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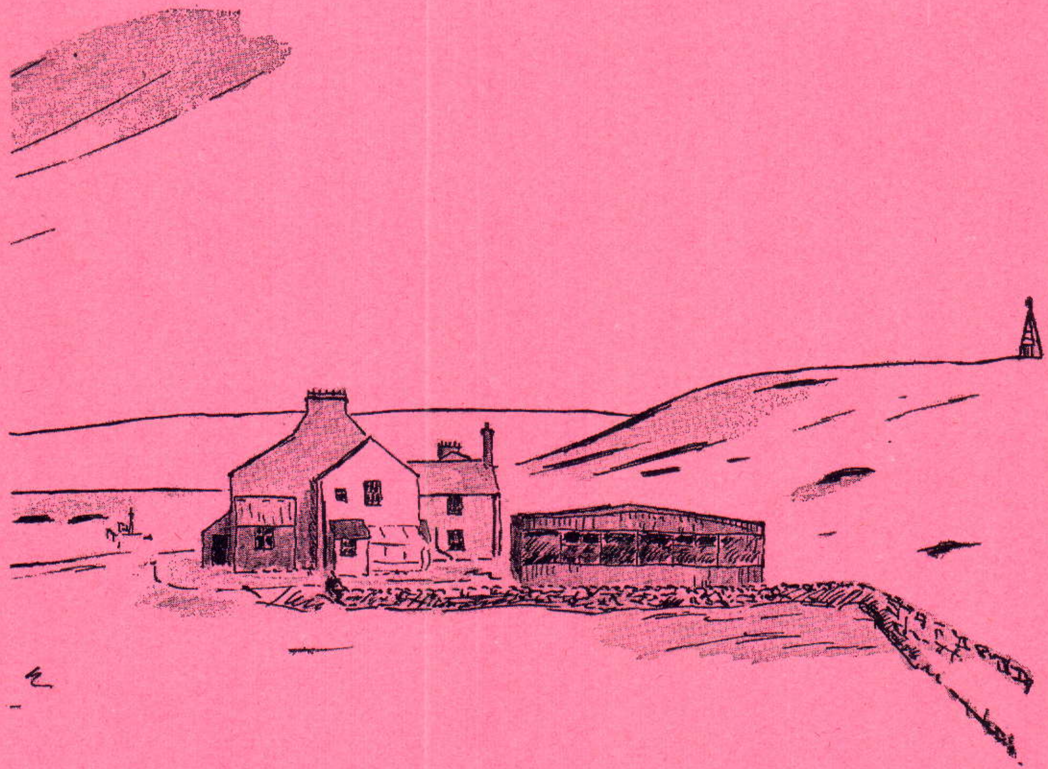

MOOR HOUSE

THE ENVIRONMENTAL PARAMETERS OF IBP EXPERIMENTAL SITES AT MOOR HOUSE

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CONTENTS

<u>PREFACE</u>

Previous to, and during the course of, the International Biological Programme, a large number of environmental observations have been made at Moor House, and the opportunity has been taken in the present work to summarise and compare these data. It is hoped that this will be useful both for the IBP project and for future work. Observations have been included both from IBP and non-IBP sites, and all sources of information have been referred to, including internal publications (e.g. Moor House Annual Reports and Occasional Papers).

This work is intended partly as a summary of the available data, and also as a guide to further sources of information on the environmental parameters of Moor House. It is realized that at present it is incomplete in some respects, and consideration will be given in the future to updating this paper. Any misinterpretation of results is entirely my responsibility.

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I INTRODUCTION

1.1 Location of Moor House National Nature Reserve

Moor House National Nature Reserve, lat. 54°65'N, long. 2°45' W, is situated on the Pennine ridge which runs north-south in central England (Fig. 1a). The reserve covers an area of 9513 acres stretching across the northern end of the range rising from 300 m. on the steep scarp slope above the Vale of Eden on the west, and including the summit ridge and much of the high level plateau to the east (Fig. 1b). The highest point of the Pennines, Cross Fell (888 m), is less than a mile north west of the Reserve, much of which is only 100-300 m below this altitude and is subject to a severe climate in comparison to the rest of Great Britain. The Reserve is a vast uninhabited tract of the north east corner of the county of Westmorland and has no roads of any importance crossing it, and only one public footpath used to any extent (The Pennine Way).

