THE SIGNY ISLAND TERRESTRIAL REFERENCE SITES: III. POPULATION ECOLOGY OF *Corythion dubium* (RHIZOPODA : TESTACIDA) IN SITE 1

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ABSTRACT. The numbers of the testate protozoan *Corythion dubium* Taranek in three horizons of the moss-turf peat of Signy Island reference site 1 were determined on 16 occasions over 15 months together with observations on the physical properties of the peat and the climatic environment of the site. Seasonal and short-term variations in population size are considered in relation to environmental factors. The activity of the population appears to be determined principally by the temperature and moisture content of the peat.

A SURVEY of the terrestrial Protozoa of Signy Island in 1968–69 showed that the testate amoeba *Corythion dubium* Taranek was a ubiquitous member of the faunas of moss peats and grass soil, and was more abundant than any other testate species. These results confirmed the previous observations of Heal (1965). A study of this species, to determine the seasonal variation in numbers of a population inhabiting moss-turf peat in relation to the environment, was initiated in January 1970 and ran until the end of March 1971. This paper describes the results of the study.

METHODS

The field site chosen for the study was Signy Island reference site 1 (Tilbrook, 1973). The protozoan fauna of this site has already been described (Smith, 1973).

On 16 occasions at approximately monthly intervals the following measurements were made on a random sample of six cores taken from the site for each of the three horizons: 0–3, 3–6 and 6–9 cm.: total numbers of Testacida (all species); numbers of *Corythion dubium*; mean peat pH; mean moisture (per cent dry weight); mean loss on ignition (per cent dry weight).

During the winter months (May–October 1970) the following data were obtained weekly: snow depths, read off six stakes; air temperature at 1·5 m.; moss surface temperature.

Early in November 1970, a thermograph station was established on the site, at an altitude of 48 m., to give a continuous record of temperature at 76 mm. above the moss surface. During the summer months (November 1970–March 1971) the following data were obtained three times weekly between 09.00 and 16.00 hr.: air temperature at 1·5 m.; air temperature at 76 mm.; moss surface temperature; peat temperature at depth 15 mm.; peat temperature at depth 45 mm.

Cores of peat were taken with a steel corer 2·5 cm. in diameter and cut into 3 cm. horizons with a sharp knife. The absolute weights of the fresh cores were determined. Testacida, alive at the time the cores were taken, were enumerated by the direct examination technique of Couteaux (1967). It proved impossible to differentiate encysted from active individuals and so this was not attempted. Empty tests of dead individuals were too fragmented to be recognized reliably so no count was made of these. Numbers per gram fresh weight were converted to numbers per square centimetre by a factor equal to three times the density of the core. Ten replicate counts were made allowing an estimate of variance due to method to be obtained; the resulting figures represent a mean value for the site, but provide no estimate of variance due to site. pHs were determined electrometrically; moisture by oven drying at 100° C for 48 hr.; loss on ignition by ashing in a muffle furnace at 450–500° C for 10 hr.

The continuous temperature record was made with a bimetallic thermograph housed in a white perforated box. Spot temperatures below the moss surface were obtained from inserted right-angled soil thermometers. Other spot temperatures were taken with a total immersion thermometer, shaded and read when steady. Throughout the study, records were kept of screen temperature, sunshine and wind speed at the meteorological station at Factory Cove, Signy Island.

Results

Mean numbers of *C. dubium* per cm.^{2}, mean pH, mean per cent moisture and mean per cent loss on ignition throughout the period of study are plotted for the three horizons in Figs. 1, 2 and 3. Errors for these means are calculated from replicate measurements; 95 per cent confidence limits are attached to each value on the plots. *C. dubium* was on all occasions the most numerous species; it constituted a proportion of the total testate fauna which varied between 32 $\pm$ 14 and 61 $\pm$ 5 per cent with a mean, for the 15 month period, of 43 $\pm$ 2 per cent.

The temperature regime of the site is plotted in Fig. 4. Temperatures are plotted as mean values for the periods between sampling occasions (of approximately 1 month). The values for 24 hr. are exact means calculated from continuous thermograph records. The values for 09.00–16.00 hr. are estimated means calculated from the thrice weekly thermometer readings; these are plotted with standard errors attached. Comparison of 77 temperature readings of the air at 1·5 m. at the site with the mercury-in-steel thermograph record of screen temperatures at Factory Cove revealed a mean difference between them of only 0·1° C which does not deviate significantly from zero (*t* test: $0\cdot4<P<0\cdot5$). Mean temperatures for month periods calculated from the Factory Cove thermograph record are therefore considered to be accurate for the site $\pm$ 0·1° C. Air temperatures are given for the whole period of the study and also for the previous 4 months in order to compare the summer of 1969–70 with that of 1970–71. The mean temperatures for the air at 76 mm. (24 hr. values) are calculated from the continuous bimetallic thermograph record *in situ*. The thermograph was subject to errors owing to heating of the screening box in sunlight; the trace was therefore corrected by the thermometer readings.

Other factors of the physical environment, for the same periods, are plotted in Fig. 5. The values for mean wind speed (index of convectional cooling) and mean sunshine per day (index of incident radiation) refer to Factory Cove and are only an approximate guide to conditions at the site. Values of mean snow cover refer to the site; owing to extremely uneven cover of the moss stands by snow, the variance about these means is high and they have standard errors of about $\pm$ 3 cm. This means that the deep snow cover during the months July to early September 1970 is significantly greater than that before June and after September; otherwise, the mean values for consecutive months are not significantly different. The data are thus more useful in a qualitative sense, denoting the presence or absence of snow.

