low moraine dumps form the boundaries of water flow. From this map Figure 4.8 was drawn. The upper continuous line is an estimation of the total ground area which is usually wetted during summer flows, and could therefore be considered suitable for plant growth. The composition of the flora at 20 m intervals down the length of the flush is indicated by the bar graphs. Algae dominated this particular flush area, however there is, in total, approximately 7300 square metres in which mosses are found making this a second significant area of bryophyte growth in the Canada Glacier region.

A similar patterning of vegetation in relation to water flow can be seen here as on the lower flush. Algae dominate the main channels with mosses occurring on the outer edges. Bryophytes on the upper flush did not appear as healthy as those on the lower, with large areas appearing encrusted. It was not possible to tell visually if much of the encrusted moss was still living. Often no green material could be found.

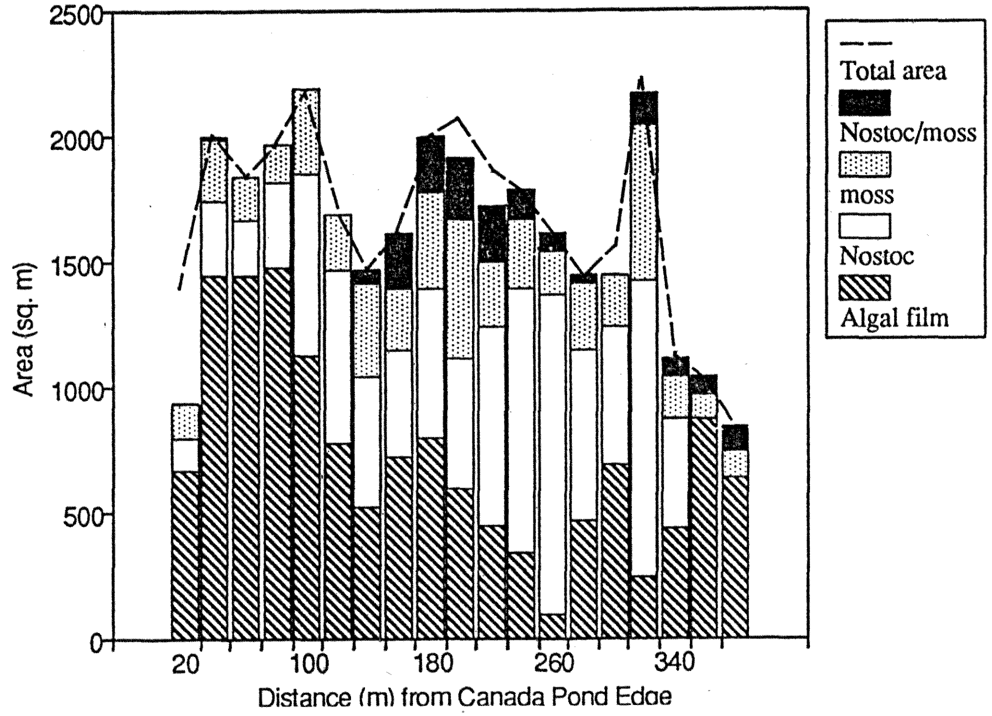



**Figure 4.8:** Bar graph showing the relative contribution of each plant group to different areas of the upper flush. The upper line indicates the total area which would appear to be available for colonisation.

**IV:II:VIII Lichens**

Lichen growth at S.S.S.I. No. 12 is relatively inconspicuous and it was only on closer inspection that the extent of *Sarcogyne* sp. and *Carbonea capsulata* was established. The distribution of these two lichen species in relation to channel configuration is illustrated in Figure 4.9. The distribution of *Sarcogyne sp.* is noted as being present or absent as indicated by an X. An abundance scale according to the number of plants present was used for *C. capsulata*.

0 thalli present =0

1 thalli present =1

2-5 thalli present =2

6-10 thalli present =3

11-15 thalli present =4

Main lines of water flow in the study area are shown in Figure 4.9 a. Figures 4.9 a, b and c relate to the channel configuration shown in Figure 4.9 e. The distribution of *Sarcogyne* sp. was related exclusively to the higher ground. This area was composed of fine gravel and was irregularly submerged during summer flows. The area supporting the growth of *Sarcogyne* sp. was distinct from the algal growths related to the main water flows in the channel.

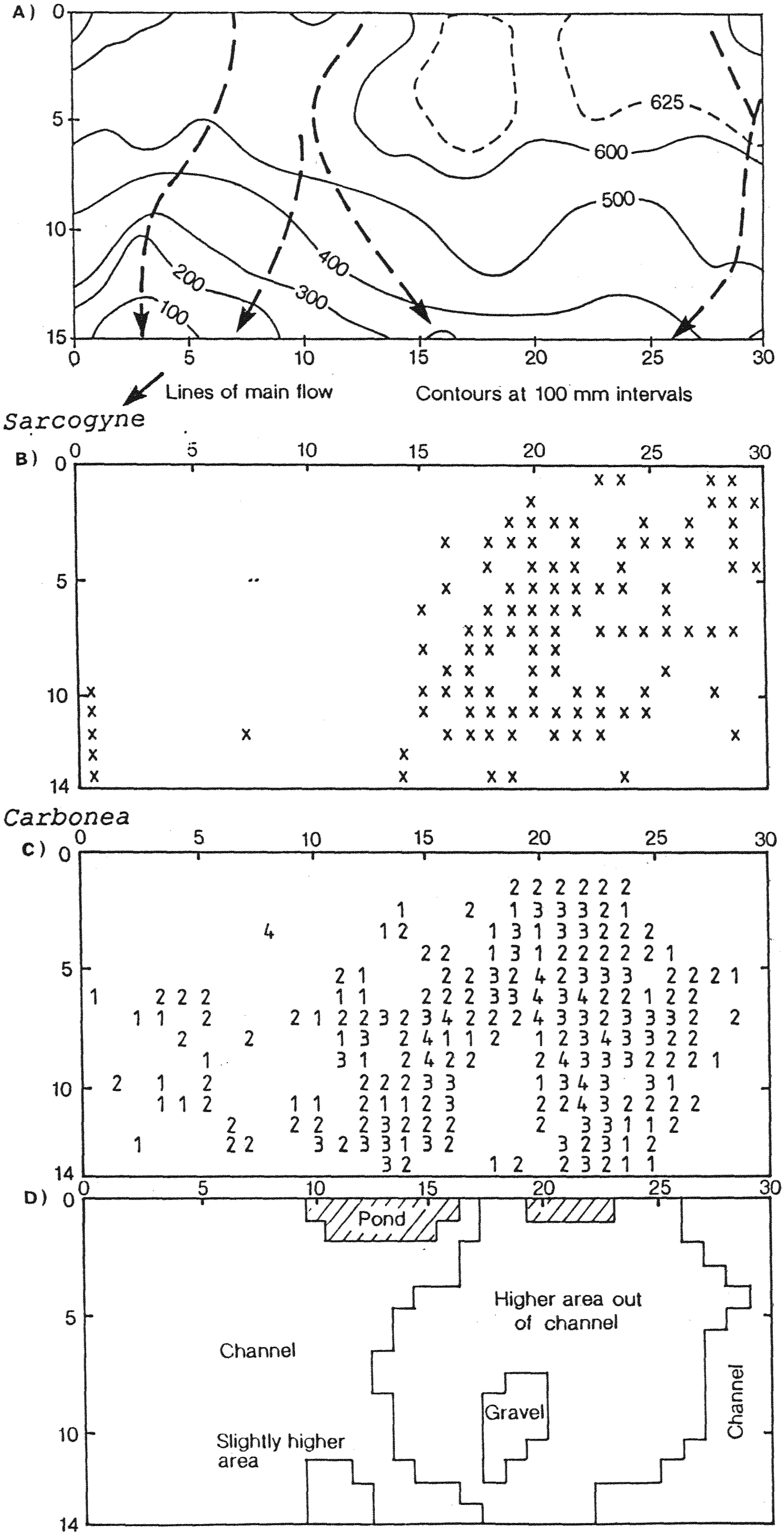



**Figure 4.9:** Distribution of lichens at the Canada Pond outwash. (Distance (m))

The distribution of *C. capsulata* was more extensive than that of *Sarcogyne* sp., extending into the main channel area, however its abundance was still higher in the more raised areas.

Two other lichens were found in the flush area. One specimen of *Lecanora expectans* and two of *Calaplaca citrina* were noted.

# Chapter V: Recovery from Damage.

## V:I Introduction

Several methods exist for assessing the growth rates of Antarctic bryophyte communities and these have been reviewed by Russell (1984). Markers can be placed so that the annual growth can be identified. A common method is some form of metal pin inserted into the bryophyte mat or turf with its head or an engraved mark level with the shoot ends. Another typical method is the cranked wire method (Clymo 1970). Use of this system is not feasible in the Dry Valleys because of the frost heave and the movement, over winter, of the dry moss turfs. Innate markers within the moss plant can sometimes be used to establish annual growth segments in the shoot, however these only provide an accurate indication of growth once it has been confirmed they are annually produced, and not subject to environmental modification (Longton 1988).

Recovery of bryophytes from damage can also give an indication of growth rates. In this method it is crucial that the date of damage be known. The recovery from damage could give indications of colonisation mechanisms which are relevant to the development of the flush communities, and also help explain vegetation patterns.

The lower flush in S.S.S.I. No.12 provides one of the few areas in the Dry Valleys where the long term effects of a previous disturbance can be measured. In this chapter, investigations are reported on the recovery of small areas of damage.

Three main types of damage were present. These were trampling damage, removal of core samples and removal of larger sections of bryophyte turf or hummock. Much of this damage can be dated using records from previous expeditions to the area. During 1979/80 and 1980/81 several samples were taken from the area for physiological studies. The elapsed time of nearly ten years is a useful period for establishing growth and recovery where these processes are slow.

Each of the disturbed sites was recorded on a map of the flush ( Fig. 5.1). During this study each of these sites was then drawn to scale and described in terms of the degree of plant recolonisation.

## V:II Results

### V:II:I Paths and footprints

Paths in areas away from the flush showed a typical and expected recovery pattern. Fine dust had been blown away so that larger stones were exposed and the surface merged visually with the surrounding undamaged areas. The portion of the path across the top of the flush was very difficult to locate. The path was formed in 1979/80 to collect water from the glacier face. It was finally found by use of a map and by extrapolation from the point where it entered the flush vegetated zone. To the casual eye the path in the area of the vegetation had effectively disappeared in ten years. Footprint damage was not easily detected but was clearly revealed during a light snow fall when the snow lay thickest within the footprint depressions.

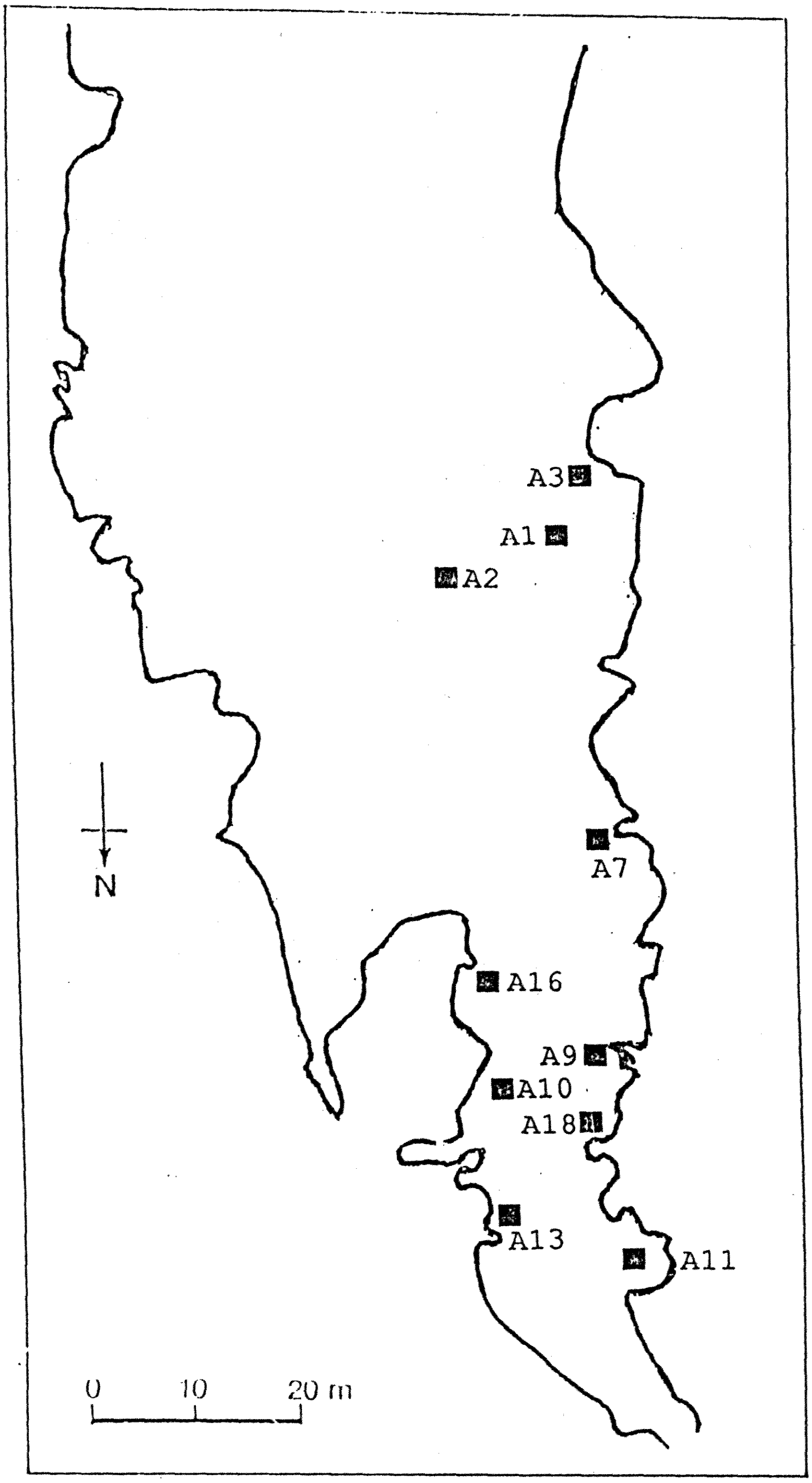



**Figure 5.1:** Map of the lower flush showing sites investigated for recovery from damage.

It seemed that the majority of the flush had been walked on but the surface integrity had been maintained.

Important microclimate effects were created by the footprints. A sporophyte was found at the deepest part of one footprint in a *Pottia* area, while more luxuriant, green *B. argenteum* occurred in another footprint with normal silvery plants around the edge.

## V:II:II Core and Section Removal Sites

A summary of core and section removal sites according to field notes is listed below.

1) Core sample sites from December 1980.

A1 *Pottia* hummock area.

*A2 *Nostoc* area, centre of flush.

A7 *Pottia* hummock area

*A10 *B. argenteum* area, site marked by cairn.

A13 *B. argenteum* area.

(* no visible damage at this site)

2) Section removal.

A3 *Pottia* area.

A9 dry salt encrusted *Pottia* area.

A11 dry *Pottia* area, 3 pieces removed.

A16 large section of *Pottia* removed.

A18 *Pottia* hummock area.

The sections were removed either in December 1979 or January 1980 for photosynthesis research by Green (pers comm.) or nutrient analysis by Greenfield (pers comm.). As the exact sample time could not be established a recovery period of at least nine years is assumed.

(i) Core sample sites

A total of five core sample sites were relocated. Only three had actual core holes present. In the vicinity of sites A2 and A10 no core holes could be seen.

Site A1 contained four identifiable core holes in *Pottia heimii* hummocks with some *B. argenteum* between them. Two holes remained open to the substrate, the others were partly infilled. All holes were less than the original 10 mm diameter, ranging from 6.5 to 8 mm. Hole closure was occurring predominantly by marginal ingrowth.

Site A7 contained four identifiable holes in 100 % cover of *P. heimii* hummock. Three holes were closed and contained sediment. One had *P. heimii* shoots in this sediment with some *Nostoc*. The holes ranged from 5.02 mm to 9.44 mm indicating a substantial amount of side growth in some cases.