1.2 History of research at Moor House

The Reserve, acquired in 1952, was of particular interest because it included one of the largest areas of blanket bog covered moorland in Great Britain (Conway, 1955). Nearly 90% of the east side of the Reserve is covered by blanket peat with an average depth of 1-2 m, with much deeper deposits (c3-4 m) on the valley bog areas. Following the acquisition of the Reserve extensive, and in many cases long term, research work was initiated to elucidate problems of upland ecology. This work is still continuing.

Then, with the development of the International Biological Programme, the Reserve was listed (Anon, 1967) as the main British IBP moorland site. It was later included in the international Tundra Biome which covers arctic and alpine sites, and high level moorland. Since 1967 much research has been carried out by Nature Conservancy and University staff, both directly financed by IBP, and receiving financial assistance from other bodies.

1.3 Moor House IBP sites

All the sites studied in the IBP, and also the non-IBP sites discussed here, are listed in Table 1a. All the IBP sites were situated on blanket bog, all but one being on the slopes or summits of small Pennine hills at an altitude of about 550 m (Fig. 1b). The site at Green Burn was however on an alluvial plain of the Tees at a rather lower altitude.

The site of Sike Hill (dry) where Forrest (1971) carried out his detailed studies on seasonal variation in productivity is described here in most detail. Only summary accounts are given for Taylor and Marks' site at Hard Hill and earlier non-IBP sites on a variety of plant communities including grasslands, where primary productivity was measured by Rawes (Table 1a). The decomposition site at Bog Hill is also described separately since this was distinct from Forrest's site of the same name.

2 MACROCLIMATE

2.1 History of documentation

The macroclimate of Moor House has been well documented, though somewhat discontinuously, both prior to and since the Nature Conservancy acquisition of the area. Between 1932 and 1942 Manley (1936, 1938, 1942, 1943) took climatic recordings at Moor House itself, mainly of temperature. He also took readings at Great Dun Fell, the highest point on the summit ridge within the Reserve, but the Moor House readings are of more relevance to the IBP sites. Since 1953 an official meteorological station has been continuously maintained adjacent to Moor House and the readings from this are probably fairly applicable to the IBP sites which are at approximately the same altitude and none of which are more than 2 miles away from the Meteorological Station. In addition, since 1968 radiation has been measured at House Hill using a Lintronic solarimeter and recorded by a Lintronic integrating counter. Owing to problems with the former piece of equipment it was replaced in September 1971 by a Kipp Solarimeter. Radiation and rainfall have also been recorded at Burnt Hill (R. S. Clymo pers. comm.), and radiation at Sike Hill for a year from May 1968 (J. Grace, pers. comm.).

2.2 General climatic characteristics

On the basis of his results Manley (1942) described the area as climatically similar to southern Iceland. The climate can generally be regarded as severe and sub-arctic in affinity, being characterised by generally cool wet and windy conditions, resulting in a short growing season (i.e. mean temperature above 5.6°C) normally of 6 months May to October (Fig. 2a), and a mean annual temperature sum (above 5.6°C) of only 621 C degrees (Fig. 2b). There is also a relatively small temperature range during the year (February mean -1.3°C, August mean 10.7°C).

Green and Millar (manuscript) described in detail the climatic characteristics from 1953-1967. Means of data of various climatic parameters for 1961-1970 (Table 2a, Figs. 2a-2i) have been calculated and show the seasonal fluctuations in some detail. Table 2a and Figs. 2a-2i illustrate in addition the monthly mean fluctuations for 1968-71, the years in which most of the primary productivity measurements were made, and thus the deviation of these years from the 10-year mean.

2.3 Summer climate

Consideration of the climatic data from the last 10 years show that in general the summer mean ($\frac{1}{2}$ max. + min.) temperatures are very low, that for August, the warmest month, being only 10.7°C, and the average highest maximum only 20.3°C. June and July have similar values. Ground frost normally occurs in every month and air frost may be expected in any. The mean lowest minimum temperature is only above 0°C in July and August but snow is normally absent from June to September inclusive. However although August is the warmest month by a small margin it is by no means the driest or sunniest. The summer is generally cloudy and wet; the sunniest month is June with a total of 173 hours and May is the next sunniest. Total solar radiation is also highest in June, followed by May, with a total in the former month (Lintronic solarimeter measurements), of 13656 gm cal/cm^2

1970; July and August have much lower values (Fig. 2l). Fig. 2 m demonstrates the large weekly fluctuations that characterise these data. June is also the driest month with 114 mms precipitation; August, with 178 mms, has almost as much rain as the months from September to December. The rainfall tends to be frequent and of relatively low intensity, rather than as short periods of heavy rain. Low cloud is a frequent occurrence and windspeeds are relatively high during all the summer months, with a mean of about 12 knots.

