Terrestrial invertebrate abundance across a habitat transect in Keble Valley, Ross Island, Antarctica

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Summary

The abundance and distribution of soil invertebrates was examined along a transect in Keble Valley, Cape Bird, Ross Island, Antarctica during and after snowmelt. During snowmelt, streams were flowing across the transect, and the moisture environment was highly heterogeneous, whereas after the cessation of stream flow the moisture environment became more homogeneous. Of the seven groups of invertebrates examined, only the prostigmatid mite *Stereotydeus mollis* showed any redistribution between the two sampling points. The streams had higher water availability, higher soil chlorophyll-a content, higher organic content and lower surface salinity than the areas beside the streams. Nematode (*Panagrolaimus davidi*), soil rotifer and soil protozoan abundance was significantly associated with this area of high productivity, and the cryptostigmatid mites *S. mollis* and *Nanorchestes antarcticus* were found near the stream centres. By contrast, the collembolan *Gomphiocephalus hodgsoni* was found at riparian margins, and it is hypothesised that this could be due to habitat and food preferences.

Key words: Antarctic, Collembola, Acari, nematode, water, soil

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Introduction

At high latitudes, Antarctic terrestrial environments are cold, dry and have low primary productivity and biodiversity (Spain 1971; Vincent 1997; Virginia & Wall 1999; Beyer et al. 2000). In the McMurdo Sound region, Collembola and mites are the only free-living terrestrial arthropods, and the number of nematode and rotifer species is in single figures (Spain 1971; Wharton & Brown 1989; Treonis et al. 1999). In these environments, the influence of abiotic factors like temperature and water stress is considered to be so important that ecological interactions (competition and predation) at higher trophic levels are assumed to be negligible (Block 1994).

Investigations of terrestrial invertebrate ecology have had three main foci in the McMurdo Sound region: the high productivity areas on the coast of the continent (eg: Wise & Spain 1967; Janetschek 1967; Davidson & Broady 1996); the Dry Valleys (eg: Schwarz et al. 1993; Treonis et al. 1999) and the coastal ice-free areas of Ross Island (Smith 1970; Peterson 1971; Duncan 1979; Block 1985). Arthropod abundance in the Dry Valleys is very low, and so most terrestrial work has been microbial (eg: Friedmann et al. 1993) or nematological (eg: Virginia & Wall 1999) in nature. Contrarily, on Ross Island, particularly at Cape Bird, the majority of research has been on the hypogastrurid collembolan *Gomphiocephalus hodgsoni* (Smith 1970; Peterson 1971; Duncan 1979; Block 1985).

This study was conducted in Keble Valley, Cape Bird, where previous researchers had also focussed their research (Smith 1970; Peterson 1971; Duncan 1979; Block 1985). In addition to *G. hodgsoni*, the prostigmatid mites *Nanorchestes antarcticus* and *Stereotydeus mollis* are also found in soil in the valley, as well as bdelloid rotifers, tardigrades, the nematodes *Panagrolaimus davidi* and *Plectus sp.* and ciliate and flagellate protozoa (Block 1985; Wharton & Brown 1989; B. Sinclair, unpublished data). *Gomphiocephalus hodgsoni* and *S. mollis* often aggregate on the undersides of surface stones, although both are found in the soil as well (Smith 1970; Duncan 1979).

The presence of both soil arthropods and microfauna at Cape Bird provides an excellent opportunity to investigate their distribution on a small scale, in this case across a small snowbank meltwater stream. At this latitude, water may provide more severe limits on life than temperature (Kennedy 1993). We describe the general patterns of invertebrate distribution in an area of high productivity on Ross Island, and also compare conditions between the period of snowmelt (when water is biologically available) and after the water sources have dried up. This is of interest because few studies in this region have repeated their sampling to reflect the changing environmental conditions over the course of the growing season; and knowledge of changing conditions and their effect on distribution are necessary to provide a framework for studies of invertebrate distribution and environmental physiology.