Discussion

Vertical distribution

No consistent difference in the numbers of *C. dubium* between the three horizons is apparent. There is no evidence either of the sharp drop in numbers below the 0–3 cm. horizon shown by metazoan species in similar habitats (Tilbrook, 1967), or of the increase in numbers with depth shown by bacteria (Baker, 1970*b*).

Seasonal variation in numbers

There is marked variation in the numbers of *C. dubium* between winter and summer (Figs. 1, 2 and 3). In each horizon a dramatic increase in numbers occurs with the thawing of the peat during September–November 1970. This is probably correlated with peaks in the numbers of yeasts and bacteria which have been observed following a thaw in a similar moss-turf peat (Baker, 1970*a*). An increase in extractable phosphate, ammonium and sodium ions has also been shown to occur in peat at this time of year on Signy Island (Northover and Allen, 1967). This "spring bloom" in the testate population occurs later in the lower horizons as the thaw extends downwards. The thawing occurs while air temperatures are still sub-zero; presumably the heat for this comes from absorbed radiant energy. Numbers remain relatively high until the onset of freezing conditions during March–April.

Air temperatures at 1·5 m. (Fig. 4) show that the summer of 1970–71 was considerably milder than that of 1969–70. The period September 1970–March 1971 was consistently warmer by an average of 1·6° C than the same period the previous year. Given this difference between the years, it is possible that the high numbers of *C. dubium* in January 1970 represent a single mid-summer peak in a short cold summer (though the absence of population data

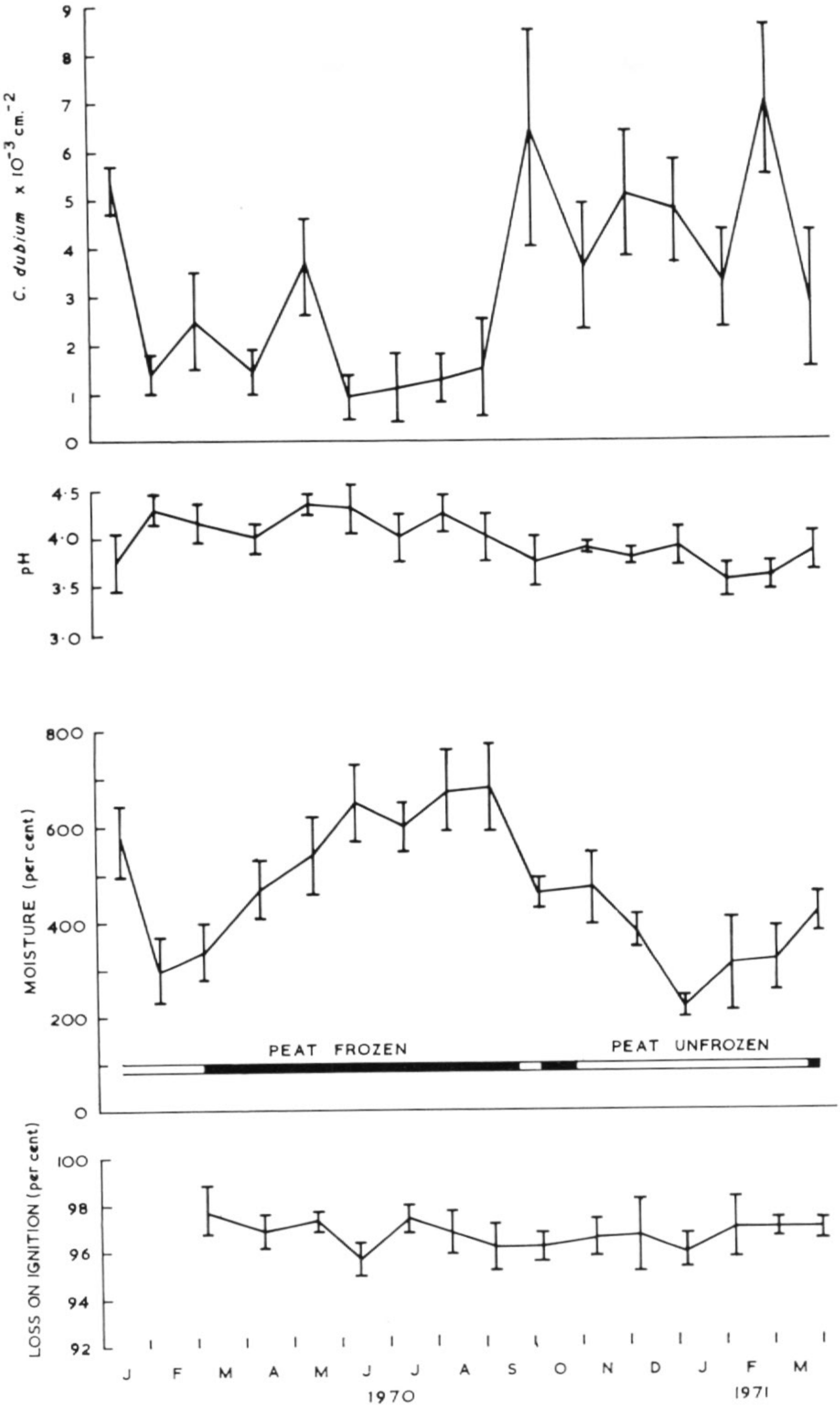

Fig. 1. Numbers of *C. dubium*, pH, percentage moisture and percentage loss on ignition, with 95 per cent confidence limits, at 0–3 cm.