2.4 Water deficit

Potential evaporation, calculated by E. J. White (pers. comm.) for 1961-70 by the method of Penman, shows that on a 10 year mean basis in no month is there a water deficit; evaporation is always exceeded by precipitation (Fig. 2f). In only three of these years, on a monthly mean basis, did a water deficit occur (in June 1967, July 1969 and May 1970). Green (1959) measured potential evaporation from grass swards at Moor House and other stations in Britain using a lysimeter, and found a water deficit on a monthly mean basis in 1957 but not in 1958, an exceptionally wet year. He regarded Moor House as having a slight water deficit in an average year, but considered calculated values for potential evaporation during the summer months (by Penman's formula and Crowes adaptation of Thornthwaites formula) were too low. Later measurements since 1967 by lysimeter at Moor House (Rawes 1968-71) give rather higher values for potential evaporation than the Penman calculated values (Fig. 2g) for the same time period. This is also supported by the work of Crisp (1966) who found lysimeter measurements were higher than Penman calculated values of potential evaporation during twelve months in 1962 and 1963. Crisp (1966) also estimated evaporation as the difference between stream discharge and precipitation input on a blanket bog dominated catchment at Moor House. Evaporation derived thus was much lower than either measured or Penman calculated values, doubtless because the catchment method gives actual rather than potential evaporation. None of these three methods used by Crisp gave a water deficit in any month over the time period studied.

However use of monthly mean data disregards day to day variation which may well produce ecologically important relatively short periods of water deficit. Green and Millar (manuscript) overcame this problem by calculating the water deficit on a pentade (5 day period) basis. On this basis the years 1957-1966 had only 8 months (from April to September inclusive) lacking a pentade with a water deficit, whereas on a monthly basis only 7 months in this period showed a deficit. The same authors also remark on the occasional occurrence of extremely low humidities of $<10\%$ at Moor House, a result of subsidence of high level air. These occasions may be very important in producing conditions of extreme potential water deficit.

2.5 Winter climate

In winter a similar pattern of wet cloudy weather emerges, fairly cold by British standards, although warm in comparison to most of the other International Biological Programme Tundra sites which are characterised by a more continental or more northerly climate. The mean temperature is below freezing for three months, December, January and February, the February mean being -1.3°C. The mean lowest minimum is -11.8°C in February and the lowest temperature in the 10-year records is -18.3°C. Ground frost occurs on an average of 26 days in January and on only slightly fewer days in November, December, February, March and April. Air frost occurs on about five days fewer per month than ground frost. Snow cover is prolonged, a mean value of 82 days per annum. Snow lies on an average of 19 days in January and February and occasionally falls in October and May although November to April are the main months.

In each of the months November, December, March and April there is approximately 12 days when there is ground frost but no snow; this is the time of most severe damage to the vegetation when there is no protective covering of snow. However in many areas this period of damage is much longer than that defined solely by overall snow cover/ground frost relationships, since the snow is irregularly distributed, being rapidly removed from the more exposed ridges etc. by the strong winds and redeposited in hollows and on lee slopes. Also, unless the snow cover is deeper than about 25 cms (not very frequent) the tops of the Calluna bushes (i.e. the frost susceptible current year's shoots) protrude through the snow and are damaged by desiccation (Forrest 1971), frost, and wind. In contrast, on the areas where snow tends to accumulate, the straggly Calluna branches are protected from frost damage but tend to be pressed onto the bog surface. This is believed to be one of the main factors encouraging their overgrowth by Sphagnum and consequent rejuvenation (p. 36).

Winter precipitation is very high from September to January with a maximum mean of 208 mms in November. Potential evaporation calculations give spurious negative values from November to January; for these months and also for February mean evaporation is negligible and low cloud is frequent. Sunshine totals are exceedingly low in the winter, being only 30 hours in January. Radiant energy input is also extremely low from October to February, the total, recorded by Lintronic solarimeter, being only 1174 gm cal/cm^2 in December 1970, but rising considerably in March and April with the longer daylength and sun at a higher angle. Windspeeds are high during the winter months, particularly in February and March, probably because of the prevalence of winds from an Easterly quarter in these months, Moor House being relatively sheltered from the more frequent and stronger Westerlies. The average windspeed in February is 17 knots.