Materials and Methods

Study site and transect

The Cape Bird ice-free area is at the northern tip of Ross Island, Antarctica (77°13'S, 166°26'E). 'Keble Valley' is a small (2 Ha) drainage basin with small quantities (c. 8 m^2) of moss and terrestrial algae around the edges of the stream and freshwater algae in the stream it-

self. It is situated within the Caughley Beach SSSI No. 10 (Anonymous 2000) southeast of the Antarctica New Zealand Cape Bird research hut. The 'soil' in Keble Valley consists of silt, coarse sand and fine gravel of volcanic and glacial origin, with an abundance of stones at the surface as a result of cryoturbation and wind ablation. Salt encrustations are common on the surface soil, a consequence of the low precipitation at this latitude (Spain 1971). Because of the fragile nature of the habitat, sampling was kept to a minimum, closed cell foam mats were used to protect the surface of the ground, small (c. 10–30 g) soil samples were taken, and no sampling of the moss or algal vegetation was conducted. The valley has a small, low gradient stream flowing roughly east-west through it that is fed by a large snowbank on the terminal moraine at the eastern end of the valley. After snowmelt on the valley floor, this large snowbank is the only source of water for the stream. The snowbank usually persists until the beginning of January after which the soils dry out considerably.

A 24 m transect was laid across the upper end of the valley, c. 1 m uphill of the positions of K067 enclosure plots Cl2 and Li3 (Antarctica New Zealand Environmental Database Record K067 99/00). The centres of the two streams were at 5m and 17m on the transect. Samples were taken at 1m intervals, except for 2.5 m on either side of the centre of the stream, where samples were taken at 0.5 m intervals to improve resolution in the biologically productive riparian margins. Sampling was conducted on 27 November 1999, about 2 weeks after the beginning of snowmelt (ice and snow were still lying on the ground in some places, but the streams had begun flowing), and 26 January 2000, about 2 weeks after the streams had stopped flowing.

Sampling

At each sampling point on the transect, the presence of macroscopic vegetation was noted, and a small surface scraping of soil taken for determination of surface salinity. Mite and springtail distribution in Keble Valley is extremely patchy, and abundance is not strongly related to rock size (B. J. Sinclair unpublished data). Microarthropod abundance on the underside of stones was determined non-destructively at each sampling point. The undersides of ten stones with diameter of 2–10 cm within a 25 cm radius were examined and Collembola and mite (*S. mollis* since *N. antarcticus* is rarely able to be seen with the naked eye) abundances graded as none, few (<10 individuals) or many (≥10 individuals). A soil sample to a depth of approximately 2 cm was taken with a spoon and placed in a plastic bag. A second, adjacent sample was taken and placed in a small weighed plastic jar for water content determination. In January, a third sample was taken and frozen for chlorophyll-a and organic content determination in New Zealand.

Invertebrate extraction from soil

Soil samples for invertebrate extraction were returned to the Cape Bird Hut, weighed and floated in c. 100 ml water for extraction of microarthropods. The slurry was then placed into weighed tissue paper in a 10 cm diameter Baermann apparatus, covered with water and left for 14 h at room temperature (15–18 °C). The bottom 40 ml of water was removed from the funnel and centrifuged at a standard rate and time in a hand-operated centrifuge, the supernatant removed, and the bottom 6 ml placed in droplets on a petri dish and examined with substage lighting at ×40 on a dissecting microscope. Although not as efficient as some other methods (Freckman & Virginia 1993) the Baermann funnel technique (Wharton 1998; Freckman & Virginia 1993) was chosen because it has low technological requirements, and does not produce chemical wastes. Numbers of nematodes (*Panagrolaimus davidi* identified at ×400), rotifers, and tardigrades were recorded, as well as approximate numbers (when >100) of protozoa. Soil and tissue paper were dried to a constant weight at 60 °C and weighed to determine dry mass of soil.