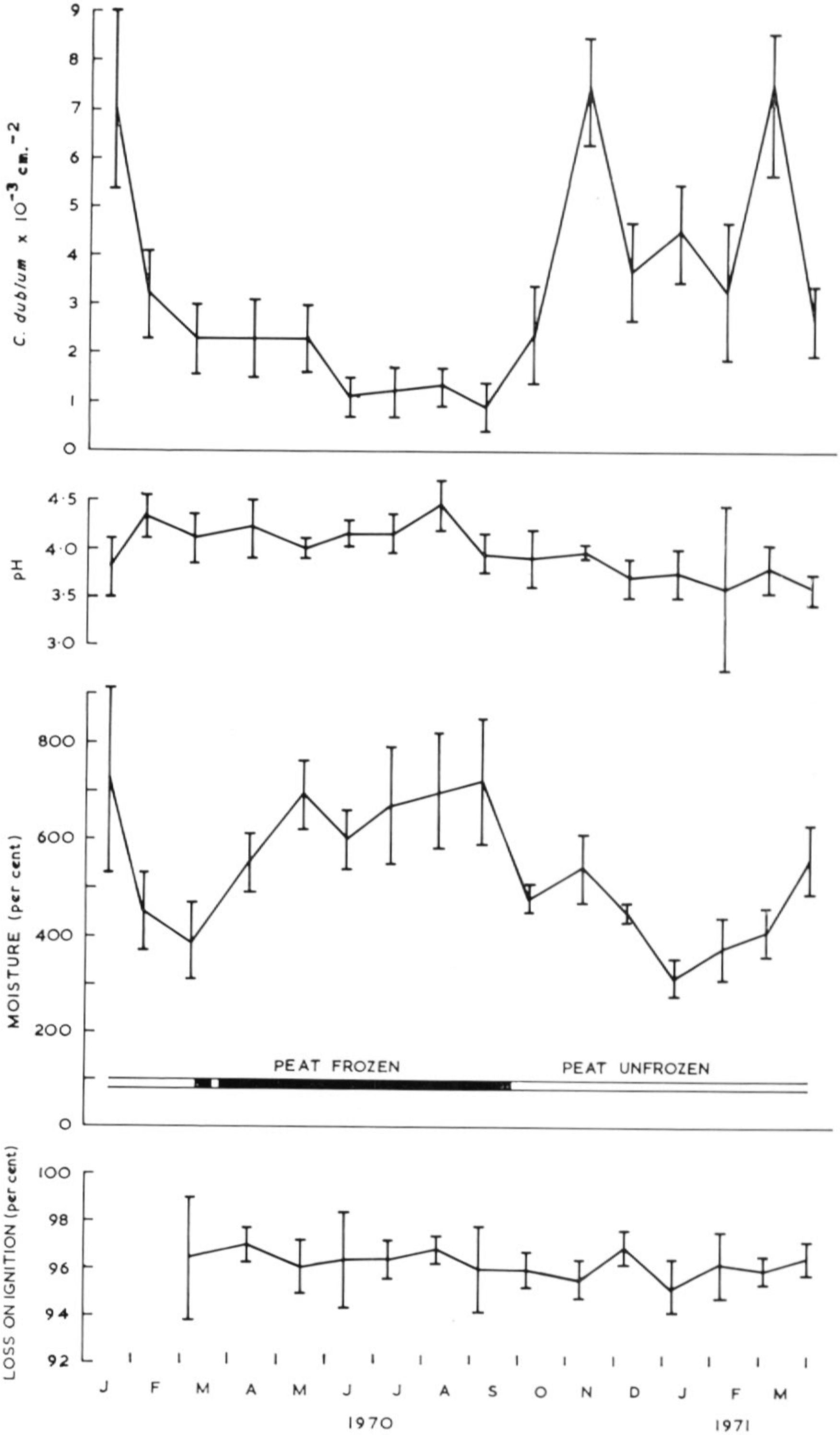

Fig. 2. Numbers of *C. dubium*, pH, percentage moisture and percentage loss on ignition, with 95 per cent confidence limits, at 3–6 cm.