Site A13 contained seven holes in 100% cover *B. argenteum* turf. The holes were much more open than in A1 and A7 and ranged from 6.4 mm to 10 mm with five of them greater than 9 mm diameter. Two holes were open to the substrate but the remainder were sealed and partially filled with sediment. Ingrowth of *B. argenteum* was occurring in the sediment from the sides but no individual shoots could be found as for *P. heimii* at the previous sites.

There is clear evidence of diminishment in sample hole size over the nine year period. This is more extensive in *P. heimii* areas. Closure in the *B. argenteum* site may be limited by the annual lifting of the freeze dried turf, away from the substrate during the winter.

It is important to note that no sign was found of a further sampling site from 1980. This site was in *B. argenteum* turf at the top of the flush, closest to the glacier. This area appears quite dynamic as evidenced by the footpath recovery in the same zone. Also a total of twenty samples were taken at each site and only a maximum of seven were found during this search. This suggests that either significant recovery has occurred or the holes had merged with other damage, such as winter cracking of the freeze dried moss.

(ii) Section Removal Sites

A total of five confirmed, large removal sites were found. The majority were probably formed in late 1980 when samples were removed for nutrient analysis. All sites were in predominantly *P. heimii* covered zones although it is known that *B. argenteum* areas were also sampled. It would, however, be very difficult to recognize sites in *B. argenteum* turf since there are many areas where small sections have been removed by wind when in a freeze-dried state. The sites were recorded by mapping in Figure 5.2 and are also located on the general flush map ( Fig. 5.1).

Site A3 (Fig. 5.2 a) contained two sampled areas about 10 cm x 10 cm, 15 cm apart. Both sites showed very similar forms of recolonization. Sheets of *Nostoc*, probably washed in, covered almost all the exposed area and contained many isolated shoots of *B. argenteum* (which was not present in the surrounding hummocks). It is highly likely that the *B. argenteum* had entered as deciduous shoot tips that are released during the early summer and float, in large numbers, down the flush. One of the sampled sites ( A3, ii) showed regrowth of *P. heimii* shoots in sand around the edges, particularly where there was shelter under the overhanging edge.

Site A9 ( Fig. 5.2 b) was a single sample site in an area of 100 % salt-encrusted, *P. heimii* hummock. Although the site was clearly in a drier part of the flush, there is evidence of regrowth in the sampled area. About 30 % of the surface was covered by dense, *P. heimii* shoots whilst the remainder has scattered shoots in the sand. The shoots projected little, if at all, above the sand surface. The extensive area of growth suggests recovery from stems embedded in the substrate which remained when the sample was taken.

Site A16 (Fig. 5.2 c) had one large, almost 20 cm x 20 cm, sample removed from an almost pure *P. heimii* hummock with some interspersed *B. argenteum*. The hole was completely filled with dry sand and no evidence of regrowth was found.

Site A11 (Fig. 5.2 d) has had three circular (10 cm diameter) samples removed in a zone of 100% *P. heimii* hummocks encrusted with algae. Regrowth was very similar to, but less extensive than, A9 (above). Numerous young shoots of *P. heimii* could be found but these were mainly concentrated within the protection of the edges of the bare site, or adjacent to small stones. Part of the area of one sample site was covered by a piece of *Nostoc* mat that had been blown in. Very robust *P. heimii* shoots occurred under the *Nostoc* demonstrating again the importance of shelter. Site A18 ( Fig. 5.2 e) is a single, approximately 10 cm x10 cm, sample site in a *P. heimii* hummock. Regrowth of *P. heimii* shoots had occurred in protected areas at the edges of the sample site but no moss growth had occurred in the central part which contains sheets of *Nostoc* either washed or blown in.

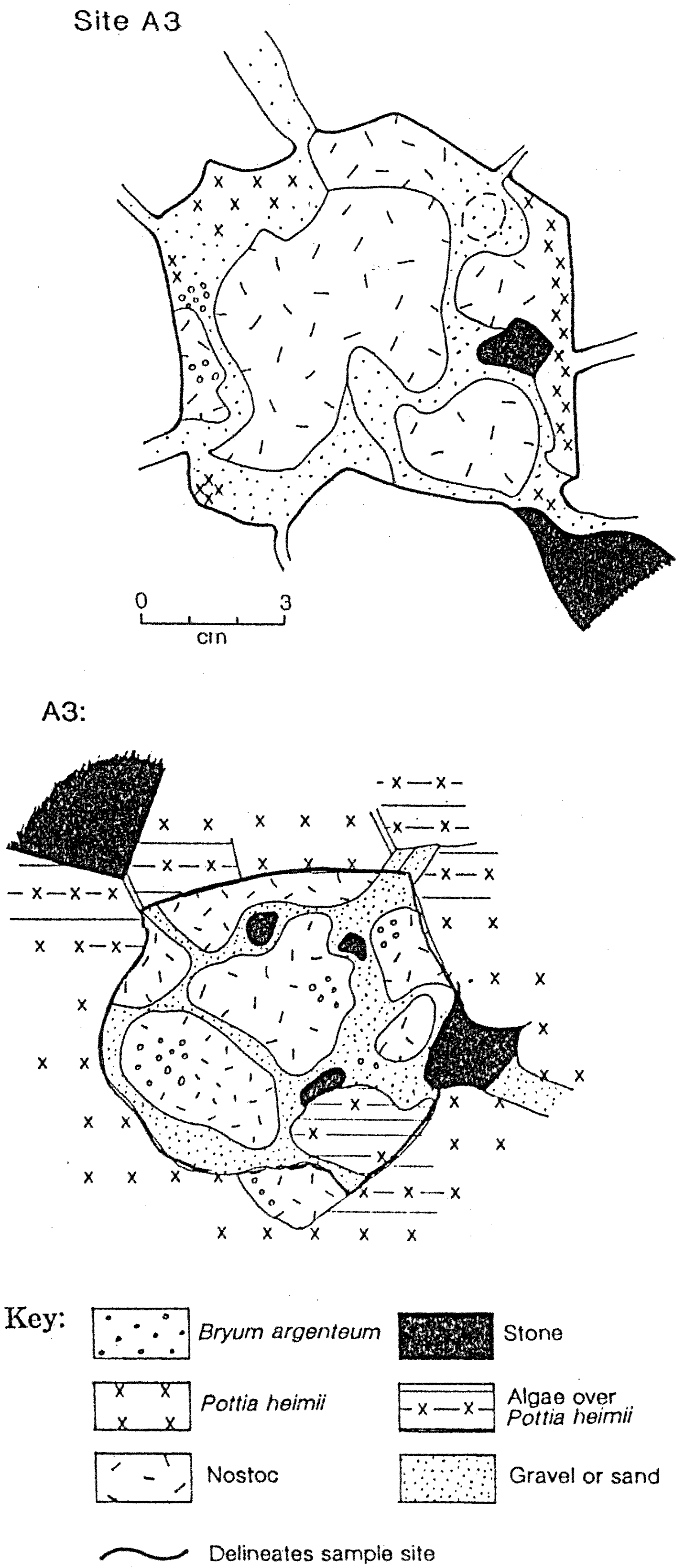
An indication of the 'rediscovery' rate of known core sample sites from nine years ago is listed below.

| Aim | Sampling Method | Number taken | Number found | 'Rediscovery' rate | Moss type |
|---|---|---|---|---|---|
| Animals A7 | core | 20 | 5 | 25% | *P.heimii* |
| Animals A13 | core | 20 | 7 | 35% | *B.argenteum* |
| Animals A1 | core | 20 | 4 | 20% | *P.heimii* |
| Animals A10 | core | 20 | 0 | 0% | *B.argenteum* |
| Algae A2 | core | 16 | 0 | 0% | *Nostoc* |
| Algae | core | 16 | 0 | 0% | *Nostoc* |

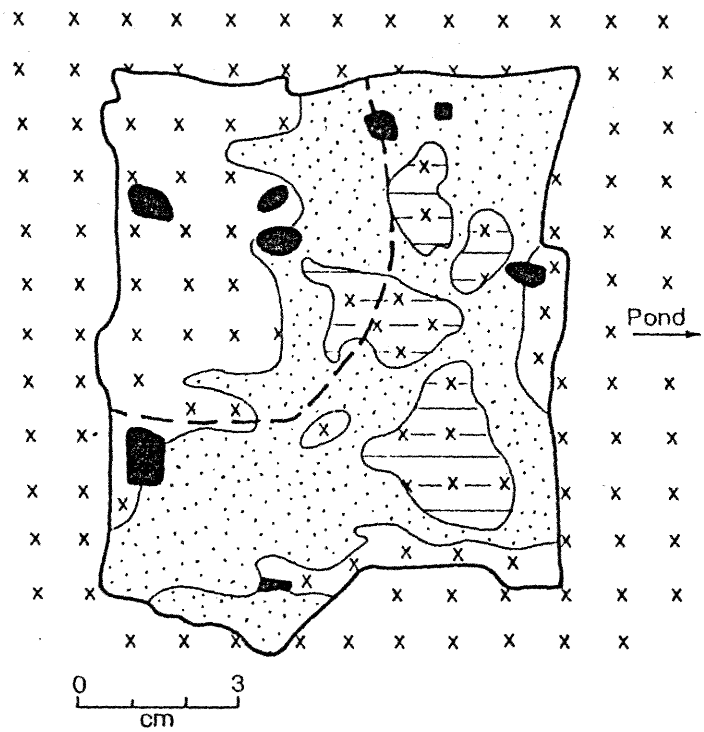
**Figure 5.2:** Sketches of section removal sites, 1989/90

a)

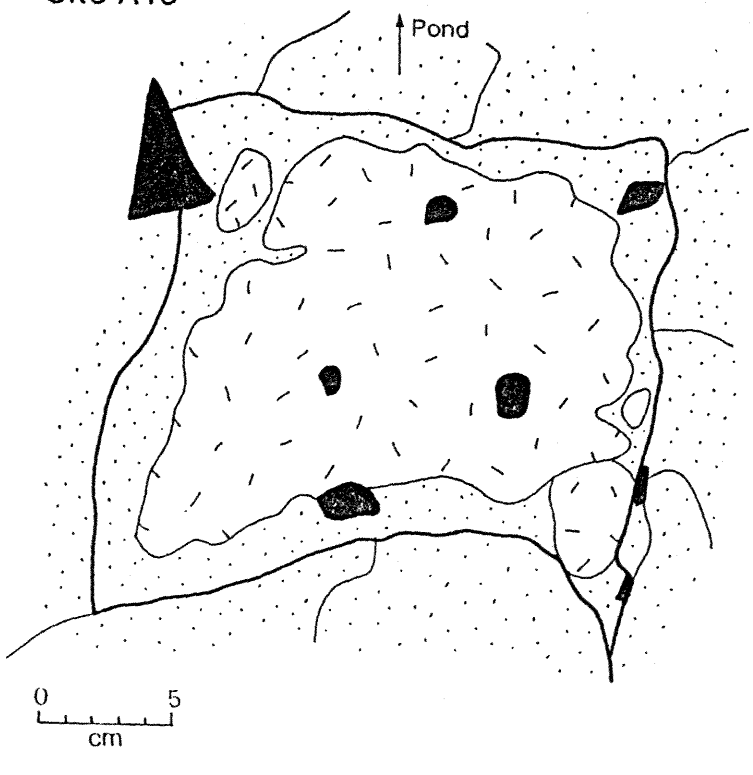
(ii)