Analysis of Soil

Soil returned to Cape Bird Hut was weighed before and after being dried for 24h at 60°C. Several samples were dried for longer periods, but no further mass loss was noted. Mass lost was assumed to be water from the soil.

Salinity of surface soil was determined indirectly by measuring the osmolality of a slurry. Small (c. 0.5 g) samples of surface soil were returned to New Zealand, mixed 3:1 (w/w) with distilled water, briefly centrifuged and the osmolality of a 10 μl subsample determined using a Wescor 5100c vapour-pressure Osmometer.

Frozen soil samples were returned to New Zealand, thawed, mixed and a 1–2 g subsample was taken. This sample was air-dried overnight at 2 °C, weighed and extracted overnight in 15 ml of acetone, and the chlorophyll-a content of the acetone determined fluorometrically including correction for phaeophyton content by acidification according to the general principles of Wetzel & Likens (1991) and the more specific methodology of Schallenberg & Burns (1997). The chlorophyll content was standardised to the air-dried soil mass. The remainder of the soil was weighed, dried at 70 °C for 24 h, and dry mass determined. It was then incinerated at 550 °C for 12 h to remove all organic content and reweighed.

Data Analysis

An index of arthropod abundance that took into account the strong levels of aggregation (up to 161 *G. hodgsoni* and 75 *S. mollis* on a single stone, B. J. Sinclair unpublished data), was calculated using the formula

$$AI = (0.1 * f) + m$$

where AI is the index of abundance for the arthropod species (between 0 and 10), f = number of rocks with few (<10) individuals of a species and m = number of rocks with many ($\geq$10) individuals of a species.

Soil fauna abundance was expressed as number of animals detected/kg dry soil. For the purposes of analysis, chlorophyll-α content was ln(x+1) transformed, while organic content was $\log_{10}$(x+1) transformed.

Paired-sample t-tests were used to compare November and January values for all parameters (Sokal & Rohlf 1981), and Pearson's correlation coefficients were calculated using SAS/STAT (SAS Institute Inc. Cary, NC, USA) for all combinations of variables measured in November and January (thus, chlorophyll-a and organic content comparions are only made for the January sample). Independence of occurrence of mites and springtails on individual rocks was tested from January data using log-likelihood (G) test of independence (Sokal & Rohlf 1981).

The relationships between soil invertebrates and January soil characteristics (water content, surface salinity, Chlorophyll-α and organic content) was examined using Canonical Correspondence Analysis (CCA, Palmer 1993; ter Braak & Smilauer 1998; Treonis et al. 1999). The significance of the first canonical axis was tested using Monte-Carlo permutations constrained for a line transect (ter Braak & Smilauer 1998).