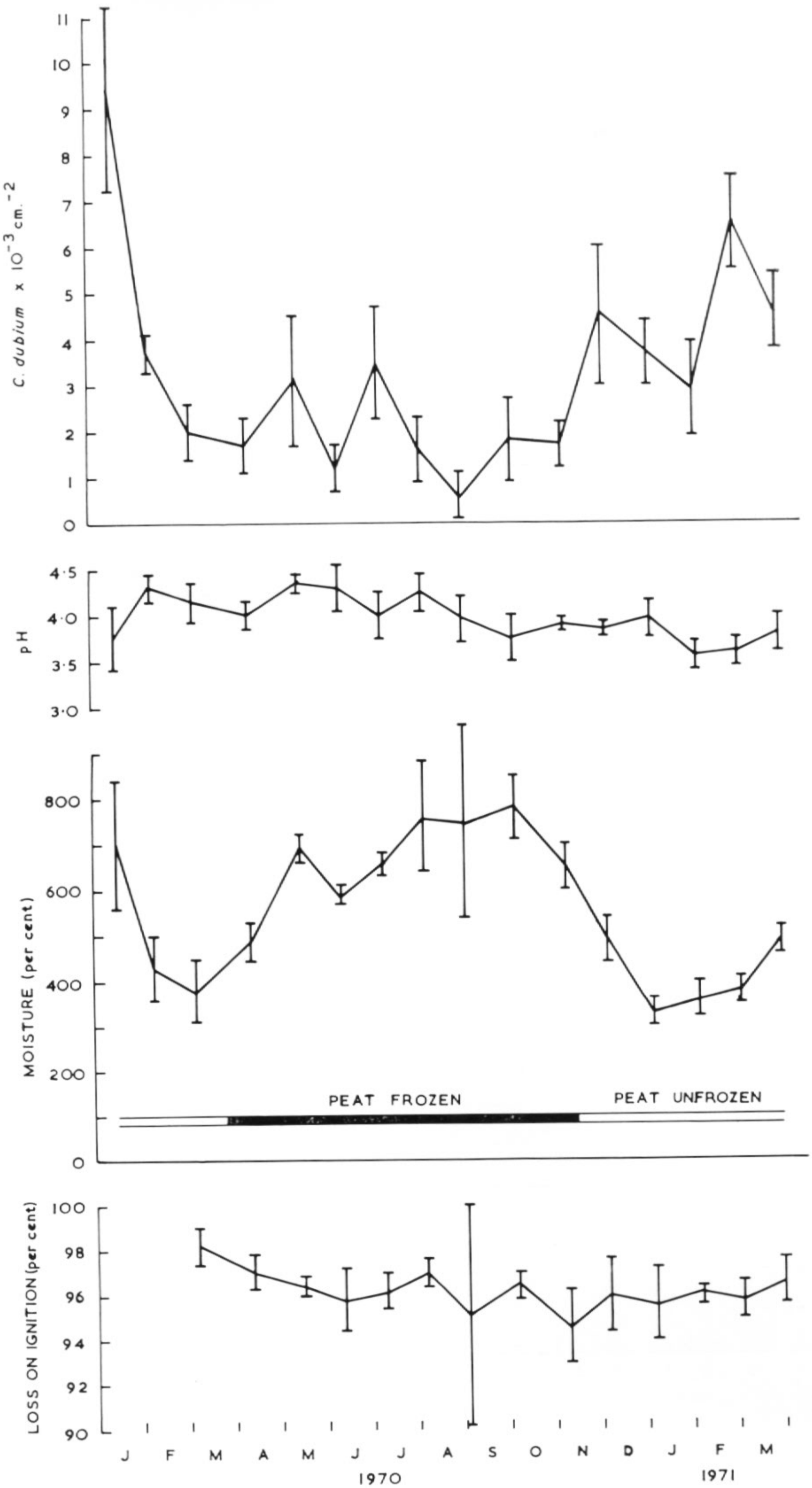

Fig. 3. Numbers of *C. dubium*, pH, percentage moisture and percentage loss on ignition, with 95 per cent confidence limits, at 6–9 cm.

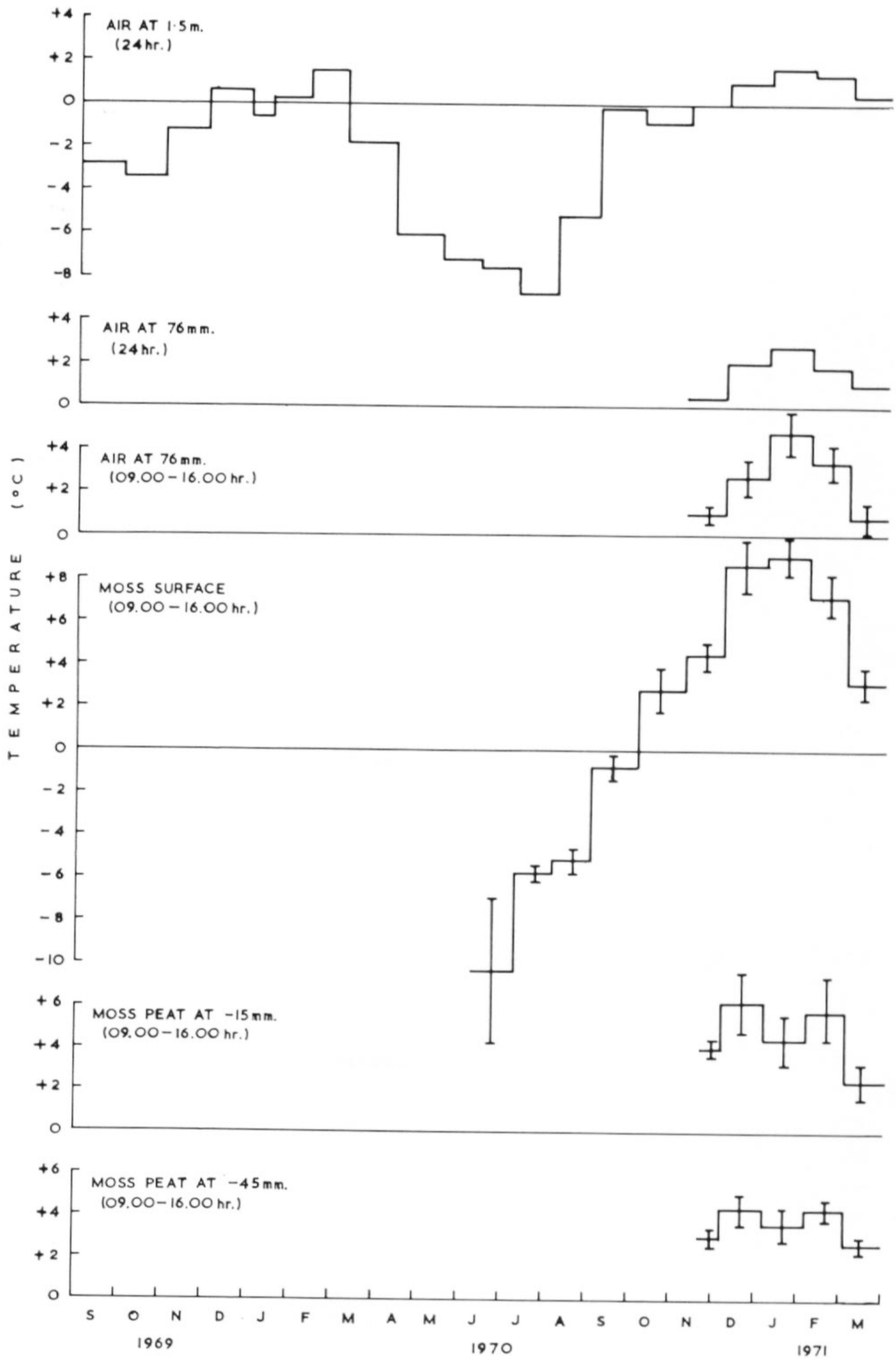

Fig. 4. Signy Island reference site temperature regime. Mean temperatures for periods between sampling occasions: air at 1·5 m. and 76 mm.; moss turf at surface, −15 mm. and −45 mm.