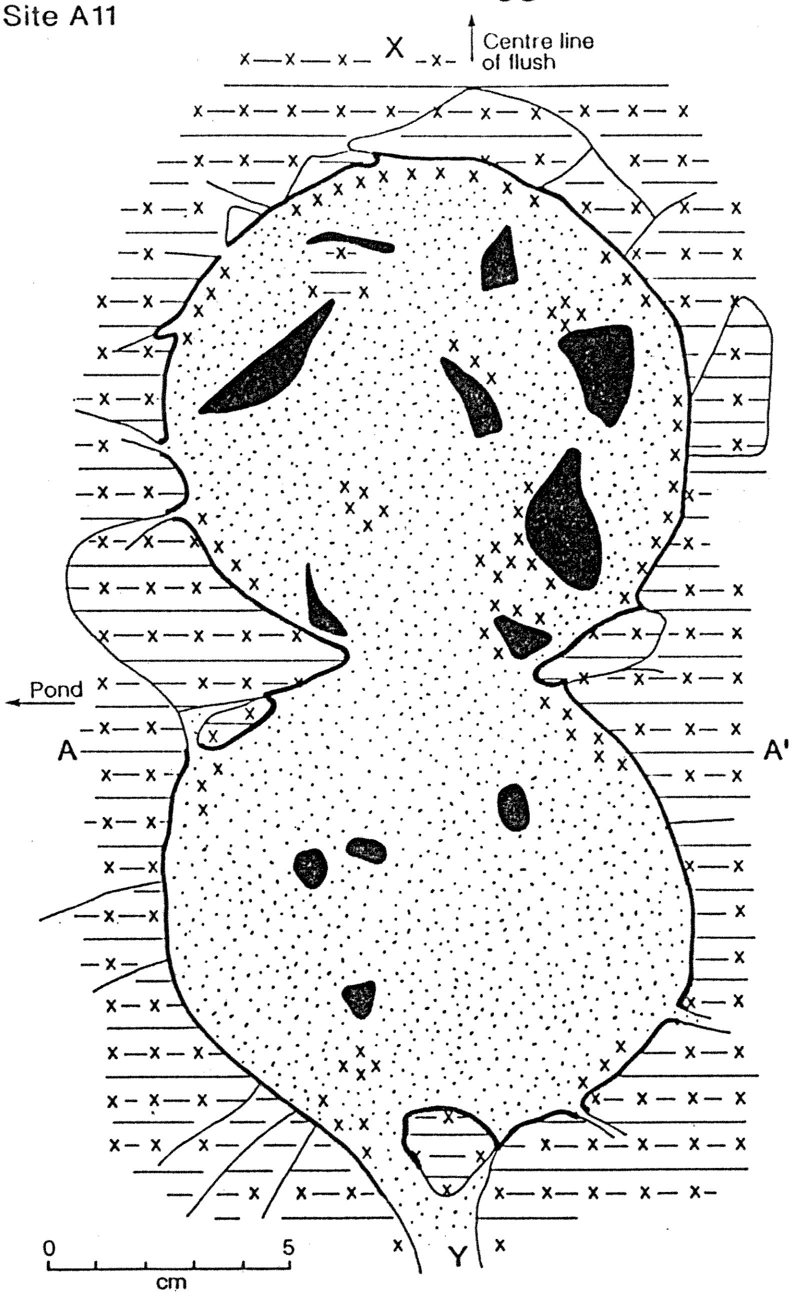
**b)** Site A9

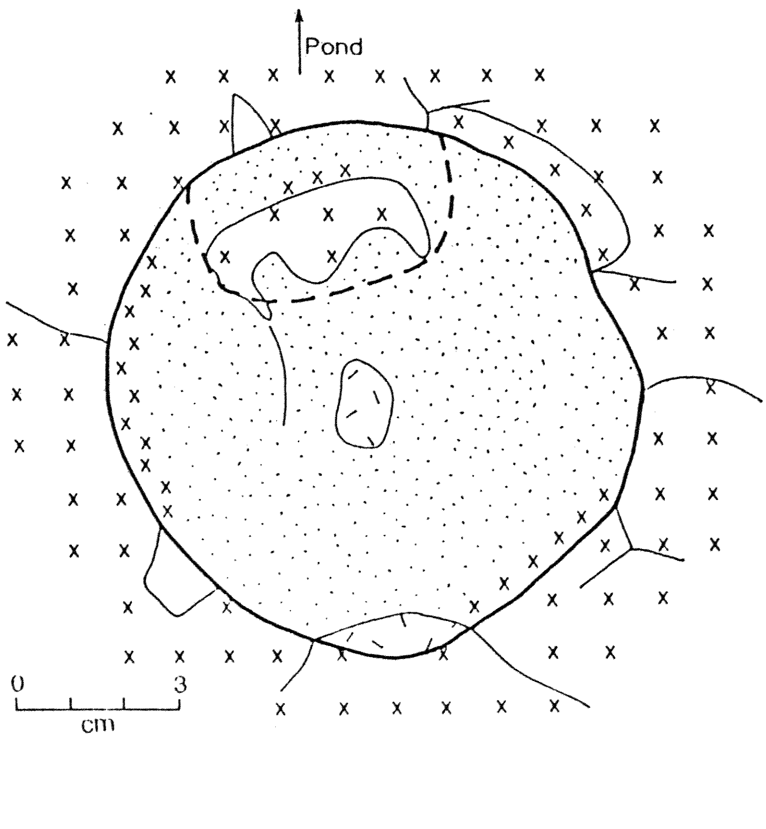



**c)** Site A16

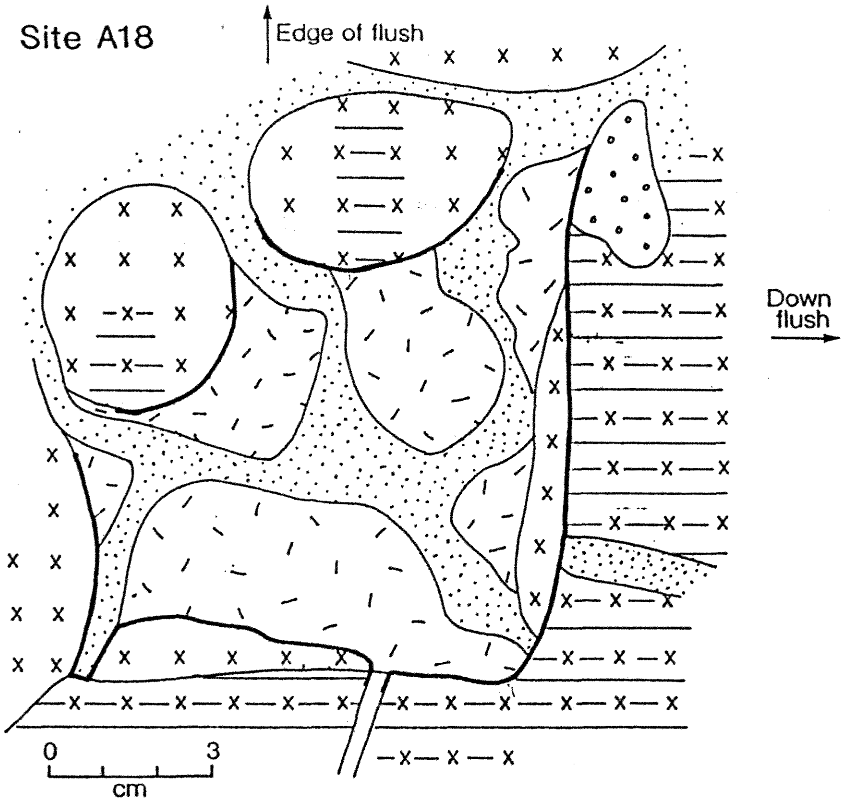


**d)** Site A11



**e)** Site A18



# Chapter VI: Invertebrates Lake Fryxell S.S.S.I./Canada Glacier

## VI:I Introduction

A list of invertebrate groups observed at S.S.S.I. No.12 is presented in this chapter. The numbers of invertebrates obtained from counting individuals in moss cores were used to estimate abundance, and to present information on their distribution both horizontally and vertically throughout the moss bed.

In order to analyze the invertebrate counts with respect to plant species present, and the microtopography of the flush, four ecological zones were assigned to each transect. These zones are based on visual observations of water flow over the transect and the corresponding plant patterning discernable from Figure 4.4. They are as follows:

Zone 1: Area of earliest meltwater. This is generally the lowest lying ground and is dominated by *Nostoc*, other algae and *B.argenteum*.

Zone 2: Receives seepage meltwater during the early weeks of flow. Transition zone from *B. argenteum* to *P. heimii*.

Zone 3: Water only during full flow and mostly via seepage from adjacent areas. Dominated by *P. heimii.*

Zone 4: Driest area, dominated by 'encrusted *P. heimii* '. The encrustation implied water was evaporating from the moss surface after moving up from the substrate below.

Rotifers, nematodes and tardigrades were investigated quantitatively to obtain a measure of their abundance and distribution across the flush. Three experiments were conducted in relation to invertebrate enumeration from moss cores. Results from these experiments are presented in this chapter.

**VI:I:I Experiments**

Experiment 1: The effect of increased temperature on invertebrate activity.

In the laboratory at Waikato University an experiment was conducted to establish whether an increase in temperature of the mosses without the addition of water accelerated the onset of activity of the invertebrates inhabiting them. Moss cores were subjected to differing temperatures in a regime that correlated to diel measurements on the 28th and 29th of November

1989 (Fig. 3.2). These diel temperature fluctuations were taken as being indicative of the temperature regime during the early part of the summer season.

Initially five samples from transect three on the lower flush (at least one from each zone), were counted in the manner previously described (Treatment 1). Ten further samples were incubated under a temperature regime of 2° C for three hours per day and -5 to -10° C for the remaining twenty one hours over a period of three days. Five of these were then counted (Treatment 2). The remaining five samples were exposed further to 10° C for ten hours and 0 to 4° C for twelve hours over the following three days before being counted (Treatment 3). Analysis of variance was performed on the counts using the t-test (Minitab version).

Experiment 2: Invertebrate abundance and distribution over the flush.

To obtain an estimation of the distribution of invertebrates across different plant community types, plant cores were taken across a variety of transects and the number of invertebrates in the cores were counted. Samples from transects 1, 2, 3, and 5 (Fig. 4.5) were used for the analysis. Cores were taken at intervals along the transects representing each zone. In order to sample each community type these were not randomly sampled. The most extensive sampling (14/15 November 1989) was prior to meltwater arriving on the flush (pre-melt), but samples were also taken after meltwater was present on the flush (post-melt).

Invertebrates were counted from one core per zone from each transect prior to the melt starting, enabling an estimate of abundance to be calculated. In order to establish whether there were significant differences in invertebrate numbers between each zone, the counts were analyzed using the non parametric Friedman test. This tests the null hypothesis (Ho) that each ranking of the random variables within a block is equally likely, (i.e. the zones have identical effects) (Conover 1980). Minitab was used to rank the data used in the Friedman test. The minitab version of the Friedman test approximates the p-value using the chi square distribution. Conover(1980) states that recent studies show the F approximation to T2 as clearly superior to the chi squared approximation, so the F distribution has been used for my results.

The alternative hypothesis (Ha) was that at least one of the zones tended to yield larger observed values than at least one other treatment. If the null hypothesis was rejected, multiple comparisons were carried out on zone pairs (Conover 1980) .

The number of cores taken for post melt counts were not sufficiently spread over the flush to analyze using the Friedman test but these did enable a further estimate of invertebrate abundance to be calculated.

Experiment 3: Vertical distribution of invertebrates.

The vertical distribution of rotifers, nematodes and tardigrades within the mosses was calculated from counts of each 5mm cross section of a core. This was done for both pre-melt and post-melt samples. The vertical distributions in 4 samples from each zone is summarized using the mean depth statistic (Usher and Booth 1984), given by

$$\bar{D}= \sum ni\ (5i - 2.5) / \sum ni = 5\ ( \sum ini / \sum ni ) - 2.5$$

Where ni is the number of invertebrates in the ith layer , i=1 for the top layer (central depth 2.5 mm) and i=3 for the bottom layer (centre at 12.5 mm), 5 = depth in mm of layer.

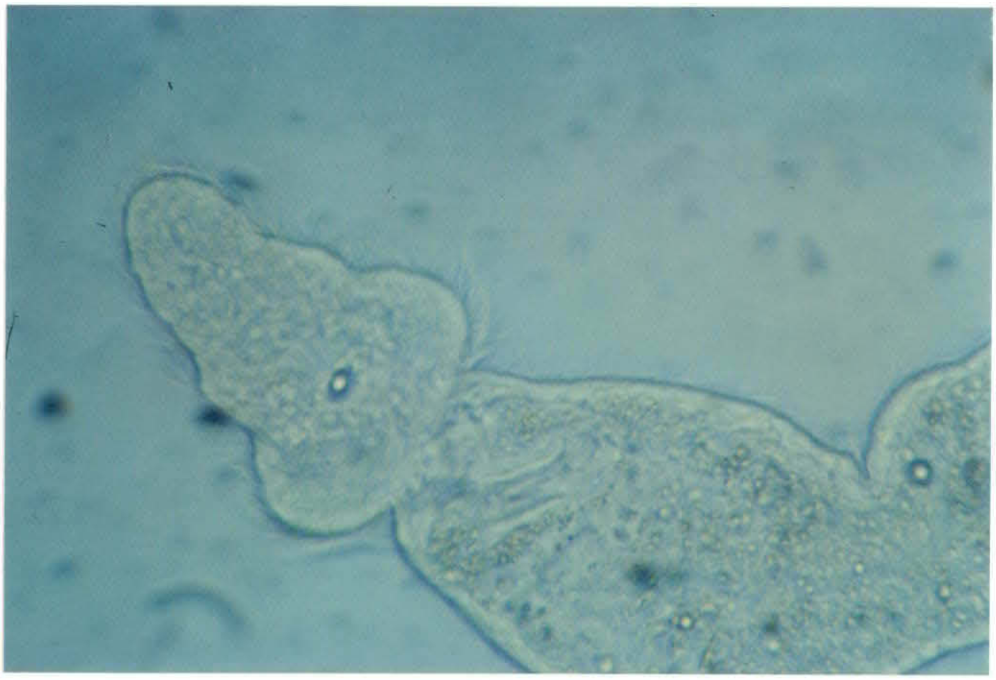
## VI:II Results

A species list of invertebrates isolated from plant samples during this study is presented in Table 6.1. Rotifers, nematodes, and tardigrades have been identified to genus level. (Dartnall and Hollowday 1985, Timm 1971, Dastych 1984). One specimen of Turbellaria was found at transect 5, zone 3 in a core of *Nostoc* over *Bryum argenteum*. The specimen was photographed at 100x and 400x magnification (see photograph 5 a and b). From the photographs I have classified the specimen as being of the order Catenulida. Catenulids usually reproduce asexually forming chains of 2 to many zooids (Edmondson 1966). Part of a chain of zooids can be seen in the photograph.

**Photograph 5.** Platyhelminthe found in moss samples from the Canada Glacier bryophyte flush.

(a)
x 100

(b)
x 400



Mites were not found during the time in the Taylor Valley but were seen in samples which had been subject to warmer temperatures on return to New Zealand. The mites were only found in samples from transect 5 in the encrusted *Pottia* zone, and after they had been wetted for up to 10 days densities reached 23 individuals per 1cm core. These are listed as *Stereotydeus* (Gressitt 1967) and although the identification has not been confirmed *S. mollis* has been identified from the flush previously (Strandtmann et al. 1973, Block 1985).

Collembolans were not seen on either the upper or lower flush but were collected during a visit to the north facing slopes of the Taylor Valley on the other side of Lake Fryxell.

Experiment 1: The effect of increased temperature on invertebrate activity.

Figure 6.1 illustrates the numbers of individuals active after each temperature treatment. The highest mean number of individuals counted was 11 nematodes per core in treatment 2.

There was no significant increase in numbers in numbers of active invertebrates ($p = 0.5$) between the three different temperature treatments. It would appear that the addition of water to the core at the time of counting was the stimulus for activity rather than solely a rise in temperature.

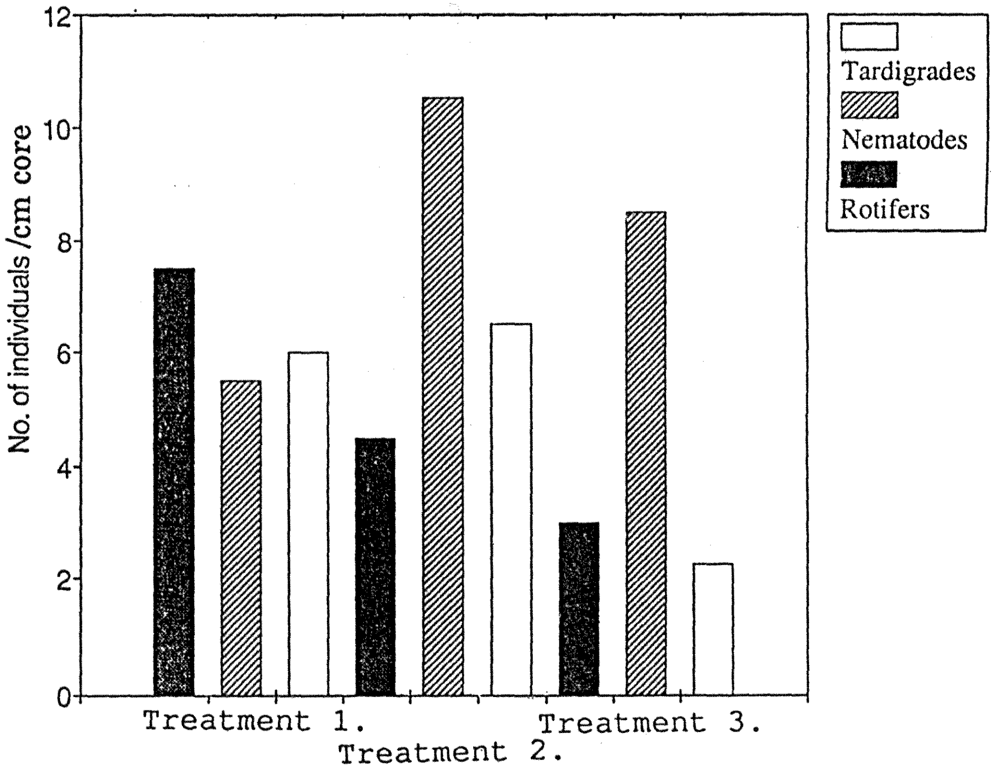



**Figure 6.1:** Experiment One; Results.

**TABLE 6.1:** Invertebrate Species List:Canada Glacier

| Phyla | Class | Genus |
|---|---|---|
| Protozoa | | |
| Platyhelminthes | Turbellaria<br>Order: Catenulida | |
| Rotifera | | *Philodina*<br>*Epiphanes*<br>*Habrotrocha* |
| Nematoda | | *Plectus* |
| Tardigrada | | *Macrobiotus* |
| Arthropoda | Arachnida | *Stereotydeus mollis* |

Experiment 2: Invertebrate abundance and distribution over the flush.

The distribution of the 3 main invertebrate groups prior to the summer melt is illustrated in Figure 6.2.

The numbers of rotifers ranged from a maximum of approximately 20 per core in zone 1 (wettest) to a low of approximately 8 per core in zone three. There is a high standard error associated with the rotifer counts and the null hypothesis ( that the zones have identical effects) was not rejected implying there was no significant difference in counts between the zones.

Nematode counts ranged from approximately 16 per core in

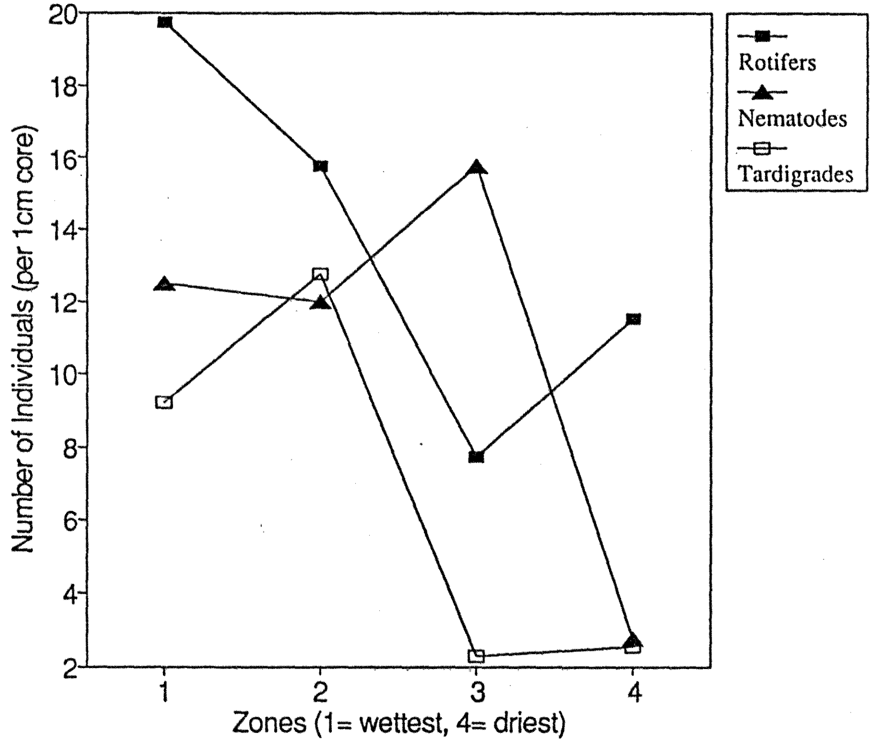



**Figure 6.2:** Invertebrate distribution on the lower flush prior to summer melt.

zone three to approximately 3 per core in zone 4. Tardigrade counts ranged from approximately 13 in zone 2 to approximately 3 in zones 2 and 4. Both tardigrade and nematode numbers appeared to decline toward the drier zones. For nematodes and tardigrades the null hypothesis was rejected and multiple comparisons were carried out. The zones which had significant differences between them according to this test are shown in Table 6.2. Nematode counts were significantly lower in zone 4 (the encrusted *Pottia* zone) and tardigrades significantly lower in both zone 3 and 4.