2.6 Radiation prediction

Regressions were established (A. D. Bailey, pers. comm.) of radiation input on sunshine duration on a monthly basis, and of the ratio of actual radiation input to total possible radiation for the month, on a similar ratio for sunshine duration. From the reversed form of these regressions (Table 2b) it is possible to predict radiation input from sunshine duration for months in which there are no radiation recordings. A rather better prediction should be obtained using the regression which incorporates maximum possible values of the parameters, than with that utilising only actual values. However to date neither the significance of these regressions has been established nor the amount of between-year variability in the relationships.

2.7 Comparison of specific years with the 10-year means

Comparisons of the years 1968, 1969 and 1970 when most of the primary production sampling was carried out, with the 10-year means for various climatic parameters, reveal that 1969 and 1970 were in many ways atypical.

1968

Considering 1968 first; this was on the whole a fairly average year with climatic parameters close to the 10-year mean values (Table 2a). This was certainly generally true for all the summer months, except August which was relatively much drier than normal. There was no water deficit in any month when calculated on a monthly mean basis. The winter of 1968 was also fairly typical although January was rather more cloudy and frostier than normal, whereas February was relatively cold and sunny with longer than usual snow cover. October was comparatively wet and mild, November and December much drier but also cloudier than usual.

1969

1969 was characterised by a warmer July and August than the 10-year mean and these months plus June were also sunnier than usual. The unusually warm summer is emphasised by the temperature ($> 5.6^{o}C$) sum of 767 C^{o} for the year (with a maximum in August, Fig. 2b), the 10-year mean being 621^{o}C. Rainfall was much lower than normal in both July and August but was similar to the mean in June. The combination of warmth and presumably low humidity in July resulted in this month showing the relatively unusual occurrence of a water deficit of 20 mms (Fig. 2j). The winter months of 1969 were in general rather colder than usual, the mean ($\frac{1}{2}$ max. + min.) temperature being less than the 10-year mean values in February, March and April. The occurrence of ground and air frost was also greater for these months, particularly March, and snow lie was much more than normal in February and March. November was also colder with an unusually high snow lie reflecting the extremely high precipitation of 350 mms recorded in this month, but in the rest of the year precipitation per month was less than normal. Winter sunshine was also less than the mean in December, January and November. Thus in summary 1969 was a year with an unusually warm and dry summer, preceded by a cold and snowy winter. It would thus be expected that winter damage of vegetation would be severe, but summer growth rate comparatively high.

1970

1970 was also an anomalous year. The summer months May, June, August and September were again warmer than usual with a temperature sum of 752^{o}C (maximum August), and sunshine was higher in May, June and August. Rainfall was lower in May and June but was higher in July and August, and July was extremely windy. There was a water deficit of 16 mms in May of this year (Fig. 2k). The winter was also colder than normal, at least in February, March and April. Frosts were more in these months and snow lie also in February and April (as was precipitation). The autumn was windy, wet and relatively mild. Thus again it would be expected that in 1970 winter vegetation damage would be more severe than usual and in this year too the summer was warm, though the favourable weather came rather earlier than in 1969, July was no warmer than normal and was wet and windy in 1970.

1971

1971 was characterised by mild winter months; January, February and also December had higher mean temperatures, less snow lie, and fewer days with air and ground frosts than the 10-year mean values. The spring of this year was fairly typical and this, combined with the mild winter, probably resulted in relatively little winter vegetation damage. June of 1971 was much colder, wetter and cloudier than normal; July in contrast was extremely warm, dry and sunny in comparison to the 10-year mean figures. Apart from June and August every month of this year had a lower rainfall than normal; in September and December the precipitation was only one third of that usual for these months.

3 MICROCLIMATE

3.1 Introduction

The general microclimatic characteristics of a typical *Calluna* dominated dwarf shrub community have been discussed by Gimingham (1964, 1972). The main characteristics are determined by the canopy structure which causes reduction of light intensity and wind velocity, the latter effect causing stratification of relative humidity and temperature profiles. However the influence of the canopy is much less in the open conditions of a wet heath typical of Moor House than in the closed dense canopy of the even aged dry heaths which Gimingham investigated, but any *Sphagnum* carpet present in the former has a significant influence by causing a layer of humid air at ground level.