Results

Water content of soil was significantly lower in January than in November when the stream was running (Fig. 1, t_{36}=8.59, p<0.001). Mite index was also lower in January than in November (t_{36}=2.43, p<0.05), but there were no significant differences between November and January values for abundance of other invertebrates or soil surface salinity (p>0.05 in all cases).
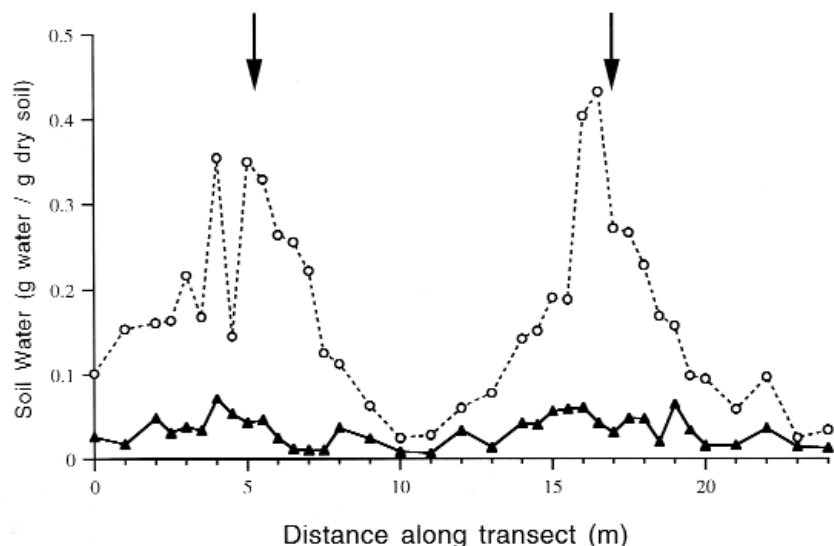
Fig. 1. Soil water content along a 24 m transect in Keble Valley, Ross Island, Antarctica in November 1999 (---○---, while streams are flowing) and January 2000 (—▲—, after stream flow had ceased). Arrows indicate the approximate centres of the two streams
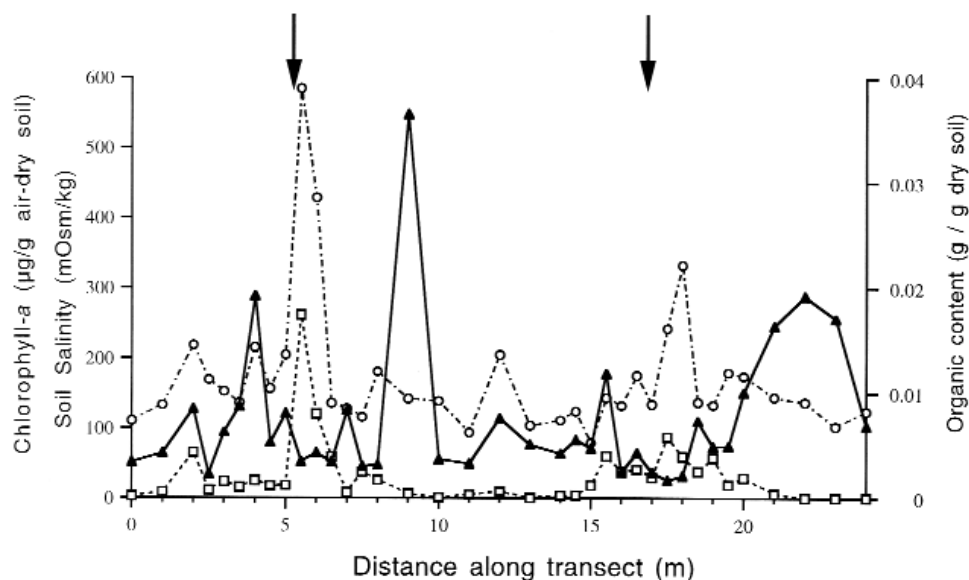

Fig. 2. Soil surface salinity (—▲—), chlorophyll-α content (---□---), and organic content (—·—·○—·—·) along a 24 m transect in Keble Valley, Ross Island, Antarctica in January 2000, when the streams were not flowing. Arrows indicate centres of stream beds

Chlorophyll-α and organic content were highest near the centres of the streams (Fig. 2), and negatively correlated with distance from the centre of the nearest stream (chlorophyll: r= -0.79, p<0.0001; organic: r= -0.46, p<0.005). Surface salinity was highest away from the stream, and negatively correlated to water content of the soil (r=-0.46, p=0.004) in November, but not in January (r= -0.03, p=0.87).