**Table 6.2:** Outcomes of the Friedman test on invertebrate counts, (multiple comparisons).

| | **Zones showing significant differences** |
|---|---|
| **Nematodes** | 1 and 4, 2 and 4, 3 and 4 |
| **Tardigrades** | 2 and 3, 2 and 4 |

Figure 6.3 shows the counts obtained from cores (taken along the same transects as for pre-melt counts) sampled from 8 to 10 December 1989 after water had been flowing over the flush for approximately fourteen days. There were not enough samples taken during the period after meltwater began affecting the flush to analyze with the Friedman test however an increase in numbers, especially of rotifers and nematodes, is evident from comparison

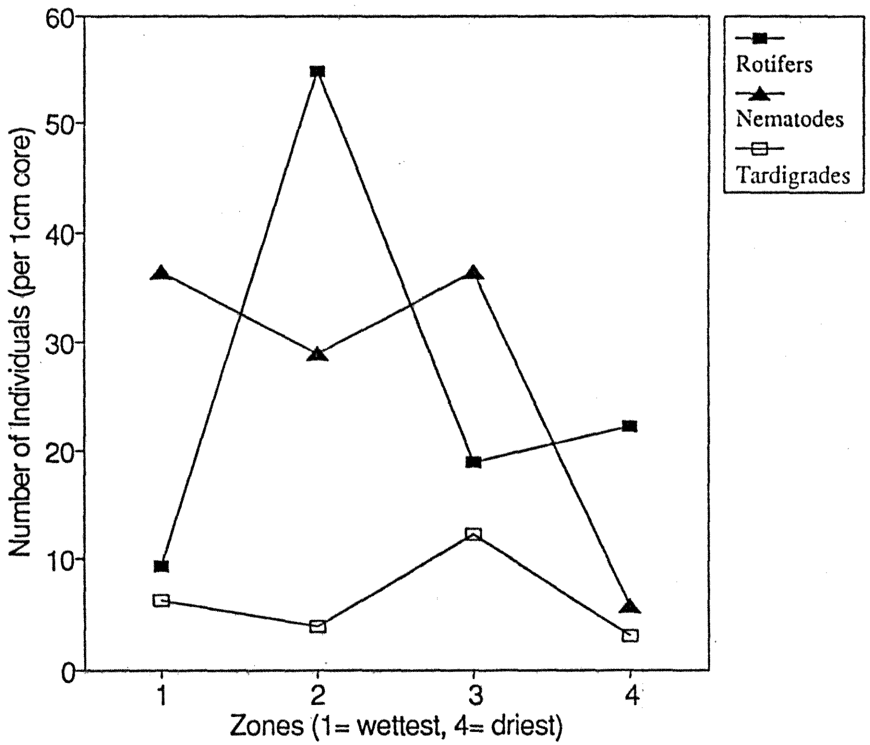



**Figure 6.3:** Invertebrate distribution on the lower flush after water was flowing over the plants.

of the scales of Figures 6.2 and 6.3. Both pre-melt and post-melt abundances are recorded in Table 6.3. A large increase in the nematode and rotifer populations associated with water flowing on the flush is evident.

Once water is flowing over the flush, rotifers emerge from their overwintering state and may be observed actively feeding, moving about, or in a contracted state. As only moving or feeding rotifers were counted, these post-melt counts are likely to be under estimates. To ascertain the effect on results of only counting moving individuals, contracted individuals were also counted in two samples where *Philodina* dominated, This brought the counts of 40 and 48 (used in analysis) up to 240 and 205 respectively.

The manner of overwintering and reproduction of tardigrades suggests there may be no sudden increase in density, (Everitt 1981, Pickard 1986) and this is discussed further in chapter eight.

**Table 6.3:** Abundances of rotifers, nematodes and tardigrades, a) Pre-melt (14-16 November 1989) and b) Post-melt (8-10 December 1989).

| | Pre-melt | | Post-melt | |
|---|---|---|---|---|
| | **Range** | **mean ($\times 10^3/m^2$)** | **Range** | **mean** |
| **Rotifers** | 0-230 | 83.75 | 0-930 | 268.8 |
| **Nematodes** | 0-170 | 70.66 | 80-670 | 239.4 |
| **Tardigrade** | 0-180 | 48.00 | 0-210 | 63.0 |

Experiment 3: Vertical distribution of invertebrates.

Data on the mean plant depth at which invertebrates were found are given in Table 6.4. There were few obvious trends to the depth distribution of invertebrates in the pre-melt samples with the mean depths over all groups ranging from 5 to 10.83 mm. In the post-melt samples there was little difference in distribution for rotifers, except in zone 4 where they were closer to the surface ($\bar{D}$ = 3.08). Nematodes and tardigrades had a shallower $\bar{D}$ in every zone in the post-melt samples compared to the counts for pre-melt. In both pre- melt and post-melt samples, tardigrades had a shallower mean depth in zone four than in other zones.

**Table 6.4:** Mean depth within a moss core at which invertebrates were found. The mean depth statistic $\bar{D}$ is described in the text.

**Pre-melt** Mean depth in mm.

| **Invertebrate group** | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
|---|---|---|---|---|
| **Rotifer** | 6.94 | 8.96 | 6.18 | 8.04 |
| **Nematode** | 6.77 | 6.75 | 8.03 | 10.83 |
| **Tardigrade** | 7.05 | 7.50 | 7.81 | 5.00 |

**Post-melt**

| **Invertebrate group** | | | | |
|---|---|---|---|---|
| **Rotifer** | 8.37 | 8.46 | 8.47 | 3.08 |
| **Nematode** | 4.50 | 5.20 | 5.75 | 4.20 |
| **Tardigrade** | 5.36 | 6.67 | 4.25 | 3.12 |

Table 6.5 summarises the percent contribution of each group within each of the three depths. A greater percentage of all groups were in the upper 5 mm in the post-melt samples. In the pre-melt samples there was little obvious trend in percent contribution at different depths with the exception of zone four, where there were almost always fewer individuals in the lower 5 mm of the moss core.

**Table 6.5:** % contribution of rotifers, nematodes and tardigrades at three depths within a moss core,

a)=0-5mm b)=5-10mm c)=10-15mm.

**(i) Pre-melt**

| | | a) | b) | c) |
|---|---|---|---|---|
| **Zone 1** | **R** | 33 | 45 | 22 |
| | **N** | 46 | 22 | 32 |
| | **T** | 45 | 18 | 36 |
| **Zone 2** | **R** | 29 | 12.5 | 58 |
| | **N** | 38.25 | 38.25 | 23.5 |
| | **T** | 35 | 30 | 35 |
| **Zone 3** | **R** | 36.8 | 15.8 | 47.4 |
| | **N** | 44.4 | 22.2 | 33.3 |
| | **T** | 25 | 44 | 31 |
| **Zone 4** | **R** | 26 | 37 | 37 |
| | **N** | 25 | 67 | 8 |
| | **T** | 50 | 50 | 0 |

**(ii) Post-melt**

| | | a) | b) | c) |
|---|---|---|---|---|
| **Zone 1** | **R** | 31 | 9.2 | 17.3 |
| | **N** | 70 | 19 | 10 |
| | **T** | 63 | 17 | 20 |
| **Zone 2** | **R** | 24 | 32 | 44 |
| | **N** | 63 | 20 | 17 |
| | **T** | 42 | 33 | 25 |
| **Zone 3** | **R** | 28 | 25 | 47 |
| | **N** | 54 | 26 | 19 |
| | **T** | 76 | 14 | 10 |
| **Zone 4** | **R** | 88 | 12 | 0 |
| | **N** | 75 | 17 | 8 |
| | **T** | 88 | 12 | 0 |

# Chapter VII: Granite Harbour

## VII:I Introduction

At Kar plateau the interaction of microclimate and cryopedolgical processes has created conditions ideal for the development of a conspicuous growth of bryophytes (Ugolini 1977). Ugolini (1977), describes protorankers (moss supporting soils) from the Kar plateau in Granite Harbour suggesting that conditions in this area are conducive to the establishment of life. He considers the Kar plateau as being unique in the support of biological life amongst the barren conditions that prevail in the rest of Southern Victoria Land.

Falling and blowing snow from south west and eastern storms is trapped by dolerite blocks which are strewn over the area. Fines accumulate where melt water and freeze/thaw cycles occur. Frost action segregates these fines into debris islands. These islands, surrounded and protected by dark, dolerite blocks, effective in trapping snow, constitute environments suitable for colonisation by mosses.

The sites I investigated at Granite Harbour provide a variety of microhabitats. Much of the area may be enriched by the presence of skua rookeries.

A detailed plant species list with a general impression of the nature of their distribution in the areas investigated at Granite Harbour are presented. Major invertebrate groups observed are also noted in this chapter.

## VII:II Results

### VII:II:I Vegetation

From the 4.12.89 to the 7.12.89 weather conditions were extremely different to those experienced in the Taylor Valley. There was little or no wind and during the cloudless days air temperatures were measured at 11.1° celsius (4.12.89) and 6.6° celsius (6.12.89).

Table 7.1 lists all plant species found during the investigation of the Granite Harbour region and includes a brief site description of the areas in which they were recorded. One area of plant growth was surveyed in greater detail. This was approximately 60 m wide bordered by a steep, high granite block toward Botany Bay and a lower granite shelf toward Scott's kitchen (Fig. 7.1). The area sloped down from a snowbank on the cliffs surrounding the bay toward the ocean. The water source appeared to be meltwater from the snowbank, shown on Figure 7.2. There may have been additional water seeping through from the major glacier source above the amphitheatre. Water was channelled around the larger rocks and there were areas of flowing water, pools and seepage. There was evidence this was a popular roosting area for skuas as there was guano on the rocks, and feathers throughout the water and plants.

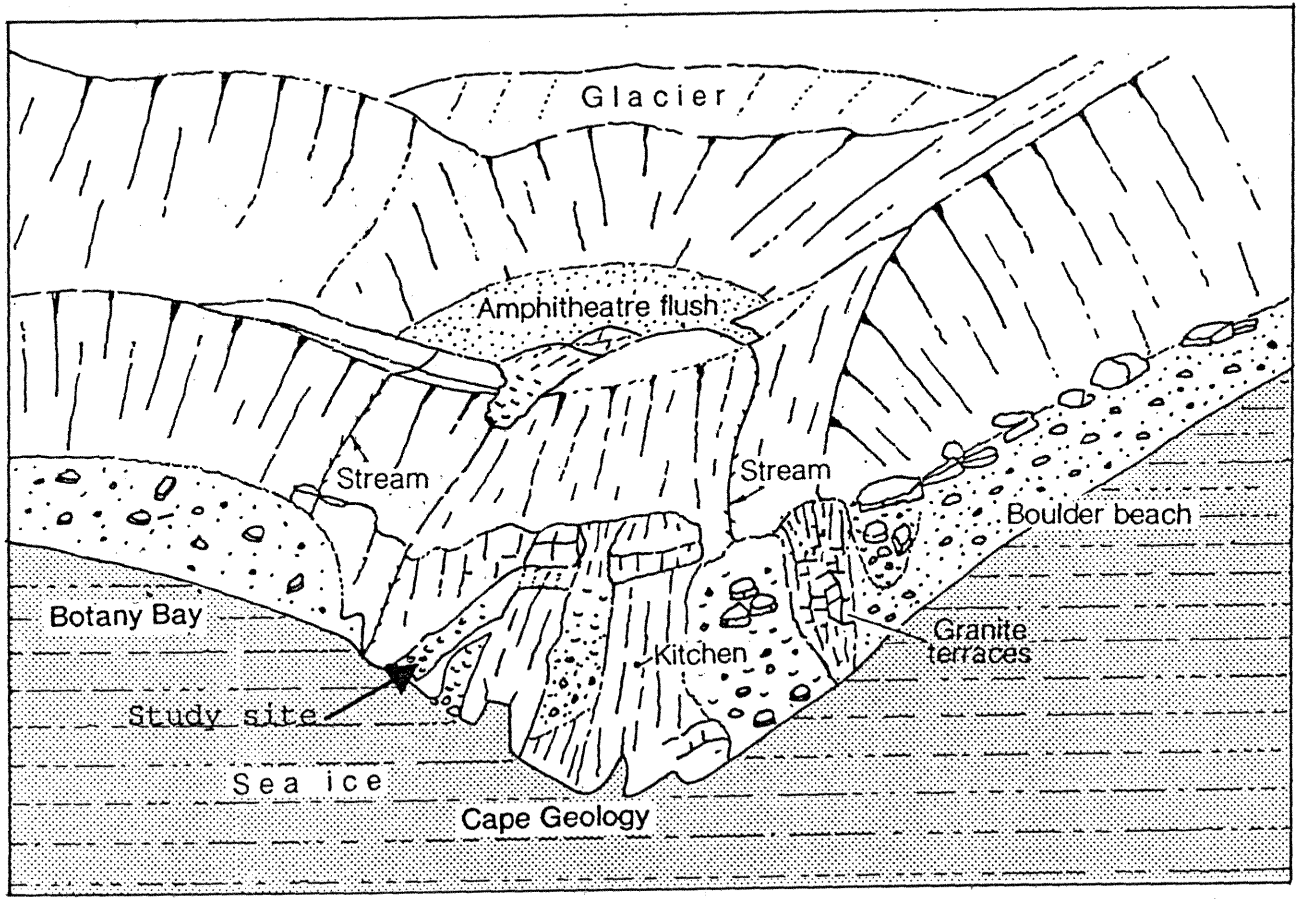



**Figure 7.1:** View of the area studied either side of Cape Geology at Granite Harbour.

**TABLE 7.1:** Plant Species List: Granite Harbour

| **Algae** | **Site Description** |
|---|---|
| *Nostoc* | Common in wetter flush areas |
| *Prasiola crispa* (Lightf.) Menegh | " |
| **Mosses** | |
| *Pottia heimii* (Hedw.) Feurnr. | Most flush areas |
| *Bryum argenteum* Hedw. | " |
| *Bryum pseudotriquetrum* (Hedw.) Gaertn. | Less common than *Pottia* and *B.argenteum* |
| *Sarconeurum glaciale* (C.Muell.) Card. & Bryhn | found in drier areas |
| *Ceratadon purpureus* (Hedw.) Brid. | Spot records |
| *Grimmia* sp. | " |
| **Liverwort** | |
| *Cephaloziella exiliflora* (Tayl.) Steph. | Botany Bay, wet areas |

Table 7.1 ctd.