The principal microclimatic documentation on the IBP sites at Moor House National Nature Reserve has been of temperature; this has been recorded hourly during various periods on three sites using probes linked to Grant recorders. The sites were Sike Hill (O. W. Heal), Burnt Hill (R. S. Clymo, J. Reddaway) and Hard Hill (K. Taylor and T. Marks). Direct comparison between these results is difficult because of problems of non-uniformity of, and definition of, microhabitat position of probes. At the time of writing limited data are available and analysis of results from the three recorders is in progress. Soil temperature has also been recorded by Horobin (1971), at several sites used in his Tipulid studies. These data were recorded on Cambridge mercury in steel thermographs, and also by measuring the rate of inversion of a sucrose solution. Other microclimatic investigations in the area have included records of light intensity (Grace 1970).

3.2 Grant temperature recordings - Sike Hill

3.2.1 Experimental details

Temperatures were recorded hourly on blanket bog and *Juncus* grassland at Sike Hill from April 1968-December 1971, with occasional breaks due to failure of the recorder. Thermistor probes were sited in various microhabitats and at different depths in the profile (Table 3a). The recorded temperatures were corrected for the calibration factor of the probes, which deviate by $\pm$ 2C^{o} from the actual temperature over the range -15 to + 30^{o}C.

3.2.2 Plots of daily means

Various approaches were used for characterising and comparing the data but were restricted to analysis of weekly, monthly and seasonal variation and included no investigation of diurnal periodicity (O. W. Heal, pers. comm.). A plot of daily means for selected probes over a month (June, 1970) (Fig. 3a) shows some of the main features of the temperature variation at different positions in the air/soil profile. The main characteristic is the increase of temperature stability with depth; this apparently holds for the whole profile from +152 cm to -25 cm. This contradicts the normal situation of greatest temperature variation at the ground/air interface possibly because of absence of probes positioned at the interface, and a dampening due to the presence of the vegetation canopy. Some lag (up to one day), for the effect of change in air temperatures to be reflected in the soil temperature, also shows in the -25 cm and -10 cm probes, and this may be up to 3 days for the -25 cm probe during extreme variations in air temperature.

3.2.3 Fourier analysis on weekly means

The annual variation of temperature considered on a weekly mean basis (Fig. 3b) approximates to a harmonic wave form. The harmonic wave with closest fit to a particular set of data can be obtained using a Fourier analysis (J. A. Webster, pers. comm.), and provides a useful way of comparing the general pattern of seasonal temperature variation of different probes. Although a series of harmonics can be obtained, each approximating closer to the actual variation of the data, in this case the first harmonic has been found to include 80% of the readings within a $\pm$ 2C° error range (Fig. 3b). The meteorological data may also be characterised in a similar fashion.

3.2.4 Temperature characteristics of profiles

Plots of harmonics (Figs. 3c and 3d) for probes at a range of depths in various profiles reveal several interesting features. In general, with the exception of the meteorological data (Fig. 3c), the curves all bear a similar relationship to each other over the whole range of temperatures. The temperature values of the meteorological data are relatively slightly lower than those from the probes; this probably reflects differences in temperature regime between Sike Hill and Moor House meteorological station. The two most obvious criteria for comparison of these curves are the range of temperature variation of each probe wave (i.e. the amplitude) and the lag of each with reference to a standard, (i.e. the phase shift). The standard was taken here as the +152 cms probe (i.e. Stevenson screen height). Considering amplitude first; plots of $\log_e$ amplitude against depth for the Calluna and Juncus profiles, shows an approximately linear relationship in both profiles (Fig. 3e). This is the relationship one would expect for a perfectly homogeneous medium (Carson, 1961), apparently the blanket peat approximates to this ideal. However in the Juncus profile the upper 6 cms are subjected to a somewhat larger temperature range, expressed mainly as high maxima. The lag of the peak of each curve increases with depth for both profiles (Figs. 3c and 3d) as would be expected.

3.2.5 Temperature characteristics of different litters

The weekly mean temperatures of different litters may differ by more than 4C°. Comparisons of Figs. 3c and 3d reveal that the upper layers of the Juncus profile have higher maxima than corresponding layers in the Calluna profile. However a graph of harmonics for the full range of litters examined (Fig. 3f) shows that the relationships between each are quite complex, altering at different phases of the seasonal temperature variation. In the highest range the warmest litters were Eriophorum, Juncus and Sphagnum (-0.5 cm) followed by Sphagnum (-5.0 cm), and the coldest was Calluna (-1.0 cm). In the cold phase the differences between the probes were considerably less; the Calluna was still the coldest but was little different to the Eriophorum and Sphagnum (-0.5 cm and -5.0 cm); rather warmer was Juncus. The position of Sphagnum litter is probably most closely represented by the -5.0 cm probe.