Macroscopic algae were found around the centres of the streams, whereas moss was distributed only sparsely on one of the riparian margins (Fig. 3). Nematodes and Protozoa were most abundant near the centre of the stream, particularly if moss was present; while *N. antarcticus* was fairly evenly distributed across the transect (Fig. 3). Mite index was highest near the centre of the stream, while collembolan index peaked at the riparian margins (Figs. 4, 5). Mite index in November and January was correlated to soil abundance of mites (November: r=0.38, p=0.02; January: r=0.55, p<0.001). While collembolan index was not correlated to soil collembolan abundance in either November or January (p>0.2 in each case), very similar patterns of distribution across the transect were observed (Fig. 4). Mite index was correlated to water content and chlorophyll-α in January (Table 1), but not in November (p>0.05). Changes in mite index between November and January were of both abundance and distribution pattern, with a distinct shift from riparian to mid-stream habitats between November and January (Fig. 5).
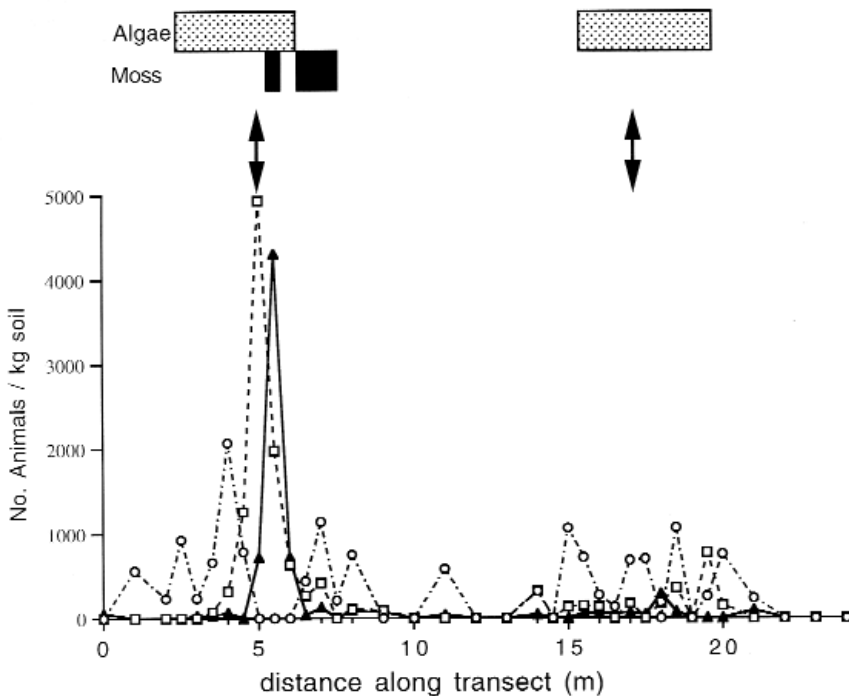
Fig. 3. Distribution of invertebrates and macroscopic vegetation along a 24 m transect in Keble Valley, Ross Island, Antarctica in January 2000. Abundance of soil nematodes (—▲—), Protozoa (---□---) and the mite *Nanorchestes antarcticus* (—·—·○—·—·). Presence of macroscopic algae (stippled bars) and moss (black bars). Arrows indicate centres of stream beds
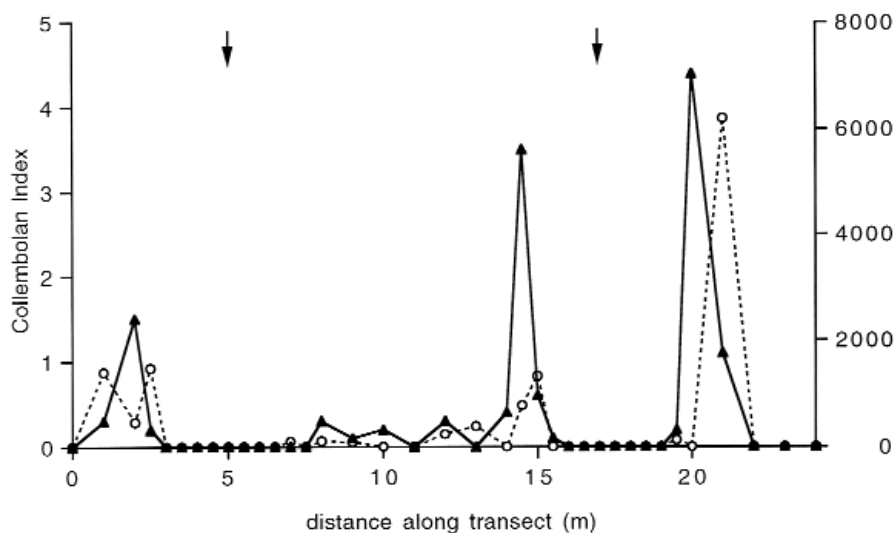
Fig. 4. Distribution of the collembolan *Gomphiocephalus hodgsoni* across a transect in Keble Valley, Cape Bird, Ross Island Antarctica in January 2000, as measured by an index from abundance on stones (—▲—) and from soil extraction (---◯---). Arrows indicate centres of stream beds
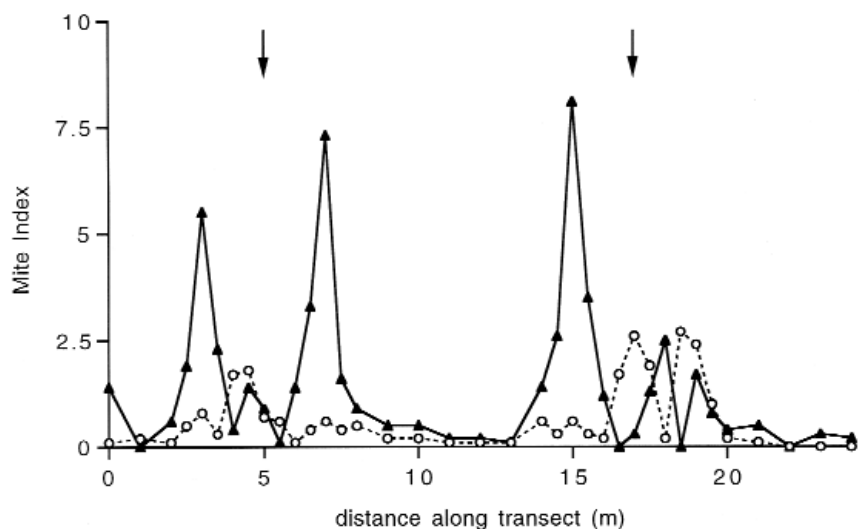
Fig. 5. Distribution of the mite *Stereotydeus mollis* across a transect in Keble Valley, Cape Bird, Ross Island, Antarctica, as measured by an index of abundance on stones during the period of snowmelt (November 1999, —▲—) and after cessation of stream flow (January 2000, ---◯---). Arrows indicate centres of stream beds