**Lichens**

| | | |
|---|---|---|
| *Acarospora gwynnii* Dodge & Rudolph | Rare, amphitheatre edge | |
| *Buellia frigida* Darb. | Common, all rocks | |
| *Caloplaca citrina* (Hoffm.) Th.Fr. | Common, on drier mosses | |
| *Caloplaca athallina* Darb. | Spot occurrence, boulder beach | |
| *Candelariella halletensis* | Occasional on rocks, wetter areas | |
| *Lecanora expectans* Darb. | Occasional-common,on mosses | |
| *Lecidia phillipsiana* Filson | Common, endolith | |
| *Lepraria* sp. | Rare, on moss | |
| *Physcia caesia* (Hoffm.) Hampe | Common, amphitheatre, | Botany Bay |
| *Physcia dubia* (Hoffm.) Lynge | amphitheatre | |
| *Physcia* sp. | " | |
| *Rhizocarpan geographicum* L. DC. | common, amphitheatre, | Botany Bay |
| *Rhizoplaca melanophthalma* (Ram.) Leuck. & Poelt | Rock surfaces | |
| *Umbilicaria aprina* Nyl. | Common, on rocks | |
| *Xanthoria elegans* (Link) TH.Fr. | Common, on granite rocks | |
| *Xanthoria mawsonii* Dodge | Common, on mosses | |

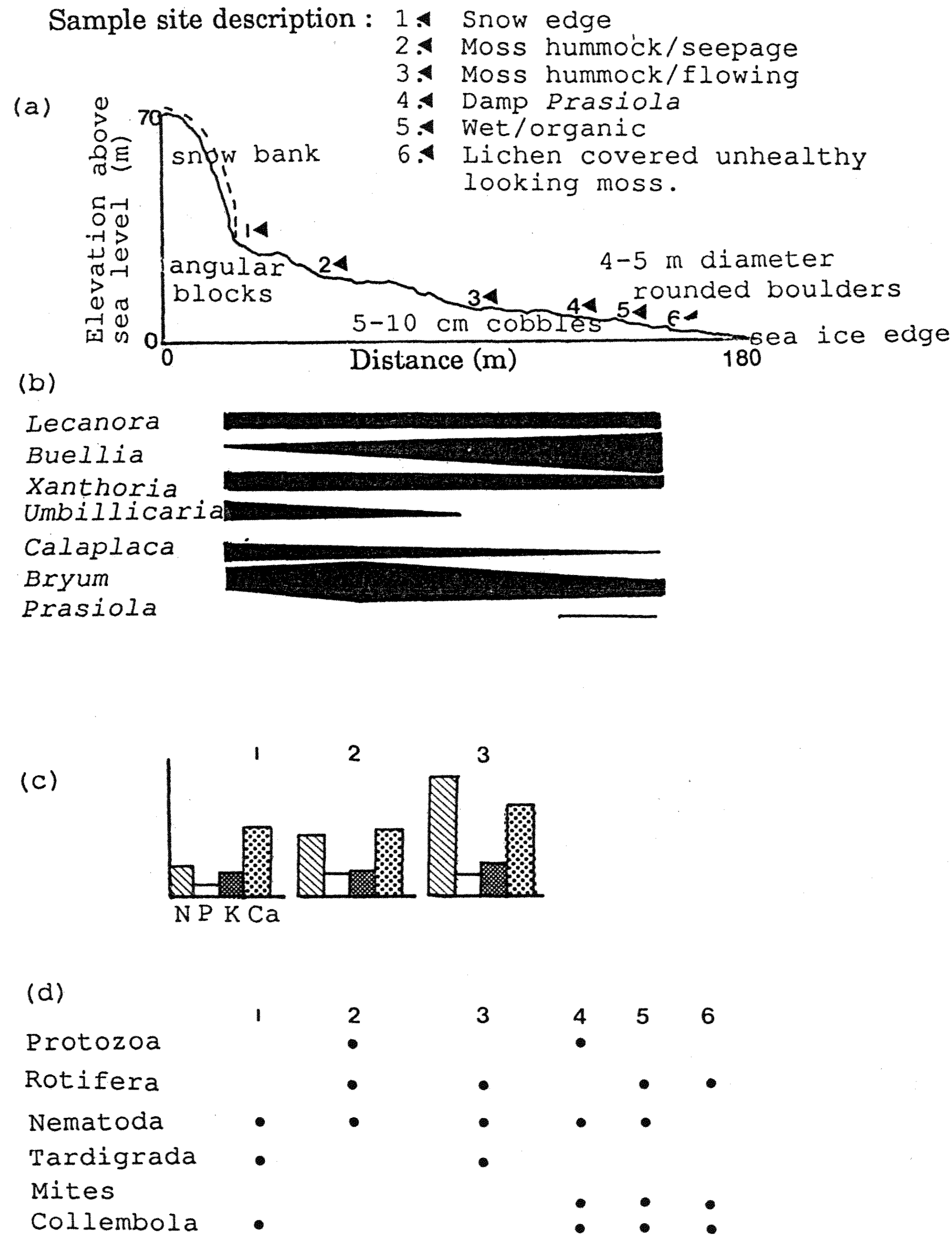



**Figure 7.2:** (a) Profile of a study site at Granite Harbour showing substrate type and approximate sampling sites◄
(b) Plant species and their relative abundance.
(c) Nutrient levels (%) at three positions on the profile.
(d) Presence of invertebrate groups at sampling sites.

The zonation of plant species from water source to ocean is presented in Figure 7.2. Mosses grew on the smaller sized sand and gravel particles between larger rocks. All obvious plant life ceased at 30 m from the sea ice edge.

Moss samples from the first three sites indicated in Figure 7.2 were analyzed for major elements. Concentrations of nitrogen, phosphorous, potassium and calcium are presented for each of the three moss samples. There is a general trend of increasing concentration of all nutrients downstream. The highest concentrations of nitrogen, phosphorous and calcium were found in the moss in flowing water which was also amongst skua perching and nesting sites.

### VII:II:II Invertebrates

Table 7.2 lists invertebrates seen during this visit to Granite Harbour. With a handlens collembolans were evident on the surface of the moss at most sites. They did not, however, appear to be present where water was flowing over the plants. Figure 7.2 incorporates a presence/ absence table for invertebrates, at the surveyed site.

**TABLE 7.2:** Invertebrate List: Granite Harbour

| **Phylum** | **Genus** |
|---|---|
| Rotifera | *Philodina*<br>*Habrotrocha* |
| Nematoda | *Plectus* |
| Tardigrada | *Macrobiotus* |
| Arachnida | *Stereotydeus* |
| Insecta | *Cryptopygus* |

# Chapter VIII: Discussion

## VIII:I Flora and Biomass

Prior to this study no definitive plant species list had been recorded for the Lake Fryxell S.S.S.I. No. 12. *B. argenteum* and *B. antarcticum* had been reported for the area (Greenfield and Wilson 1981, Green 1986).
*B. pseudotriquetrum* had not previously been recognised in this area.
*B. antarcticum* is now considered to be synonymous with *Pottia heimii* by Kanda (1981). The so-called *B. antarcticum* from the Fryxell area has now been identified as *Pottia heimii* by Dr. Rod Seppelt (pers comm.). Seppelt and Kanda (1986) conclude that only two species of the genus *Bryum* namely *B. argenteum* and *B. pseudotriquetrum* should be recognised in the continental Antarctic flora.

The distribution of *Nostoc, Pottia* and *B. argenteum* on the lower Fryxell flush was correlated closely with the water regime of the area. The bryophytes had distinctive areas of optimum growth. *Nostoc* grew in an opportunistic manner where there was sufficient water flow, which included epiphytic growth on bryophytes.

Ohtani and Kanda (1987) suggest that the growth of prominent algal flora on moss colonies at Syowa Station might be caused by abundant water supply from the continental glacier during the summer season.They conclude that water availability and nutrient supply for moss growth largely influence the presence of epiphytic algae.

It is the freezing and melting cycle that exerts the dominant influence on Antarctic life forms, either directly or indirectly (Vincent 1988). While temperature may be of prime importance in determining the dominance of cryptogams in cold and frigid polar environments, water availability is of higher importance in controlling the distribution of cryptogamic growth both locally and regionally (Longton 1988).

The importance of the interaction between incident radiation and temperature in determining the appearance and maintenance of meltwater flow has become evident from these results. Where the frozen ground layer is shallow, ponding and waterlogging are common. This unfrozen water may be of great importance to soil dwelling animals and plants (Laws 1984).

The Canada Glacier is not only the source of meltwater crucial to plant growth but it also provides the necessary shelter from potentially destructive winds. Chinn (1986) suggests that because of their low erosion rates, dry based glaciers may act as protective cover against wind erosion of bare rocky slopes. The lower lying ground on the easterly side of the glacier where the flushes occur is protected from easterlies as the air rises up to pass over the glacier. The bulk of the glacier itself provides substantial protection from stronger katabatic winter westerly winds.

The importance of microclimate has been noted by a number of workers (Greene et al. 1967, Laws 1984, Campbell and Claridge 1987 and Longton 1988). Laws (1984) states that the climate experienced at lower levels has only a rather general relationship to standard meterological data emphasising that conditions close to the ground must be taken into account when interpreting climate effects on biota. Longton (1974) emphasised the influence of microclimate in determining biomass and productivity by using microclimate data from different sites to estimate these parameters.

A much longer plant species list was obtained for the Granite Harbour area than for the Fryxell flush. Distinct plant zonation could be seen from the freshwater source to the ocean. *Bryum* growth continued to the seaward limit of plant distribution which correlates with observations by Ugolini (1977) who noted from studies at Kar plateau that *B. argenteum* appeared to be able to tolerate highly saline conditions.

As there are no detailed records of climate from the Granite Harbour region it is difficult to make comparisons between the climate in this area and at the Canada Glacier site. Because this is a coastal site, it is not subject to up and down valley winds as is the Canada Glacier site in the Taylor Valley. The region of Cape Geology and Botany Bay where this study was conducted appeared to be protected to the south by the Wilson Piedmont Glacier and to a certain extent to the east by Discovery Bluff.

The area of most extensive plant growth in Botany Bay was protected from westerly winds by Cape Geology. These factors may enhance the area as a favourable habitat for bryophyte and lichen colonisation. The nature of the rocks in the area provide an additional microclimate as described by Ugolini (1977) which he considers conducive to the establishment of life.

In the Antarctic, biomass is low due to the scattered nature of the vegetation but it may be considerable within moss and lichen communities of 100% cover (Longton 1988). This study reports biomass values ranging from

950 g to 1250g $m^{-2}$ for bryophytes making up the flushes at the Canada Glacier, which correspond to the values of 250 to 1500 g $m^{-2}$ reported for the flush by Greenfield (1981). They compare with reports of 1100 g $m^{-2}$ in short moss turfs on Ross Island (Longton 1988) but are considerably larger than the 177 g $m^{-2}$ reported for *B.algens* at Birthday Ridge by Kappen (1985). Stands of *B.argenteum* considered to be exceptional by Longton (1988) were recorded as having a biomass of 938 g $m^{-2}$. My results are comparable to those reported for a *Bryum algens*/ *Grimmia lawiana* mix at Mawson Rock of 1100 g $m^{-2}$ for 100% plant cover (Seppelt and Ashton 1978), whose report however, refers to green biomass alone.

The significance of the finding of lichens growing on the surfaces of rocks at the outwash area of the Canada Pond is emphasized by a statement by Friedmann and Ocampo-Friedmann (1984). They state that the most striking feature of the McMurdo Upland (Dry Valleys) is the apparent absence of life, emphasising that the exposed surfaces of rocks are practically abiotic, except for the very infrequent, small patches of surface lichens in particularly sheltered microhabitats. Certainly the distribution of lichens at the Canada Pond appeared to be closely related to the microhabitat existing in the area.

### VIII:II Nutrient Composition

There is no marked difference in the composition of major elements between mosses from the Canada Glacier flushes and the Granite Harbour samples. The exception may be the higher value for nitrogen in the main flow at the Granite Harbour site. Nutrient values for *Nostoc, Bryum*, and *Pottia* from the Canada Glacier flushes can be compared with data obtained elsewhere. Nitrogen values from Fryxell are approximately 50% less than those presented for two mosses in the Arctic tundra (Chapin et al. 1980). Phosphorus and potassium values are approximately the same but calcium levels at the Canada Glacier are up to twice as high as those presented for Arctic species. Pickard (1986) presents nutrient data for moss beds with epiphytic *Nostoc* at Mossel Lake in the Vestfold Hills. Values range from 0.84% - 4.18% for nitrogen 0.064% - 0.076% for phosphorus and 0.260% - 1.36% for calcium. My data is within this range suggested for calcium however phosphorus values at the Canada Glacier would appear to be up to three times higher than moss beds at Mossel Lake. Nitrogen values from the Canada Glacier bryophytes are similar or slightly lower than at Mossel Lake. *Pottia* has the lowest nitrogen value. This may relate to it having less epiphytic *Nostoc*, as cyanobacteria growing epiphytically on mosses provide significant N fixation on damp mosses (Longton 1988). It is the nutrients in soil moisture and surface runoff which appear to be of greatest significance to small plants growing appressed to the substratum or those forming dense colonies. In these communities upward external movement of water occurs by capillarity or due to humidity induced diffusion gradients (Longton 1988).

Longton (1988) emphasises that the combined characteristics of nutrient cycling in polar ecosystems often result in available nitrogen and phosphorus being limiting and suggests that low rates of nitrogen cycling could impose restrictions on production as severe as those attributable to direct effects of temperature on metabolism.

Release of nutrients by chemical weathering is retarded by cold, particularly when combined with aridity and the same factors restrict N fixation. Rates of N cycling in polar systems are further depressed by slow decomposition and the limited extent of herbivory which result in nutrients accumulating in an unavailable form in dissolved organic matter (D.O.M). Nutrient cycling is influenced to a large extent by water supply (Longton 1988). Downes et al.(1986) suggest that the dry non-living epilithon persisting from the previous summer in Dry Valley streams may provide a source of D.O.M. and particulate organic matter at first flows each year.

Green et al. (1989) cite values of approximately 0.9 uM NO3-N for Fryxell stream, which, although one of the highest values they present for the area, is extremely low compared to other flowing waters of the world. Howard-Williams and Vincent (1989) present some physical characteristics for the Fryxell Stream including a comparison of nutrients at an upstream and downstream site (Table 8.1). Nitrogen and phosphorus values were much higher at the upstream site. It is the water with these higher values that the mosses and algae received.

**Table 8.1:** Selected environmental features of four south Victoria Land streams (Howard-Williams and Vincent 1989).

ND = not detectable.

| | | Adams | Fryxell | Onyx | Alph |
|---|---|---|---|---|---|
| Length (km) | | 2.7 | 2 | 30 | 12 |
| Midseason discharge* $m^3\ s^{-1}$ | | 0.15 | 0.06 | 1.1 | 1.0 |
| Suspended sediments $g\ m^{-3}$ | | 8 | 2 | 27–131 | 5 |
| Nutrients midseason | | | | | |
| Upstream | DRP $mg\ m^{-3}$ | 28 | 6.5 | 0.3 | 12.1 |
| | $NH_4$-N $mg\ m^{-3}$ | 35 | 1.5 | 2 | 3.4 |
| | $NO_3$-N $mg\ m^{-3}$ | 46 | 17.6 | 13 | 5.1 |
| Downstream | DRPmg $m^3$ | 5.4 | 0.2 | 1.9 | 12.3 |
| | $NH_4$-N | 8.5 | ND | 8.0 | 2.8 |
| | $NO_3$-N | 7.5 | 2.0 | 4.0 | 1.3 |

* Daily maximum
\# DRP = Dissolved Reactive Phosphorus

In a study of streams in Southern Victoria Land by Howard-Williams et al.(1986) it was noted that none of these streams appeared to be ultra-oligotrophic and that there were high nutrient levels associated with first flows. While this is a transient phenomenon, Vincent and Howard-Williams (1986) suggest this initial pulse may be advantageous to stream flora which rapidly resumes metabolic activity on rehydration.

Howard-Williams et al.(1989) noted that nitrogen fixed by *Nostoc* mats of the Adams stream in the Miers Valley and the Fryxell Stream in the Taylor Valley ranged from 9-939 mg N $m^{-2}$/year. A growth rate of 100 g $m^{-2}$ has been proposed for *B. argenteum* turfs on Ross Island (Longton 1988). With a nitrogen content of 0.82% (this study) then the nitrogen requirement of this moss would be 0.82 g $m^{-2}$ /year (820mg). It may be possible that nitrogen fixation by *Nostoc* in the flush systems may be able to supply the entire nitrogen requirement of the mosses.

It seems very unlikely that nitrogen could be limiting to the mosses in this system because of:

1) the position of the mosses at water flows where nutrient levels are high
2) high nitrogen fixation by epiphytic and surrounding *Nostoc* and
3) slow growth rates implying a low nutrient requirement.