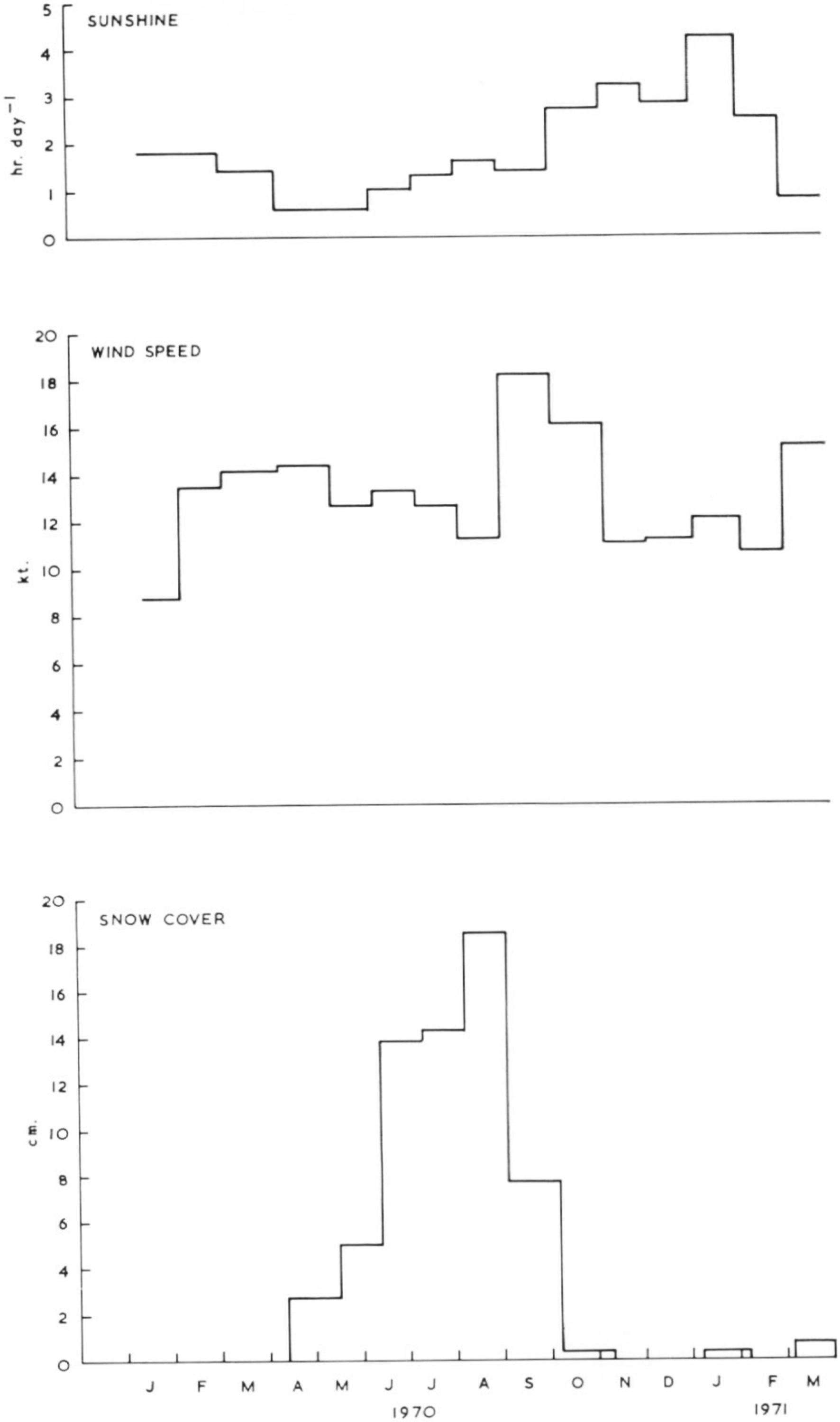

Fig. 5. Signy Island reference site climatic environment. Sunshine in hr. day^{-1} (index of incident radiation); wind speed in kt. (index of convectional cooling); mean depth of snow cover in centimetres.

for 1969 means that this cannot be proved), while the long mild summer of 1970–71 allowed an early spring peak and a late autumnal peak.

The pH and per cent loss on ignition of the peat show no significant seasonal variation. The per cent moisture of the peat shows a clear annual cycle, being considerably higher in winter than summer. The high values for the winter months refer to ice; it is the seasonal change of state rather than the quantitative change which is biologically significant on the seasonal scale.

Short-term variation in numbers

Whilst the numbers of *C. dubium* follow the annual cycles of temperature (directly) and per cent moisture (inversely) on the seasonal scale, there are no simple correlations between numbers and environmental factors on a month-to-month basis. The data therefore require more sophisticated scrutiny. The data plotted in Figs. 1, 2 and 3 refer to the standing crop of the *C. dubium* population at points in time; for an understanding of its ecology, rates of activity over periods of time are more useful. To aid interpretation, the data have been transformed, using the logistic equation:

$$r = \frac{\log_e N_t/N_o,}{T}$$

where N_o is number of *C. dubium* on a sampling occasion (at time 0); N_t is number of *C. dubium* on the next sampling occasion (at time t); T is time in days between consecutive sampling occasions (time t — time 0); r is the geometric rate of population growth or mortality; it constitutes an index of the net activity of the population (positive or negative) over the period of time T.