Table 1. Correlations between invertebrate abundance and physico-chemical aspects of soil across a transect in Keble Valley, Cape Bird, Ross Island, Antarctica in January 2000. + = positive correlation; *=P<0.05, **=p<0.01, ***=p<0.001; ns=no significant correlation (p>0.05). n=37 in all cases

	Soil Water (g/g dry soil)	Surface salinity (mOsm/kg)	ln (Chlorophyll-a+1)	log$_{10}$(Organic Content +1)
Springtail Index	ns	ns	ns	ns
Mite Index	+*	ns	+*	ns
Soil G. hodgsoni	ns	ns	ns	ns
Soil S. mollis	+**	ns	+*	ns
Soil N. antarcticus	ns	ns	ns	ns
Soil Nematodes	ns	ns	+*	+***
Soil Rotifers	ns	ns	ns	+**
Soil Tardigrades	ns	ns	ns	ns
Soil Protozoa	ns	ns	ns	+*

Of the soil-dwelling fauna, nematode (only *Panagrolaimus davidi* was detected) abundance was correlated to chlorophyll-a and organic content of the soil. Both protozoan and rotiferan abundance were correlated to organic content (Table 1).
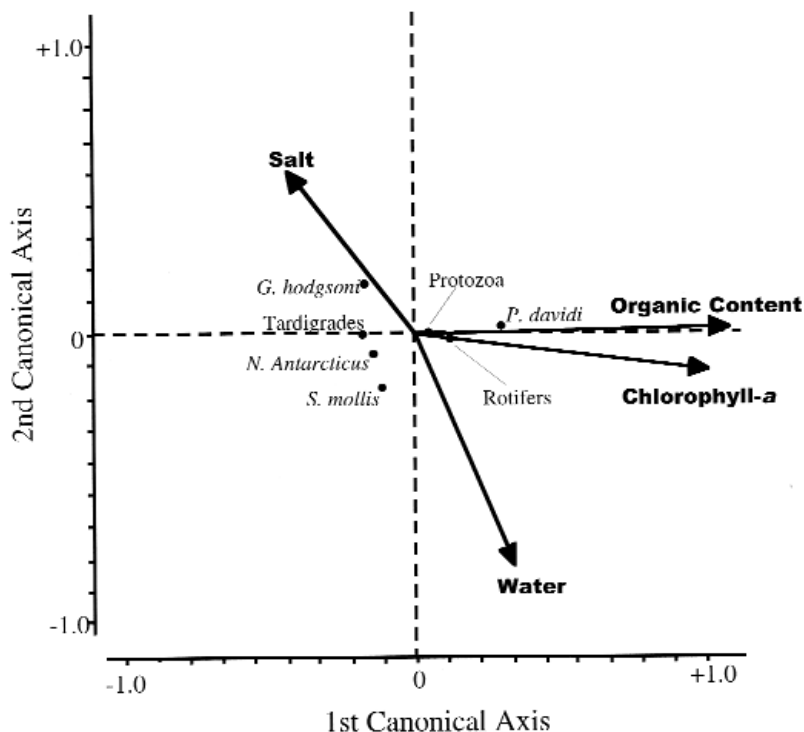
The environment-species biplot generated by CCA (Fig. 6) shows the relationship between the invertebrate community and the environmental variables. The 1st canonical axis explained 29.3 % of the variation among species (eigenvalue = 0.535, F-ratio = 11.525, p<0.01), while the first and second axes together explained 38.7 % of species variation. Figure 6 shows that the abundance of Protozoa, *P. davidi* and rotifers is correlated to organic and chlorophyll-α content of the soil, and that there is a negative relationship between those variables and tardigrade abundance. Mite and springtail abundance in the soil is negatively correlated to organic and chlorophyll-α content, but lies more along the water content – surface salinity axis.

Although there is apparent partitioning of habitats between mites and Collembola on the basis of indices (Figs. 4, 5), mite and springtail presence on rocks were significantly associated on an individual rock level (G=4.45, df=1, p<0.05). In January, there were strong correlations between abundance of nematodes and rotifers (r=0.69, p<0.0001), and nematodes and protozoa (r=0.46, p=0.004).

Discussion

During the period of snowmelt, the streams running perpendicular to the transect, resulted in a highly heterogeneous moisture environment (Fig. 1), which is probably the source of spatial variation in soil surface salinity. As the main source of water, the streams are also the driver of primary productivity in the valley. After the streams had stopped running, the moisture regime of the habitat became considerably more homogeneous, and this resulted in a redistribution of *S. mollis*, but not *G. hodgsoni*. The low water content January habitat is still adequate for *G. hodgsoni* and *S. mollis*, both of

Fig. 6. Species-environment biplot generated by Canonical Correspondence Analysis (CCA) on soil characteristics and invertebrate community data collected in January 2000 from a transect across Keble Valley, Ross Island, Antarctica. Arrows indicate direction and magnitude of environmental variable changes. Organic content (r=0.97, p<0.01) and chlorophyll-α content (r=0.90, p<0.01) are significantly correlated to the 1st Canonical axis, Water content (r=-0.73, p<0.01) is negatively correlated to the 2nd canonical axis. Soil surface salinity is negatively correlated to the 1st canonical axis (r=-0.40, p<0.01) and positively correlated to the 2nd Canonical axis (r=0.51, p<0.01). Thus, a positive direction on the 1st Canonical axis indicates increasing Organic and chlorophyll-α content of the soil, and decreasing soil surface salinity; while a positive direction on the 2nd Canonical axis represents decreasing soil moisture and increasing soil surface salinity. Points indicating the invertebrate community are the centroids for each species or group

which were observed to be active around the time the January transect was made. However, it is unclear whether the aquatic microfauna (nematodes, rotifers, tardigrades and protozoa) are active or quiescent once stream flow has stopped. The components of the microfauna are all resistant to desiccation (and probably anhydrobiotic, Gilbert 1974; Wright et al. 1992; Wharton & Barclay 1993), and it is possible that once the streams dry up they spend the winter in a desiccated state.