In relation to algal growth in Dry Valley streams, Howard-Williams et al. (1986) suggested that the physical features of streams seemed to be of greater importance than nutrients in determining biological activity. It is possible that the presence of a skua rookery at the Granite Harbour site may affect nutrient availability for plants in this area. Work by Ryan and Watkins (1989) at the Robertskollen nunataks in western Dronning Maud Land, suggested that while fine scale dispersion patterns of plants were determined primarily by physical factors affecting water availabity, coarse scale analysis showed significant responses along the bird influence gradient. Soil concentrations of major plant nutrients, nitrogen, phosphorus and potassium were significantly greater closer to bird colonies.

**VIII:III Recovery from damage.**

Observation of sites which had vegetation removed ten years ago indicated that detectable moss growth can occur over a nine year period. This is the first demonstration of growth at these latitudes. The growth rate, however is very slow and patchy being greatly influenced by shelter. These results suggest that several decades would be required to obtain a general growth rate for the flush.

Some indications have been obtained on the general dynamics of the flush and flush mosses. The central, upper flush, dominated by *B. argenteum* and *Nostoc* appears to be very active as shown by the recovery from footpath damage. This activity is also supported by the 'rediscovery' rate of other damage sites. The sites close to the central, wet part of flush (*Nostoc*) show low recoveries, while one of the *B. argenteum* sites, near the flush centre showed zero recovery.

The large sample sites suggest that the individual plant species also differ in their resistance to damage and ability to recolonize. *P. heimii* and *B. argenteum* differ markedly in their morphological response to overwinter freeze drying. *B. argenteum* sheets appear to have no firm contact to the substrate and can curl up extensively at the edges. In contrast *P.heimii* hummocks remain an integral part of the substrate, and show little or no lifting. It is no surprise then to discover that after damage, *P. heimii* can regrow from shoots immersed deeply in the underlying substrate. *B.argenteum*, however shows no ability to do this and relies it seems, on waterborne, deciduous shoot tips to enter new areas.

Wind and water dispersal of vegetative fragments are probably the most important factors for plants on the Canada Glacier bryophyte flushes. These processes, together with faster water flow, would amply explain the more 'active' nature of some areas of the flush.

It is noted however, that part of the reason the flush exists is due to the sheltered aspect which in turn reduces wind dispersal. As sporophyte production is sporadic in polar regions most bryophytes rely exclusively on asexual reproduction. Longton (1988) suggests the majority of bryophytes in the more severe polar regions produce neither spores or specialised asexual propagules. These plants are more likely to be dependent on gametophyte branching, fragmentation and regeneration for local dispersal and establishment, development and maintenance of colonies. *P. heimii* recovers by regrowth from deep shoots. The evidence suggests that growth is limited by exposure at the sand surface and that shelter is needed for any rapid growth. The overall growth rate of *P. heimii* may even be limited by the rate of arrival of fine sediment by wind or water.

Evidence has been presented as to the unpredictability of water flow from season to season in the Dry Valley area, which may affect propagule dispersal or the photosynthetic activity of the plants during the summer months. Even if the plants do manage to disperse to damaged areas there is likely to be an extensive period of time before these areas recover completely due to the low productive rates of these plants. As decomposition is slow in these communities a relatively high phytomass does not necessarily imply comparable levels of production and 100 g $m^{-2}$ has been proposed as a realistic annual production for *B. argenteum* turfs on Ross Island (Longton 1974). In contrast Ino (1983) predicted mean annual production for *B. argenteum* turfs of only 4 g $m^{-2}$ in *B. pseudotriquetrum* turfs near Syowa Station with negative values as low as -16 g $m^{-2}$ during years when meterological data suggested that respiration exceeded gross photosynthesis. Production rates of epilithic biomass in Dry Valley streams may be very low. Howard-Williams and Vincent (1986), report that in many cases the biomass observed in mid summer is of the same order of magnitude, or less than that of the over wintering stock. The production values presented for Antarctic bryophytes are comparable to figures presented for arctic zones. Wiegolaski (1975) states that generally annual primary production increases from polar to temperate regions but the variation between plant communities in each zone is great. Bryophyte production of greater than 200 g $m^{-2}$/year have been noted for hummocky sites in the southern arctic tundra at Devon Island in Canada (Pakarinen and Vitt 1973) and an annual bryophyte production of 250-1000 g $m^{-2}$ is reported from the sub and maritime Antarctic (Clark et al.1971, Collins 1973).

The relatively low production rates mean that the ability of these bryophytes to recover from damage is not high and depends to a great extent on the variation in climatic factors from year to year.

Kallio and Kärenlampi (1975) note that in the evaluation of growth rates of mosses and lichens in high latitude and high altitude ecosystems one should consider the rate of functioning of the ecosystem in which they play the role of primary producers. A higher growth rate would necessitate a higher decomposition rate or consumption rate (where applicable). So although rates of photosynthesis and reproduction are low by temperate standards they are in good balance with other rates of functioning of their ecosystems.

**VIII:IV Invertebrates**

Despite the harshness of conditions in the Dry Valleys the invertebrates listed from the Canada Glacier lower flush represent most major groups recorded as being present on continental Antarctica (Laws 1984). Notable for their absence are collembolans which have been collected from the north facing slopes of the Taylor Valley. The absence of collembolans at the Canada Glacier flush was also noted by Greenfield and Wilson (1981).

The two sites where collembolans are noted in this report (Southern face, Taylor Valley and Granite Harbour) are both north facing areas which as a result, receive a greater average amount of solar radiation per annum. This may be sufficient to create a more favourable microclimate for cllembolans over a longer part of the summer than on the eastern side of the Canada Glacier.

While Platyhelminthes are noted at the Canada Glacier they were not included in Laws' (1984) compilation of terrestrial invertebrates, although turbellarians were mentioned as making up part of the aquatic invertebrate fauna of Moss Lake, Signy Island. Dougherty and Harris (1963) emphasized that while nearly all samples of wet algal felt they examined contained populations of rotifers, nematodes and tardigrades, the occurrence of micro-turbellarians was inconsistent.

Mites were collected from the Lake Fryxell area in 1972 (Strandtmann et al.1973), in 1980/81 (Greenfield and Wilson 1981) and in 1984/85 (Block 1985). The first collection site was adjacent to the Canada Glacier on the Lake Fryxell side. Strandtmann (pers. comm.) has found mites to be present in some areas but to be completely absent at others that appeared identical and a similar phenomenon was observed in the present study. More detailed examination of mites would give more of an insight into their distribution in this area.

The invertebrate species list obtained for the Granite Harbour region differs from that for the Fryxell area in that there were no turbellarians recorded (although the cursory nature of investigation here would not have picked them up if they were present). However abundant collembolans were seen and these insects appeared to be grazing the surface of the mosses. Broady (1979a), in a study of collembolans on Signy Island found no evidence that they feed on living bryophyte tissue but that there was a preference for dead and decaying bryophyte material.

Both pre-melt and post-melt rotifer densities calculated for the Fryxell flush are comparable with densities published for the maritime Antarctic (Table 8.2 ). Nematode and tardigrade densities calculated are within the range of values presented in Table 8.2.

My results show a tendency for animals to inhabit the upper zones of the mosses once free water is available on the flush. Jennings (1979) found that 70% of tardigrades occurred in the upper 3cm of mosses on Signy Island. Caldwell (1981) showed the majority of nematodes in the upper 1cm of moss. Broady (1979b) notes the presence of most algae in a restricted region of 0-6mm down the bryophyte shoots on Signy Island and studies indicate that the surface 1-1.5 cm of the moss turf is the zone where virtually all of the primary production of mosses and algae occurs (Usher and Booth 1984). Broady (1979a) suggests that *Habrotrocha* sp. and tardigrades may graze on this algae.

**Table 8.2:** Published records of invertebrate abundance. ($\times 10^3$)

| **Plant type** | **Rotifers** | **Nematodes** | **Tardigrades** | **Reference** |
|---|---|---|---|---|
| moss carpet | | | 11 | |
| *Prasiola* | | | 14130 | Jennings (1976) |
| algal mat | 426 | 49.6 | | Suren (1989) |
| moss | | 1200 | | Tilbrook (1967) |
| | 28 - 931 | | | Block (1985) |

Williams (1987) terms natural bodies of water which experience a recurrent dry phase of varying duration as temporary water bodies. Cyclical temporary water bodies, then, select for species which are adapted to these conditions. Survival of an organism, under these conditions, depends on effective emigration and immigration abilities or on exceptional physiological tolerance (Williams 1987). Antarctic species due to their general isolation and the presence of uniformly harsh conditions tend to rely on the latter. Many lifecycle 'strategies' have developed among the inhabitants of ephemeral waterbodies to enable them to exploit the resources of these environments.

Experiments on the cooling of desiccated tardigrades, rotifers and nematodes have led to the definition of 'anabiosis' (suspension of life) in these groups (Block 1982). This anabiosis can manifest itself as different survival 'strategies' between invertebrate groups.

Williams(1987) lists some of these strategies. Rotifers survive as dehydrated individuals and some bdelloids secrete protective cysts. The most abundant rotifers in the bryophyte flushes are bdelloids. Rotifers which inhabit mosses must necessarily be forms that can survive drying, and for the most part be creeping species owing to the lack of room for swimming. Bdelloids have the ability to pass into a state of anabiosis when dried and to remain in this condition for years. During this latent life they can stand extremes of temperature even lower than -200 degrees celsius. Upon being moistened again they resume activity and are directly ready to deposit eggs. *Habrotrocha* sp. secrete shells which defend them against too rapid drying (Donner 1966).

The parthogenetic reproduction of bdelloid rotifers enables a rapid increase in population. Rotifer activity begins very early in the season as soon as free water is available (Everitt 1981). While no quantitative records were kept of the difference in number between bdelloids and monogonont rotifers during the 1989 study, it was noted that the monogononts were more prevalent in samples taken later in the season. Everitt (1981) suggests they complete their life cycle during summer with the resistant resting egg (the product of the sexual phase) as the overwintering stage.

Nematodes survive the winter as eggs, larvae or cysts (Williams 1987). All of the three wetter zones at the Fryxell flush had significantly higher numbers of nematodes than the drier zones in pre-melt counts. The same pattern can be seen in post-melt counts. Previous studies at Signy Island indicated that nematodes were more numerous in wetter mosses (Tilbrook

1967), however Spaull (1973) showed that while this is true there is no direct correlation between water content of mosses and total numbers of nematodes. My results would indicate a similar conclusion.

There was very little increase in tardigrade numbers between the pre-melt and post-melt samples during this study. This may be explained by tardigrade life history tactics leading to a relatively slow development rate. In order to survive desiccation and freezing tardigrades incorporate a resistant 'tun' stage in their life cycle. When tardigrades enter this stage (reducing their surface area by assuming a short barrel shape) they are able to withstand a wide range of physical and chemical stress (Barnes 1968). Everitt (1981) indicates there is a rise in total numbers of *Hypsibius* (which has a high fecundity) during the summer in an algal mat in Deep Lake Tarn. Other tardigrade species may only have 2-6 eggs/ female compared to the 30 of *Hypsibius* and Everitt (1981) notes it took from November to February for tardigrades to reach full size. *Macrobiotus* sp. was studied at Mossel Lake (Pickard 1986). There was no sudden increase in 1st instars at any time and there was no summer peak in density as new generations emerged.

In the Mossel Lake area, it seems that all instars and the egg stage develop when free water is available and stop when the moss dries out. Experimental results indicated that *Macrobiotus* normally require at least two years to develop and possibly live for several years as an adult (Pickard 1986).

The life histories of nematodes and tardigrades mean that numbers do not increase dramatically early in the summer season. Rotifers with rapid parthogenetic reproduction have the capacity for rapid population increase as soon as free water arrives on the flush. Mites may persist as larvae over winter continuing their life cycle with the onset of favourable conditions (Williams 1987).

## VIII:V Conclusions

My study has outlined the extent of two major areas of bryophyte growth in the Taylor Valley. A description of these communities with regard to cover estimates, species distribution and associations has been outlined. Comment has been made on the importance of environmental conditions in determining these factors. The invertebrate groups inhabiting the plants have been enumerated and initial observations of their correlation with plants on the flushes made.

The area of bryophytes at S.S.S.I. No. 12 are an important community in that they have attained relatively high biomass figures in a particularly harsh environment, and they provide niches for representatives of most invertebrate groups found on the continent. This area also provides us with an accessible site where it is possible to monitor rates of recovery from damage. The general fragility of the plant communities forming flush vegetation in the Dry Valleys is confirmed. Although recovery processes do occur it is clear that many decades, or even centuries, will be needed to finally repair the existing damage.

It is interesting to note the significant differences in fauna and especially the flora between the Taylor Valley and Granite Harbour sites. The Granite Harbour site provides a useful comparison of the effect of microclimate on these polar communities, and is an example of the increased diversity that can be achieved given a slightly less harsh environment.

It is by increasing, and accurately evaluating our knowledge of the dynamics of these ecosystems, that we can implement management strategies which are suited to the environment, and the likely pressures which will be imposed upon it in the future.

# Appendix

## EXTREME SOUTHERN LOCATIONS FOR MOSS SPOROPHYTES IN ANTARCTICA

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## ABSTRACT

Abundant immature sporophytes of the moss *Pottia heimii* are reported from the Lower Taylor Valley, McMurdo Dry Valleys and from Cape Chocolate, both near Ross Island. These finds extend the reported southern limit for the occurrence of abundant moss sporophytes to 77°55's..

## KEYWORDS

Bryophyte, Moss, McMurdo Dry Valleys, Sporophytes.

# INTRODUCTION

Mosses represent a significant component of the terrestrial flora in continental Antarctica. Plants have been reported as far south as 84°42'S (Wise & Gressitt 1965) but there is a sharp decline in species number from around 90 species in the maritime Antarctic, about 12 species at 68°S (main Antarctic coastline) to 4 species in the McMurdo Dry Valley (Seppelt 1984). There is a similar decline, with increasing latitude, in the reported occurrence of fruiting mosses. Capsules can be commonly found in the Antarctic Peninsula, although reported in less than 25% of the moss species (Longton 1988) but are much rarer in continental Antarctica. Seppelt (1984) gave only three records from the latter region: *Bryum algens (= B. pseudotriquetrum)* from Fold Island (Filson & Willis 1975); *Pottia heimii* from Syowa Station (Nakanishi, 1977; Kanda 1981); and *Grimmia trichophylla* from the Bunger Hills (Australasian Antarctic Expedition 1912). Young, immature sporophytes of *B. antarcticum* (now reidentified as *P. heimii*) had previously been reported once at both Cape Bernacchi (77°28.9'S) and Marble Point (77°25.8'S) (Greene *et al.* 1967). More recently there have been reports of fruiting in *Pottia austro georgia, Bryum pseudotriquetrum* and *Bryum amblyodon* from Syowa Station (Kanda 1981); *Bryum pseudotriquetrum* from the Stillwell Hills, near Fold Island, and Vestfold Hills (Seppelt, unpublished data).

Only two of the records come from areas south of the main Antarctic coastline at around 68°S. This paucity may well result from an increase in environmental severity (lower mean summer temperatures, lower free water availability and shorter growing season) with increase in latitude. It must also reflect a lack of suitable growth sites, the North Victoria Land coastline representing one of the few, almost continuous ice-free areas that reach farther south from 68°S. We report here the finding of numerous *Pottia heimii* sporophytes at two locations in the McMurdo Dry Valleys near Ross Island (Fig. 1).

## Cape Chocolate/Hobbs Glacier

This location, visited briefly in December 1976 by a Victoria University expedition, was on the coast between Cape Chocolate and the delta of the Hobb's Glacier melt stream; 77°55'S, 164°32'E. The fertile mosses, all *Pottia heimii*, showed relatively luxuriant growth in loose gravel wetted by melt water from Hobb's Glacier. Sporophytes were found at several sites and capsule expansion was noted in some cases with setae up to 8-10 mm in length. No microclimate data are available for the Cape Chocolate/Hobb's Glacier area but it can be expected to be milder than most of the Dry Valleys. The site is coastal but sea ice is present almost continuously in most years so that maritime influences are not strong. The aspect is predominantly southerly and there is considerable protection from the strong westerly winds by mountains up to 1600 m high. A west to east ridge above 600 m high lies to the north and provides protection from cold air flow down Blue Glacier. These features could be expected to provide a much milder microclimate than at Marble Point and Cape Bernacchi, about 50 km further north.