To obtain a measure of the activity of the *C. dubium* population relative to the total testate fauna, the following equation has been used:

$$d\%N = \left(\frac{N_t}{A_t} \times 100\right) - \left(\frac{N_o}{A_o} \times 100\right),$$

where A_o is number of all Testacida at time 0; A_t is number of all Testacida at time t.

A positive value of $d\%N$ indicates that the *C. dubium* population has grown more rapidly (or died off less rapidly) than the rest of the testate fauna; a negative value indicates the reverse. The parameters r and $d\%N$ for each peat horizon, plotted in histogram form, are shown in Figs. 6, 7 and 8.

The plots of r for all horizons show the burst of spring activity in September, October or November 1970, further activity in February–March 1971, and high mortality at the onset of winter in late March. An apparent anomaly is the high positive value for r in the 6–9 cm. horizon in the middle of winter. However, when numbers are low, a small increase in absolute numbers, due to sampling error, will result in a relatively large geometric increase.

An interesting feature of the plots in Figs. 6, 7 and 8 is the correlation of r with $d\%N$:

Spearman's rank correlation coefficient:

0–3 cm.	$\rho = 0\cdot81$	$P<0\cdot001$
3–6 cm.	$\rho = 0\cdot70$	$P<0\cdot01$
6–9 cm.	$\rho = 0\cdot35$	$P<0\cdot2$

This indicates that the growth and mortality of the *C. dubium* population is in some degree asynchronous with the rest of the testate fauna. It is possible that this species responds more rapidly to changes in environmental conditions than other species and so occupies a dominant position in the fauna.

Reference to Figs. 4 and 5 shows that, during the summer 1970–71, the warmest period and also the period of maximum sunshine was 5 January 1971–6 February 1971 yet during this period there was net mortality of the *C. dubium* population in all horizons (Figs. 6, 7 and 8). However, this was also the period of minimum peat moisture (Figs. 1, 2 and 3). Previous observations on a similar moss-turf peat by Baker (1970*a*) indicated that lack of moisture in midsummer may cause the numbers of bacteria to decline, and these were supported by experimental evidence which suggested that low moisture content depressed the

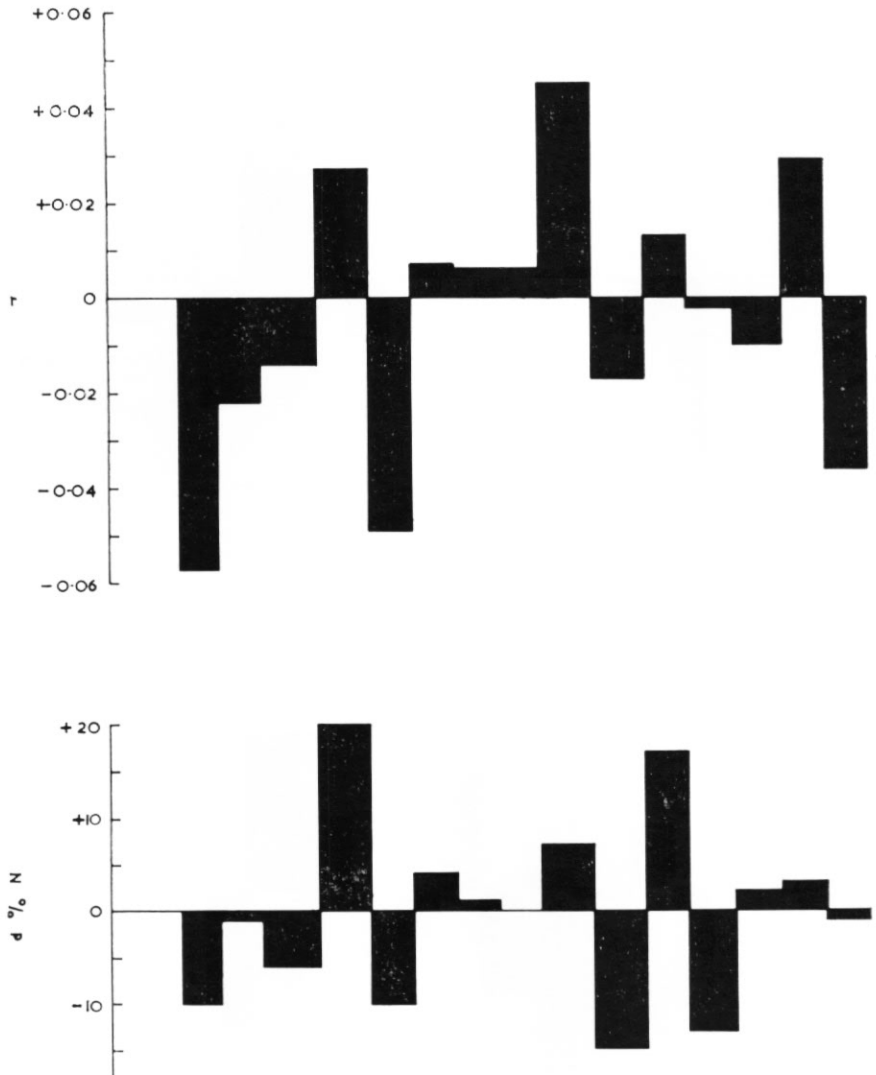

Fig. 6. *r*. Geometrical rate of population growth or mortality of *C. dubium*. d %*N*. Arithmetic change in numbers of *C. dubium* as a percentage of total testate fauna. Horizon 0–3 cm.