3.2.6 Temperature sums and plots of maxima and minima

The plotting of curves on the basis of weekly means tends however to obscure the extremes of variation. This difficulty was partly overcome by comparing accumulated temperature sums (day degrees above 0°C) and by examination of weekly mean maxima and minima. Accumulated temperature sums (Table 3b) for all litters examined show the rather higher temperatures of the Juncus, Eriophorum and Sphagnum (0.5 cm). Graphs of weekly mean maxima and minima for Juncus and Sphagnum (-5.0 cm) and E. vaginatum and Calluna, (Figs. 3g and 3h) reflect generally the conclusions of Fig. 3f, namely the warmest litter being Eriophorum followed by Juncus. However the Calluna litter had a higher maximum than Sphagnum (-5.0 cm), in contrast to the relationship between the mean values (Fig. 3f). The differences between maxima were about 2C°. There were smaller differences between minima, although there was a tendency for the warmer species to have the lowest minima. These differences between the temperature ranges of various litter types probably result, apart from differences in the degree of exposure of the probes, from differences in reflective properties, surface areas available for heat loss and absorption, and surface area:volume ratios, of the different litters.

3.2.7 Isotherm plots

Although it is apparent from these Fourier plots that there is some lag of transfer of air temperature changes, both within the canopy and below the bog surface, the precise spatial relationship with profile depth has not been determined. This relationship was illustrated by plotting 2 degree isotherms for weekly means throughout the year (Fig. 3i). Here a long-term lag of temperature transfer of up to three weeks is apparent, particularly at more than 10 cms below the bog surface. However short-term temperature fluctuations are not illustrated on a weekly mean basis, but are if daily means are plotted. These plots (Fig. 3j), for one winter week and one summer week, show a more pronounced lag of heat transfer, there being little temperature variation below 10 cms depth in the peat. Hornung (1968) observes that the soil temperature at 1 foot is always above freezing point. In contrast to the tautochrome plots the temperature lag as represented by isotherms is greater at low temperatures than high.

3.2.8 Temperature prediction

It has been found possible to utilise the closeness of fit of the seasonal variation of different probes to a harmonic wave-form, for predictive purposes. This enables temperatures in a particular microhabitat over a period to be predicted from the meteorological data for that period, providing a relationship between the deviation of the meteorological readings from the 'average' Fourier meteorological plot, and the deviation of the probe readings from the average Fourier plot for that probe, has been determined. The relationship must be based on three parameters:

(a) Level of meteorological variation at which correction should start
(b) Amount and type of correction
(c) Whether consider calculated results for previous weeks.

The relationships have been determined by computer (O. W. Heal, pers. comm.) and good agreement has been obtained between predicted and actual temperature values (Table 3c).

3.3 Grant temperature recordings - Burnt Hill

R. S. Clymo and J. Reddaway recorded temperatures at Burnt Hill for 44 months during 1968-1972 with probes positioned as shown in Table 3d. A small sample of preliminary results (Table 3e) showed that pools were often warmer than lawn and hummock Sphagnum habitats, there being a similar difference (about 2C°) at night as during the day (Clymo and Reddaway, 1968). The south west side of a hummock was warmer than the top, the north was the coldest, and slightly warmer, at least during the afternoon, was the north west aspect (Table 3e).

Emphasis in Clymo's treatment of the data was however on mathematical simulation of the daily temperature variation (R. S. Clymo, pers. comm.) He obtained a good prediction, accounting for 72% of the variance, by extending a Fourier analysis to the 9th harmonic, but did not favour this approach because the nineteen coefficients produced were meaningless parameters. He therefore used a mathematical modelling approach, with coefficients representing the mean temperature, elapsed time, and the amplitude and phase of the curve. The first equation used represented a sine wave with a curvilinear trend, but this accounted for only 25% of the variance. Clymo then tried to characterise the observed variation in terms of a quadratic equation. Further analysis is in progress.

3.4 Grant temperature recordings - Hard Hill

K. Taylor and T. Marks recorded temperatures on the Hard Hill experimental plots for 79 days in 1970. The probes were in corresponding positions in short rotation burnt and control unburnt areas (Table 3f). The analysis of these data was mainly with the aim of comparing the temperature regimes in the two areas, and also to find the probes at Sike Hill with the most similar temperature variation and mean to each of the Hard Hill probes, thus enabling extrapolation of the latter set of readings to cover a longer time period (T. Marks, pers. comm.).