**Canada Glacier flush**

The flush lies at 77°37'S, 163°33'E in the Lower Taylor Valley, McMurdo Dry Valleys and occupies a small area of about 0.5 hectare adjacent to the eastern edge of the Canada Glacier. Moss growth appears to have been encouraged by local microclimate at the flush site. The presence of the adjacent 30m ice face of the Canada Glacier to the west protects the flush from both the easterly and westerly winds (up and down the Taylor Valley respectively). The mosses are therefore not subjected to abrasion by wind-borne dust nor are they blown away in their freeze-dried condition over the winter. The glacier also provides a regular water supply, in December and January, which flows across a gentle slope with little risk of scouring. The flush is believed, from field surveys made in the region, to be the largest, high-density area of moss in the McMurdo Dry Valleys.

Over the 1989/90 Austral summer detailed mapping of the flush was carried out to determine the interactions between the two dominant mosses, *Bryum argenteum* and *P. heimii*, and the rarer *B. pseudotriquetrum*. A general plan of the flush is shown in Fig. 2A. There is a relatively simple pattern of a central, predominantly cyanobacterial zone, dominated by a *Nostoc* sp. (Broady 1982) along the lines of main water flow, then a *B. argenteum* zone and an outer *P. heimii* zone (Fig. 2B). Overall, *B. argenteum* occupies wetter sites and is not found in the drier margins where only salt-encrusted *P. heimii* occurs. Immature sporophytes of *P. heimii* were initially found on the upper, western part of the flush, but, after an exhaustive search, a total of 40 sites were confirmed. (Fig. 2A). At each site one to several (but less than ten) many sporophytes were found, generally 3 to 6mm in length and were of normal, healthy colour except for occasional white, dead specimens. The capsules had not expanded.

Detailed mapping was carried out to further define the locations in which sporophytes occurred. Two typical microtopographic profiles are given in Figs. 3A and 3B. These demonstrate that throughout the flush sporophytes occurred only in well protected, ephemerally wet but not saturated, locations. Shelter was the dominant factor since many large areas of *P. heimii* receive adequate water but sporophytes occurred only adjacent to rocks or in hollows. A warmer, more humid environment would be expected at these locations because of the lower wind speed.

## DISCUSSION

These discoveries have extended the southernmost records of sporophyte occurrence to 77°37'S and 77°55'S. The latter is the most southerly fruiting location reported for a moss. The microtopographic studies strongly support the belief that harsh environmental conditions, low temperatures, wind, minimal free water availability, and the short growing season limit sporophyte production. A careful search of protected microsites of the type described here in moss areas along the Ross Sea coast will probably yield additional records of fruiting mosses, particularly of *P. heimii*.

Broady, P.A. 1982 Taxonomy and ecology of algae in a freshwater stream in Taylor Valley, Victoria Land, Antarctica. *Arch. Hydrobiol. Suppl. 63.3, Algalogical Stud.* 32, 331-349.

Filson, R.B. & Willis, J.H. 1975 A fruiting occurrence of *Bryum algens* Card. in East Antarctica. *Muelleria* 3(2), 112-116.

Greene, S.W., Gressitt, J.L., Koob, D., Llano, G.A., Rudolph, E.D., Singer, R., Steere, W.C. & Ugolini, F.C. 1967 Terrestrial Life of Antarctica. *In*: Antarctic Map Folio Series - Folio 5.

Kanda, H. 1981 Two mosses of the genus *Pottia* collected from the vicinity of Syowa Station, East Antarctica. *Antarctic Record,* 71, 96-108.

Kanda, H. 1987 Handbook of Antarctic Mosses. National Institute of Polar Research, Tokyo. 83pp (in Japanese).

Nakanishi, S. 1977 Ecological studies of the moss and lichen communities in the ice-free areas near Syowa Station, Antarctica. *Antarctic Record,* 59, 68-06.

Seppelt, R.D. 1984 The bryoflora of the Vestfold Hills and Ingrid Christensen Coast, Antarctica. ANARE Research Notes, 20.

Wise, K.A. & Gressitt, J.L. 1965 Far southern animals and plants. *Nature,* 207, 101-102.

## FIGURE CAPTIONS:

Fig. 1

Known sites for sporophytes in the Ross Desert region; open symbols, Green *et al.* (1967); closed symbols, this study.

Fig. 2 Bryophyte/Algal flush adjacent to Canada Glacier;

A: distribution of plants and lines of main water flow. Closed circles indicate points at which sporophytes were found.

B: Distribution of *Pottia heimii* (>5% cover); major algal cover occurs along the lines of main water flow (2A) and *Bryum argenteum* occupies sites between pure algae and *P. heimii* with variable cover of epiphytic algae.

Fig. 3 Microtopographic profiles at two sporophyte locations on the Canada Glacier flush. Positions of sporophytes are shown indicated by arrows; horizontal and vertical intervals are centimetres.

A: extremely protected site under edge of rock;

B: sporophytes adjacent to rock face; position of sporophytes approximates the melt water flood level indicated by the clearly marked algal line on rock.

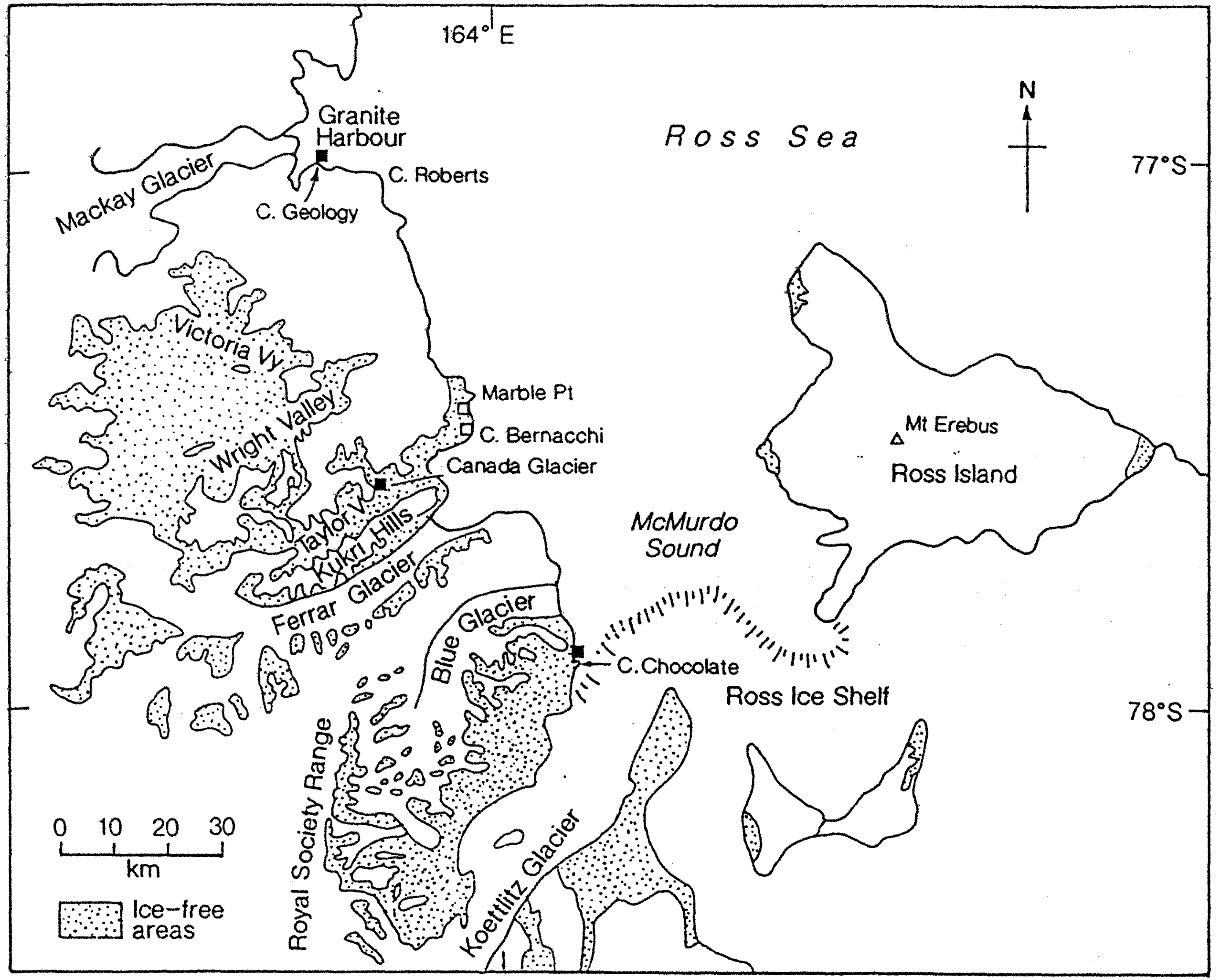

164° E
Ross Sea
N
77°S
78°S
Granite Harbour
C. Roberts
C. Geology
Mackay Glacier
Victoria Vy
Wright Valley
Marble Pt
C. Bernacchi
Canada Glacier
Taylor V.
Kukri Hills
Ferrar Glacier
Blue Glacier
C. Chocolate
McMurdo Sound
Mt Erebus
Ross Island
Ross Ice Shelf
Royal Society Range
Koettlitz Glacier
0 10 20 30
km
Ice-free areas

Fig. 1

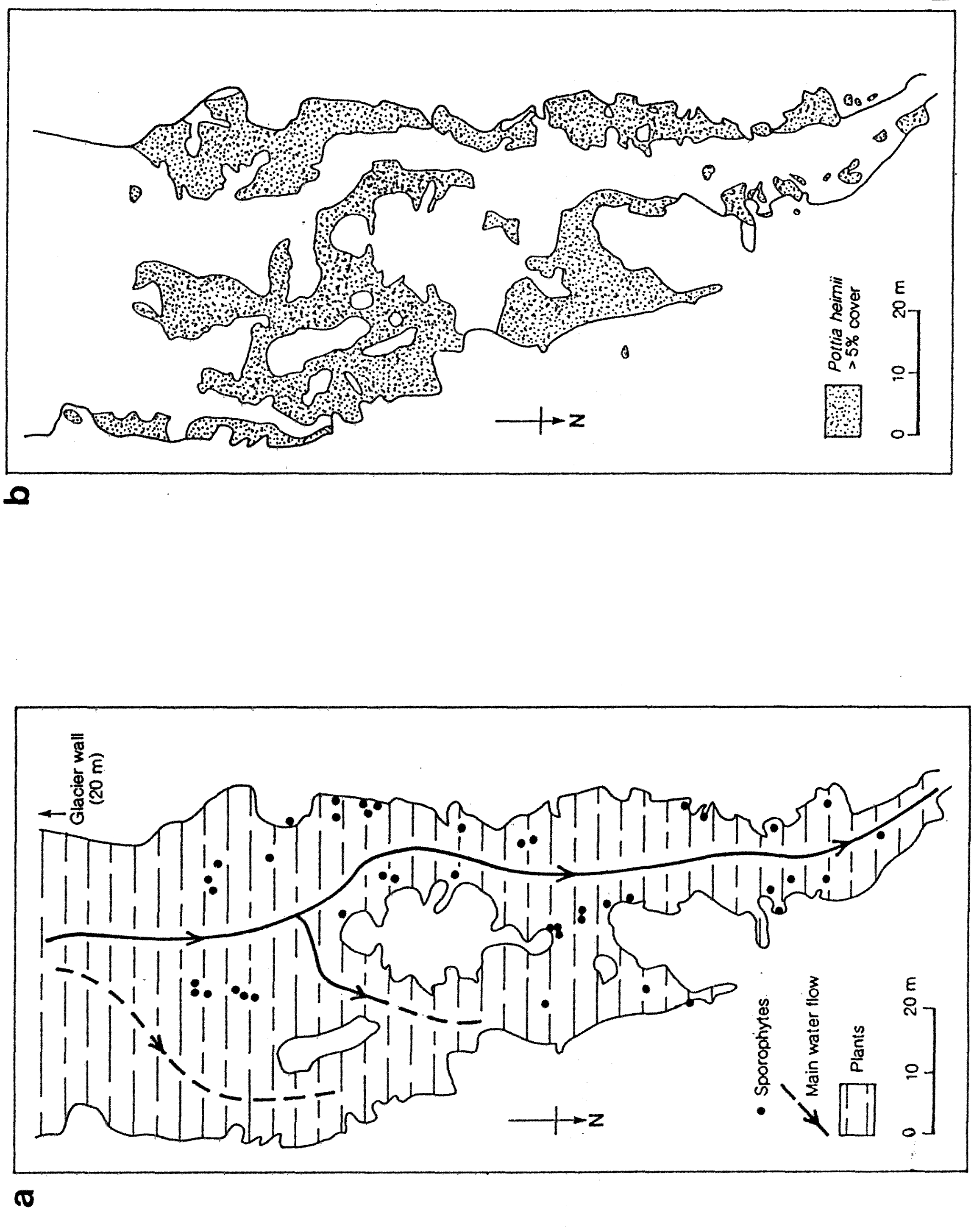
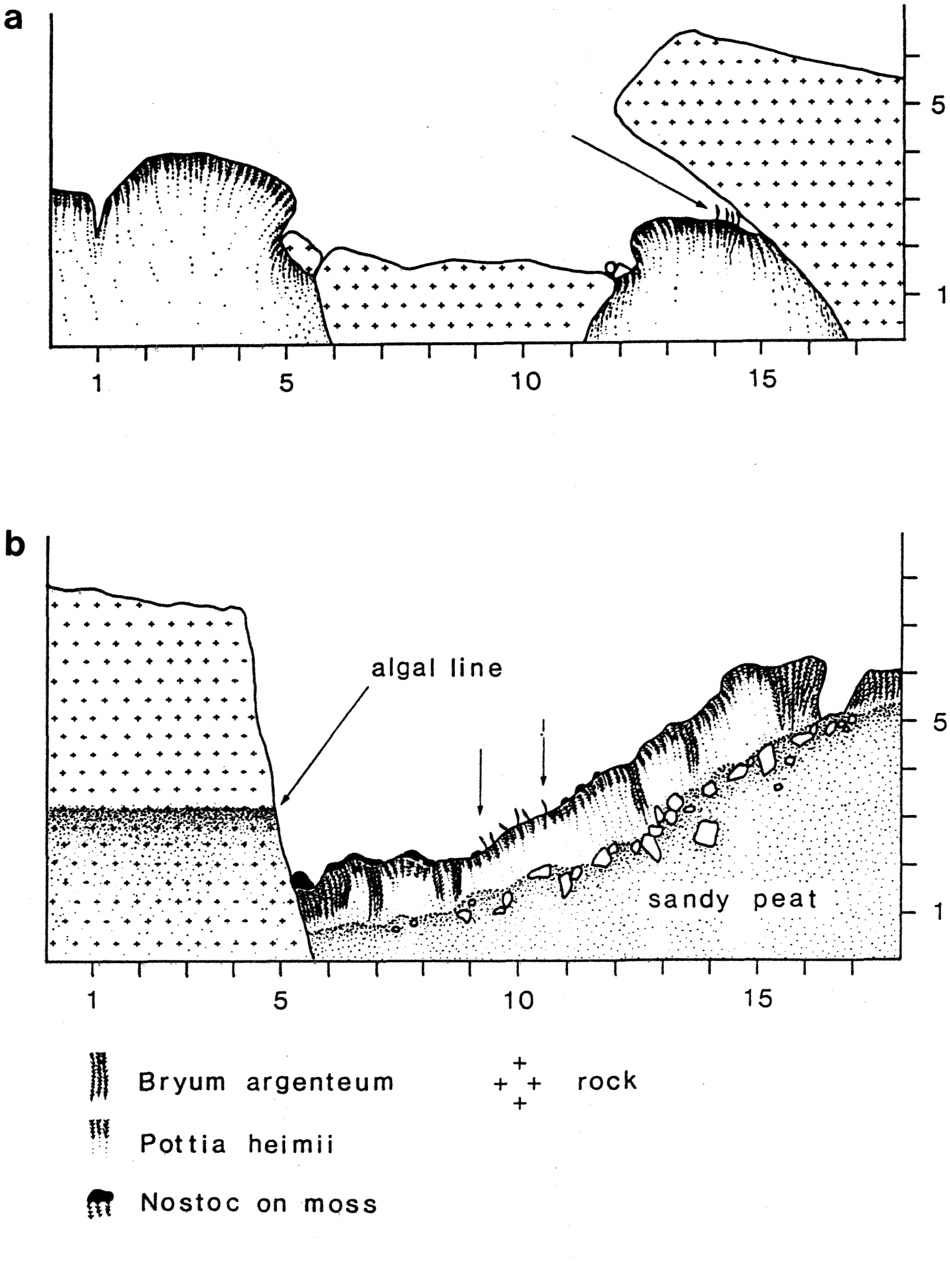

a
Glacier wall
(20 m)
N
Sporophytes
Main water flow
Plants
0 10 20 m
b
N
Pottia heimii
> 5% cover
0 10 20 m

Fig.2

Fig.3


a
5
1
1
5
10
15
b
algal line
sandy peat
5
1
1
5
10
15
Bryum argenteum
Pottia heimii
Nostoc on moss
rock

## BIBLIOGRAPHY

**Barnes R D (1968)** *Invertebrate Zoology* 2nd Edition W B Saunder & Co.

**Block W (1982)** Cold hardiness in invertebrate poikilotherms. *Comp. Biochem. Physiol.* Vol 73A No. 4 , 581-593.

**Block W (1985)** Arthropod Interactions in an Antarctic Terrestrial community. In *Antarctic Nutrient Cycles and Food webs* (ed.Siegfried W R Condy P R and Laws R M) Springer - Verlag.