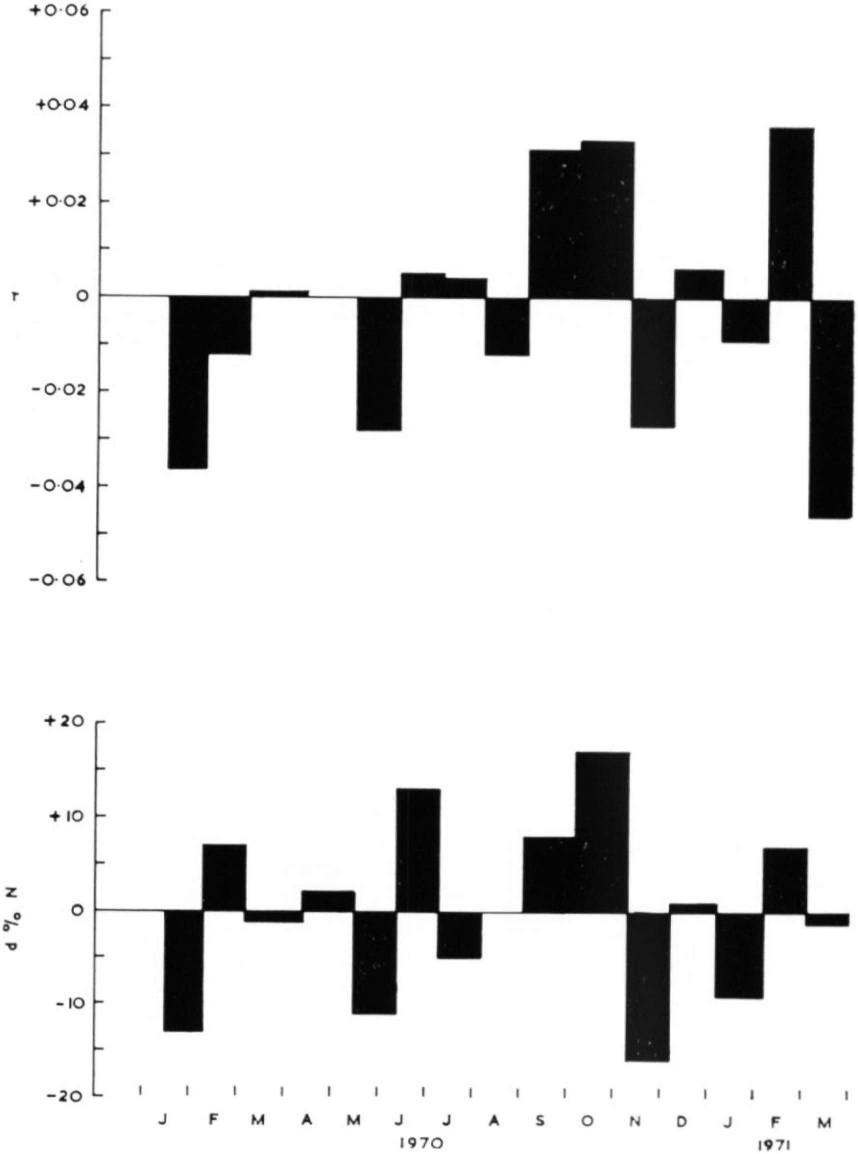

Fig. 7. *r*. Geometric rate of population growth or mortality of *C. dubium*. d %*N*. Arithmetic change in numbers of *C. dubium* as a percentage of total testate fauna. Horizon 3–6 cm.