Comparison of probes in similar microhabitats on the burnt and unburnt treatments revealed that any corresponding pair of probes were more closely related than any other two probes in different microhabitats on the same treatment. There was little difference between the two treatments, the mean temperature on the burnt area being slightly higher than on the unburnt. However there was no replication; thus any temperature differences may be due to slight differences in the microhabitats of corresponding probes. Plots of daily temperature variation of each probe for a day with large diurnal fluctation (Fig. 3k), showed (T. Marks, pers. comm.) that the layer close to the ground (+ 8 cm probes) attained a higher temperature on the burnt than the unburnt plot, presumably the Calluna canopy on the latter area prevented radiant energy penetration. However in the case of the surface (0 cm) probes the temperature was lower, and the range less, on the burnt plot in comparison to the unburnt, believed (T. Marks, pers. comm.) to reflect the insulating properties of the thick Eriophorum mat on the burnt area. This pattern was repeated on all the days with large temperature fluctuation, on days with less dirnal variation the temperature differences between the two areas were also reduced.

Taylor and Marks also compared the frequency with which each probe recorded a particular temperature (Fig. 3l). This again demonstrated the much reduced temperature variation at depth in the profile.

3.5 Grant temperature recording - between site comparisons

No conclusions are yet available from these comparisons, but analysis of the data is in progress.

3.6 Thermograph and chemical inversion temperature recordings - Tipulid sites

Horobin (1971) recorded soil temperatures on thermographs at 1 cm depth on five sites at different altitudes during various periods in 1967-69. He compared the results on the basis of weekly means, and weekly mean maxima and minima. He found that in general mean temperatures decreased with altitude but there were occasional anomalies. These he did not think resulted from inversions, but rather from between-site differences of water content or windspeed.

Horobin (1971) also obtained values for arithmetic mean soil temperatures at -1 cm on eight sites at different altitudes on Great Dun Fell, and seven sites on different vegetation types near Moor House, by measuring the rate of inversion of a sucrose solution to fructose and glucose, dependent on temperature and pH. These arithmetic mean temperatures covered periods from two weeks to five months and the temperature:altitude relationship anomalies, found by the thermograph readings, were absent in the arithmetic mean data taken over a longer time period. Maximum and minimum values also generally decreased with altitude, as did the range of temperature variation. There was a lapse rate of 0.1C^{o} on the mean annual temperature, for every 100 ft altitude increase.

The arithmetic mean temperature data for the sites near Moor House showed only small differences between vegetation types. The caricetum and peaty podsol (Juncetum) were generally warmer than the mean, with blanket bog and Above Netherhearth site (on the edge of the blanket bog) rather cooler.

The limestone grassland and peaty gley (Juncetum) were fairly close to the mean values. The caricetum was situated within a sheltered valley, the peaty podsol on a south facing slope. The relative coldness of the blanket bog site is attributed by Horobin (1971) to its wetness, evaporation from the Sphagnum dominated surface, and the shade provided by the canopy of Calluna and E. vaginatum. The Above Netherheath site was also shaded.

3.7 Light intensity measurements

Grace (1970) examined the interception of light by the Calluna canopy, both in terms of the spectral distribution of the intercepted light, and the variation of light intensity with depth in the profile. There were few differences between the spectral distribution above and below the canopy (Fig. 3 m) indicating that absorption by the canopy was non-selective. This was supported by laboratory investigations, using a model stand of 6 cm long Calluna shoots, which showed that light transmission at each wavelength was similar with or without the stand; the canopy thus acts as a neutral filter with just a slight peak at 550 mu (green light). This was expected in view of the low transmission properties of Calluna shoots; most of the light is transmitted via the gaps in the canopy.

Grace also used a similar model stand, successively clipped at 1 cm intervals, to characterise the variation of light interception with depth in the canopy. This investigation showed that variation of absorption with depth closely approximated to Beer's Law, which states that the light present falls exponentially with increased path length. It was also found that the possibility of light interception is maximal at a low angle of incidence, and minimal with a vertical beam. However, since these measurements were carried out by successively cutting a model stand, the validity of their extrapolation to field conditions is questionable. Grace discusses this point. The mean differences are the multidirectional nature of light in the field (in contrast to the parallel beam used by Grace), the extreme variation in height and structure of the Calluna canopy in situ (compared to the uniform 6 cm high canopy of Grace), and edge and mutual shading effects of 'blocks' of Calluna in the field.

4 GEOLOGY

4.1 General

This topic is fully described in Johnson and Dunham (1963) and Hornung (1968), from which much of the following account has been drawn.