**Booth R G and Usher M B (1984)** Arthropod communities in a maritime Antarctic moss-turf habitat: Effects of the physical and chemical environment. *Journal of Animal Ecology* 53 , 879-893.

**Broady P A (1979a)** Feeding studies on the collembolan *Cryptopygus antarcticus* Willem. at Signy Island South Orkney Islands. *British Antarctic Survey Bulletin* No.48 , 37-46.

**Broady P A (1979b)** The Signy Island Terrestrial Reference Sites:ix The Ecology of the algae of site 2, A moss carpet. *British Antarctic Survey Bulletin* No. 47 , 13-29.

**Broady P A (1981)** Non Marine Algae of Cape Bird,Ross Island and Taylor Valley,Victoria Land ,Antarctica. *M.U.P.A.S. report* No.37.

**Broady P A (1984)** Taxanomic and Ecological Investigations of algae on steam warmed soil on Mt. Erebus, Ross Island, Antarctica. *Phycologia* Vol. 23 (3), 257-271.

**Broady P Given D Greenfield L Thompson K (1987a)** The Biota and Biology of fumeroles on Mt. Melbourne, Northern Victoria *Polar Biology* 7: 97-113.

**Broady P A Greenfield L G Kibblewhite A (1987b)** Ecological and Taxonomic Studies of Antarctic Plants and Microbes. 1986-87 *N.Z.A.R.P. Report* No.1 Immediate Scientific Report.

**Byrd R E (1947)** Our Navy explores Antarctica. *National Geographic Magazine* 92: 429-522.

**Caldwell J R (1981)** The Signy Island Terrestrial Reference Sites:xiii. Population dynamics of the nematode fauna. *British Antarctic Survey Bulletin* No.54.

**Campbell I B and Claridge G G C (1987)** *Antarctica : Soils, weathering processes and environment. Elsevier.*

**Chapin F S iii Johnson D A McKendrick J D (1980)** Seasonal Movement of Nutrients in Plants of Differing Growth Form in an Alaskan Tundra Ecosystem: Implications for Herbivory. *Journal of Ecology* 68, 189 - 209.

**Chinn T J (1983)** Hydrology and Glaciology Dry Valleys, Antarctica. Annual Report for 1976-77 and 1977-78. *N.Z. Ministry of Works and Development report* WS 531, 49p.

**Chinn T J and Cumming R J (1983)** Hydrology and Glaciology Dry Valleys, Antarctica. Annual Report for 1978-79. *N.Z. Ministry of Works and Development Report* WS 810, 137p.

**Chinn T J (1986)** Structure and equilibrium of the Dry Valley Glaciers. *N.Z. Antarctic Record* 6.

**Chinn T J and Oliver A K (1983)** Hydrology and Glaciology Dry Valleys, Antarctica. Annual Report for 1979-80 *N.Z. Ministry of Works and Development Report* WS 808, 49p.

**Clarke G C S Greene S W Greene D M (1971)** Productivity of bryophytes in polar regions. *Ann.Bot.* 35, 99-108.

**Clow G D McKay P Simmons Jr. G M Wharton Jr. R A (1988)** Climatological Observations and Predicted Sublimation Rates at Lake Hoare, Antarctica. *Journal of Climate* Vol 1 No.7 July.

**Clymo R S (1970)** The growth of *Sphagnum*: Methods of measurement. *Journal of Ecology* 58, 13-49.

**Collins N J (1973)** The productivity of selected bryophyte communities in the maritime Antarctic. In *Primary Production and Production Proccesses, Tundra Biome,* eds. L C Bliss and F E Wiegolaski, pp37-46. Edmonton and Oslo, IBP Tundra Biome Steering Comittee.

**Conover W J (1980)** *Non parametric Statistics.* Wiley (publishers)

**Dartnall H J G and Hollowday E D (1985)** Antarctic Rotifers. *British Antarctic Survey Scientific Reports* No. 100.

**Dastych H (1984)** The Tardigrada from Antarctica with descriptions of several new species. *Acta. Zool.* Cracov. 27 19. 377 - 436.

**Donner J (1966)** *Rotifers.* Fredrick Warne and Co. Ltd.

**Dougherty C C and Harris L G (1963)** Antarctic micrometazoa, Freshwater species in the McMurdo Sound area. *Science* New York 140 No.3566, 497-8.

**Downes M T Howard-Williams C Vincent W F (1986)** Sources of organic Nitrogen, Phosphorus and Carbon in Antarctic Streams. *Hydrobiologia* 134, 215-225.

**Edmondson W T (1966)** (ed) *Freshwater Biology* 2nd Edition. John Wiley and Sons Inc.

**Everitt D A (1981)** An Ecological Study of an Antarctic Freshwater pool with particular reference to Tardigrada and Rotifera. *Hydrobiologia* 83 , 225-237.

**Friedmann E I (1982)** Endolithic micro-organisms in the Antarctic cold-desert. *Science* Vol 215, 1045-1053.

**Friedmann E I and Ocampo - Friedmann R (1984)** *The Antarctic cryptoendolithic Ecosystem: Relevance to Exobiology.* D Reidel publishing company.

**Given D (1988)** *Botany Division Report.* Review of D.S.I.R. Antarctic Science, Statement on the work and role of Botany Division D.S.I.R.

**Green T G A (1986)** Dry Valley Terrestrial Plant Communities. The Problem of Production and Growth. N.Z. Antarctic Record 6.

**Green W J Gardner T J Ferdelman T G Angle M P Varner L C Nixon P (1989)** Geochemical Processes in the Lake Fryxell Basin (Victoria Land, Antarctica) *Hydrobiologia* 172 ,129 - 148, in High Latitude Limnology, Developments in Hydrobiology 49 (eds) W F Vincent and J C Ellis-Evans.

**Greene S W Gressitt J L Koob D Llano G A Rudolph E D Singer R Steere W C Ugoloni F C (1967).** Terrestrial Life of Antarctica. *Antarctic map folio series* folio five.

**Greenfield L.G. and Wilson G.J. (1981)** *Report: University of Canterbury Antarctic Research Unit* Expedition 19.

**Gressitt J L (1967)**(Ed) Entymology of Antarctica *Antarctic Research Series* Vol. 10. American Geophysical Union.

**Holdgate M W (1970).** *Antarctic Ecology* Volume 2 Academic Press.

**Howard-Williams C and Vincent W F (1986)** Ecosystem Properties of Antarctic Streams *N.Z. Antarctic Record* 6 (supplement), 21-27.

**Howard-Williams C Vincent C L Broady P A Vincent W F (1986)** Antarctic Stream Ecosystems. Variability in Environmental Properties and algal community structure.
*Int. rev. ges. Hydrobiologia* 71: 511-544.

**Howard-Williams C and Vincent W (1989)** Microbial Communities in Southern Victoria Land Streams (Antarctica) 1.Photosynthesis *Hydrobiologia* 172:27-38 W F Vincent and J C Ellis-Evans (eds) High Latitude Limnology.

**Howard-Williams C Priscu J Vincent W (1989)** Nitrogen Dynamics in two Antarctic Streams *Hydrobiologia* 172:51-61 In *High Latitude Limnology* eds. W F Vincent and J C Ellis-Evans.

**Ino Y (1983)** Estimation of primary production in moss community on East Ongul Island, Antarctica. *Antarctic Record* 80, 30-8.

**Jennings P G (1979)** The Signy Is. Terrestrial Reference sites :X. Population dynamics of the Tardigrada and Rotifera.
*British Antarctic Survey Bulletin* No. 47.

**Kallio P and Kärenlampi L (1975)** Photosynthesis in mosses and lichens in: *Photosynthesis and Productivity in different environments.* (ed)J P Cooper I.B.P.

**Kanda H (1981)** Two moss species of the genus *Pottia* collected from the vicinity of Syowa Station, East Antarctica. *Nankyoku Shiro Antarctic Record.* 71, 96-108.

**Kappen L (1985)** Vegetation and Ecology of Ice Free areas of Northern Victoria Land, Antarctica I: The lichen Vegetation of Birthday Ridge and an Inland mountain. *Polar Biology* 4 , 312-25.

**Kershaw K A (1964)** *Quantitative and Dynamic Ecology.* Edward Arnold (publishers) Ltd.

**Laws R M (1984).** *Antarctic Ecology Volume 1* Academic Press.

**Longton R E (1974)** Microclimate and Biomass in communities of the *Bryum* association on Ross Island, Continental Antarctica.
*Bryologist* 77, 109-27.

**Longton R E (1988)** *Biology of Polar Bryophytes and Lichens.* Studies in Polar Research Cambridge University Press.

**McInnes S J and Ellis-Evans J C (1987)** Tardigrades from maritime Antarctic Fresh water Lakes In: Bertolani R (ed) : *Biology of tardigrades. Selected Symposia and Monographs. U.Z.I.* 1 Mucchi Modena ,111-123.

**McInnes S J and Ellis-Evans J C (1988)** Micro invertebrate community structure within a maritime Antarctic Lake. Presented as a poster at SCAR conference on Antarctic Biology, Hobart Aug-Sept 1988

**Miller J D Horne P A Heatwole H Miller W R and Bridges L (1988)** A survey of the terrestrial tardigrada of the Vestfold Hills Antarctica. *Hydrobiologia* 165:197-208.

**Murray J (ed) (1929)** *The Voyage of the 'Discovery' R F Scott*. London.

*New Zealand Antarctic Operations Manual* **(1989)** N.Z. Antarctic research Programme, Antarctic Division D.S.I.R.

**Ohtani S and Kanda H (1987)** Epiphytic Algae on the moss community of *Grimmia lawiana* around Syowa Station, Antarctica. *Proc. NIPR Symp. Polar Biology* 1, 255-264.

**Pakarinen P and Vitt D H (1973)** Primary production of plant communities of the Truelove Lowland, Devon Island, Canada. Moss communities. In *Primary Production and Production Proccesses, Tundra Biome,* eds L C Bliss and F E Weigolaski pp 37-46 Edmonton and Oslo IBP Tundra Biome Steering Committee.

**Pickard J (1986)** *Antarctic Oasis Terrestrial Environments and History of the Vestfold Hills.* Academic Press.

**Pyne A (1984)** Victoria University of Wellington. *Antarctic Expedition 28 1983-1984 Immediate Report.*

**Quartermain L B (1967)** *South to the Pole.* The Early History of the Ross Sea Sector Antarctica Oxford University Press

**Report on the joint IUCN/SCAR working group on long term conservation in Antarctica (1986).**

**Russell S (1984)** Growth measurements in bryophytes: a case study. *Journal of the Hattori Botanical Laboratory* 56: 147-157.

**Ryan P G and Watkins B P (1989)** The influence of Physical factors and Ornithogenic products on Plant and Arthropod Abundance at an Inland Nunatak group in Antarctica. Polar Biology 10: 151-160.

**Savours A (1966)** (ed) *Edward Wilson, Diary of the Discovery Expedition to the Antarctic Regions 1901-1904.* Blanford Press London.

**Seppelt R D (1983)** The status of the Antarctic moss *Bryum korotkevicziae* *Lindbergia* 9: 21-26.

**Seppelt R D (1984)** The Bryoflora of the Vestfold Hills and Ingrid Christensen Coast, Antarctica *ANARE Research Notes* 20.

**Seppelt R D and Ashton D H (1978)** Studies on the Ecology of the Vegetation at Mawson Station Antarctica. *Australian Journal of Ecology* 3: 373-388.

**Seppelt R D and Kanda H (1986)** Morphological Variation and Taxonomic Interpretation in the moss genus *Bryum* in Antarctica. *Memoirs of the National Institute of Polar Research Series E. Biology and Medical Science* No.37 National Institute of Polar Research Tokyo Japan.

**Seppelt R D Green T G A Schwarz A-M J Frost A (1990)** Extreme southern locations for moss sporophytesin Antarctica. *Antarctic Biology.*

**Snedecor G W and Cochran (1967)** *Statistical Methods* (sixth edition) The Iowa State University Press.

**Spaull V W (1973)** Distribution of soil Nematodes in the maritime Antarctic. *British Antarctic Survey Bulletin* No.37.

**Strandtmann R W et al. George J E (1973)** Distribution of the Antarctic mite *Stereotydeus mollis* Wormersley and Strandtmann in Southern Victoria Land. Antarctic Journal of the United States July-August 8(4), 209-211

**Suren A (1989)** Microfauna associated with algal mats in melt ponds on the Ross Ice Shelf *Polar Biology.*

**Thompson K T (1980)** Plant Growth in Antarctic Desert Ecosystems. Antarctic Research Unit. *University of Waikato Report* No.9.

**Tilbrook P J (1967)** The terrestrial Invertebrate Fauna of the Maritime Antarctic In Smith J E (organiser) A Discussion on the Terrestrial Antarctic Ecosystem *Phil.Trans. R. Soc* Ser. B 252 No. 777 , 261-78.

**Timm R W. (1971)** Antarctic Soil and Freshwater Nematodes from the McMurdo Sound Region. *Proceedings of the Helminthological Society* of Washington Vol 38 No.1

**Ugolini (1977)** The Protoranker soils and the Evolution of an ecosystem at Kar Plateau Antarctica. In Llano. *SCAR symposium.*

**Usher M B and Booth R G (1984)** Arthropod Communities in a Maritime Antarctic moss-turf Habitat: Three dimensional Distribution of Mites and Collembola. *Journal of Animal Ecology* 53, 427-441.

**Usher M B and Booth R G (1986)** Arthropod Communities in a Maritime Antarctic moss-turf habitat: Multiple Scales of Pattern in the Mites and Collembola. *Journal of Animal Ecology* 55 , 155-170.

**Vincent W F (1988)** *Microbial Ecosystems of Antarctica.* Studies in Polar Research Cambridge University Press.

**Vincent W and Howard-Williams C (1986).** Antarctic stream ecosystems Physiological Ecology of a blue-green algal epilithion *Freshwater Biology* 16.

**Wharton D A and Brown I M (1989)** A survey of terrestrial nematodes from the McMurdo Sound Region, Antarctica. *New Zealand Journal of Zoology* Vol 16 467-470.

**Wiegolski F E (1975)** Primary Production of Tundra In: *Photosynthesis and productivity in different Environments* (ed) J P Cooper I.B.P.

**Williams D D (1987)** *The Ecology of Temporary Waters* Timber Press Portland.

**Wise K A J and Gressitt J L (1965)** Far Southern Animals and plants. *Nature*(london) No. 4992