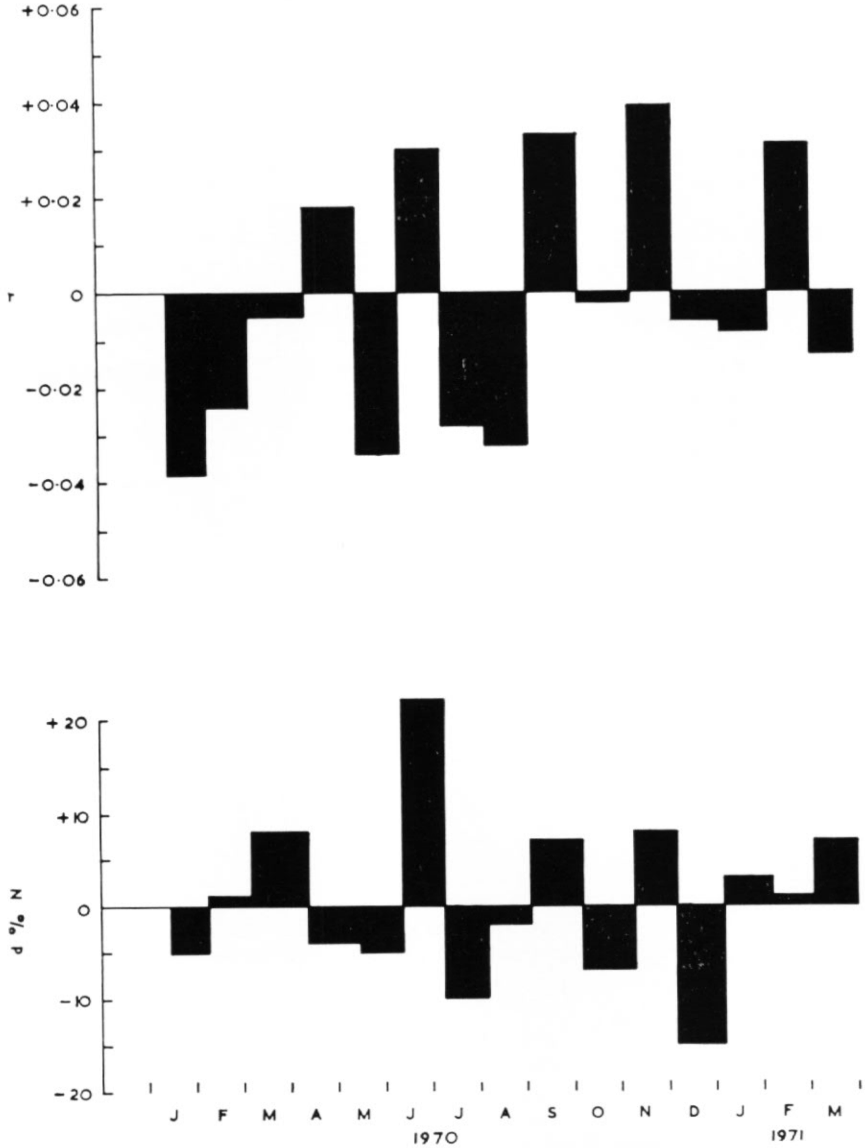

Fig. 8. *r*. Geometric rate of population growth or mortality of *C. dubium*. d %*N*. Arithmetic change in numbers of *C. dubium* as a percentage of total testate fauna. Horizon 6–9 cm.

respiration rate of the total peat community. Therefore, it is possible that, at this time of year, the *C. dubium* population is limited by moisture—either directly or as a result of its effect on the peat micro-flora. Further, the mean temperature of the peat, between 09.00 and 16.00 hr. (the time of maximum heating by radiation), was lower during this mid-summer period than during the periods immediately before and after, despite maximum air temperature and incident radiation. While the data available are insufficient to account for this anomaly completely, the following hypothesis provides a possible explanation.

During the summer daytime the moss absorbs solar radiation, resulting in surface temperatures considerably greater than those of the ambient air (+17·5° C was recorded on 26 December 1970). The peat below is heated by conduction from the surface at a rate which depends on the thermal diffusivity of the peat.

$$D = \frac{K}{ds},$$

where D is thermal diffusivity; K is thermal conductivity; d is density; s is specific heat.

As the peat becomes drier, water is removed from interstitial spaces and is replaced by air. This process will affect all three properties of the peat mentioned above, but it will reduce conductivity more than density or specific heat since the conductivity of water is approximately 30 times that of air and (assuming there is no heat transfer by convection or percolation within the peat) the boundary-layer resistance to the flow of heat from peat particle to air space is approximately 150 times that of the flow from peat particle to water space (Patten, 1909). The low moisture content of the peat in January 1971 will thus reduce the thermal diffusivity of the peat and so impede conduction of heat from the moss surface. Evidence in support of this comes from the fact that the mean temperature gradient below the moss surface, during the hours of maximum incident radiation—09.00–16.00 hr.—was at a maximum during this period (Table I). The high incident radiation will also cause an increase in

TABLE I. MEAN TEMPERATURE GRADIENTS IN SIGNY ISLAND REFERENCE SITE—MOSS-TURF PEAT FROM SURFACE TO 45 mm. DEPTH DURING 09.00–16.00 hr.

Period	*Temperature gradient* (°C cm.$^{-1}$)
5 December 1970–1 January 1971	0·98±0·15
5 January–6 February 1971	1·42±0·24
6 February–4 March 1971	0·59±0·14
4–29 March 1971	0·36±0·11

evaporation rate and consequently have a greater cooling effect on the moss. The combination of these two effects could result in decreased temperatures of the moss peat.

ACKNOWLEDGEMENTS

I wish to extend grateful thanks to the British Antarctic Survey personnel who gave considerable assistance with the field work on Signy Island: R. J. Cook, O. H. S. Darling, A. Feenan and A. H. Gilmour. I am also grateful to Dr. O. W. Heal for advice on protozoological techniques, to D. W. S. Limbert for advice on the interpretation of the micro-climate and meteorological data and to Dr. J. F. Darbyshire for criticism of the manuscript.

MS. received 19 October 1972

REFERENCES

BAKER, J. H. 1970*a*. Yeasts, moulds and bacteria from an acid peat on Signy Island. (*In* HOLDGATE, M. W., *ed. Antarctic ecology*. London and New York, Academic Press, 717–22.)

———. 1970*b*. Quantitative study of yeasts and bacteria in a Signy Island peat. *British Antarctic Survey Bulletin*, No. 23, 51–55.

COUTEAUX, M. M. 1967. Une technique d'observation des thecamoebiens du sol. *Rev. Ecol. & Biol. Sol.*, **4**, No. 4, 593–96.
HEAL, O. W. 1965. Observations on testate Amoebae (Protozoa : Rhizopoda) from Signy Island, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 6, 43–47.
NORTHOVER, M. J. *and* S. E. ALLEN. 1967. Seasonal availability of chemical nutrients on Signy Island. (*In* SMITH, J. E., *organizer*. A discussion on the terrestrial Antarctic ecosystem. *Phil. Trans. R. Soc.*, Ser. B, **252**, No. 777, 187–89.)
PATTEN, H. E. 1909. Heat transference in soils. *Bull. Div. Soils U.S. Dep. Agric.*, No. 59, 54 pp.
SMITH, H. G. 1973. The Signy Island terrestrial reference sites: II. The Protozoa. *British Antarctic Survey Bulletin*, Nos. 33 and 34, 83–87.
TILBROOK, P. J. 1967. The terrestrial invertebrate fauna of the maritime Antarctic. (*In* SMITH, J. E., *organizer*. A discussion on the terrestrial Antarctic ecosystem. *Phil. Trans. R. Soc.*, Ser. B, **252**, No. 777, 261–78.)
————. 1973. The Signy Island terrestrial reference sites: I. An introduction. *British Antarctic Survey Bulletin*, Nos. 33 and 34, 65–76.