The distribution of mites and springtails in relation to the streams suggests considerably different habitat requirements: while the mites were present in some of the

wettest areas, where primary productivity was highest, collembolan abundance was highest at the riparian margins. Wise et al. (1964) found *G. hodgsoni* absent from habitats where soil moisture was greater than 12 %, and Peterson (1971) considered drowning a major source of mortality for *G. hodgsoni* at Cape Bird. The hydrophobic nature of *G. hodgsoni*'s cuticle makes 'drowning' *per se* unlikely, although a considerable number of individuals may be swept away by streams (Sinclair & Sjursen, unpublished data). Thus, the riparian margins may be the area closest to the centres of productivity where the risk of drowning or being swept away is minimised for *G. hodgsoni*. Davidson and Broady (1996) report that *G. hodgsoni*'s diet at Cape Geology does not seem to include macroscopic algae, although it is unclear whether this is a direct dietary preference or an indirect result of the selection of riparian microhabitats. The lack of redistribution of *G. hodgsoni* after the cessation of stream flow does not support hypotheses of habitat selection wholly on the basis of habitat water content, so dietary or habitat structure (the stream bed is considerably more silty than the riparian edges) may be the proximate cause of the observed distribution.

In contrast to *G. hodgsoni*, *S. mollis* (as measured by mite index) did show a redistribution between November and January. Even in November, *S. mollis* was closer to the centre of the stream than the majority of *G. hodgsoni*, but its absence from the centre is probably for the same reasons of avoiding being washed away. The redistribution following the cessation of stream flow could be due to broader food preferences, but also due to moisture requirements: algal cover and sediment mean the areas at the centre of the stream dry out more slowly than the riparian margins.

In January, after the streams have stopped flowing, water probably has a weaker environmental influence on invertebrate abundance, hence its apparently limited importance in the CCA (which was only performed on January data). However, chlorophyll-α and organic content are strong proxies for the moisture-mediated productivity of the flowing stream. The CCA biplot shows an interesting split between nematodes, rotifers and protozoa that are dependent on soil autotrophs (or microbial biomass associated with them), and the microarthropods, which are more correlated with the water-salinity axis, even in January. Tardigrades appear negatively correlated to productivity, but the number of tardigrades found was very low, so this may not be truly indicative of their ecology at this site. Overall, the relationships are very similar to those observed by Treonis et al. (1999) on transects across streams in the Dry Valleys.

There is little evidence of interactions between invertebrates from habitat selection along the transect. When abundance is considered, springtails and mites apparently occupy different habitats, but when this is reduced to presence/absence, it is found that springtails and mites are significantly associated on the same rocks. This suggests that mites and Collembola may share similar preferred habitats at the individual rock level, although the factors that make a rock 'good' are not apparent (Smith 1970). Nematodes, rotifers and Protozoa are all influenced by organic content of the soil, and any correlations between them are probably a result of an intersection between an appropriate (wet) microhabitat, and a suitable level of productivity and microbial activity.

This study shows that there are strong seasonal changes in water availability at a single site in Antarctica, and that some (but not all) terrestrial invertebrates may respond to these changes with changes in distribution. This has implications for soil biological studies in the McMurdo Sound region, which are often conducted over a re-

stricted time period that may not necessarily be the period of water availability (and hence growth and activity). Conclusions drawn from such studies about small-scale invertebrate distribution may not present the complete picture of the biology of the animals themselves.

Acknowledgements

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