The northern Pennines, in which Moor House is situated, consist of a fault block of Carboniferous rocks of the Yoredale series lying unconformably on a basement of Silurian and Ordovician deposits (Fig. 1a). The western side of the block consists of a fault scarp which forms the steep western flank of the Pennines, the eastern side of a dip slope which forms the eastern plateau. The dip slope is only slightly eroded into the successive strata, and its predominantly gentle gradient is produced by the influence of the Teesdale anticline superimposed on the overall dip of the strata in the block.

The block is composed of a series of alternating horizontal limestone, sandstone and shale layers of sedimentary origin, which cause a stepped topography, and these are intruded by more recent igneous sills, dykes, and veins (Figs. 4a and 4b). The most important intrusion, the well-known Whin Sill, is composed of quartz dolerite of post Upper Carboniferous age, and outcrops extensively with a marked influence on topographical features. The intrusive veins are often mineralised and usually contain ores of lead and zinc within a gangue of variable proportions of calcite, fluospar, barytes and quartz.

4.2 Geology of IBP sites

All the IBP primary production sites lie on the Carboniferous or more recent intrusive formations. On the majority of the sites however, obscuring the possible differentiating effects of variable country rock, are widespread deposits of glacial boulder clay overlain by extensive deposits of peat. However the sites on the various grassland communities are mainly on mineral soils or very shallow peat deposits.

5 SOILS

5.1 Factors influencing soil development

The soils of the Moor House National Nature Reserve have been extensively studied by Hornung (1968) and much of the following, particularly that part referring to the non-blanket bog sites, is summarised from his account. However neither his work, nor that of Johnson and Dunham (1963), included detailed documentation of the peat deposits, which do not conform to normal pedological classification. Fig. 5a shows the distribution of the main soil types of the Reserve. Blanket peat is the typical soil over much of the area, mineral soils are confined to limestone and sandstone outcrops, fell-tops and river valleys (Cragg, 1961). The soil type which develops on a particular site is influenced mainly by climatic factors, the underlying rock type, depth and nature of the drift deposit, and topography. Many of the soil groups of the Reserve can be related directly to the depth of the drift deposit (p. 24) (Fig. 5b), providing other factors remain constant. Similarly, the interaction of underlying geology and its associated topography can produce a characteristic range of soil groups (Fig. 5c). The vegetation also influences soil development; particularly important is Agrosto-Festucetum (producing a mull humus) in contrast to the other vegetation types (all of which produce a mor humus).

Consideration of the characteristics of the soil profile of different sites is essential to explain the results of decomposition, microbiological and primary production studies. The majority of the experimental sites were situated on blanket peat; the exceptions to this, mainly the grassland sites of Rawes et. al., are dealt with separately (p.22).

5.2 Blanket bog sites

5.2.1 Introduction

The dominant edaphic factor on all these sites is the deep deposit of blanket peat. This layer, normally c. 1 m deep, usually overlies mineral soil which is often gleyed by a process analogous to that in peaty gleyed podsols (p. 23).

Much of the work on the profile of this peat layer has been as a background to other projects, consequently data on various aspects are extremely scattered and largely unco-ordinated. Although there is a fair amount of descriptive data, definition of any of the characteristics of the profile on a functional basis is almost entirely lacking.

Most of the work has involved examination of the top 30 cms of the profile - probably the region which in any case is of most interest since microbial activity and rooting of higher plants are practically confined to this part of the profile. This section of the profile is less highly humified than the deeper zones and the nature of the original peat forming vegetation is usually easily recognisable. Often this upper profile section consists of a series of zones dominated by different species, the change in species composition possibly on some sites representing a cyclical hummock/hollow succession (p. 38). These zones are often markedly different in colouration, dominance of Sphagnum remains resulting in a yellowish tinge, while those of Calluna give a dark reddish brown colour. However no definite L, F and H horizons can be recognised (Johnson and Dunham 1963), because of variation in the humification of successive bands. Usually the Calluna dominated peat formed in drier conditions is well humified (Martin 1971), as is that of the delicate S. cuspidatum characteristic of pools (Clymo 1965). The hummock forming sphagna are the least decomposed.

Superimposed on this zonation resulting from differences in the original peat forming vegetation, are the probable effects of variation in redox potential down the profile. These are believed to include the formation of further colour zones which are probably a reflection of the oxidation state of iron, humic acids etc., at a particular point in the profile. Thus on some sites three distinct colour zones; dark brown or black brown, green brown or green, and red brown or rust, have been recognised in the upper profile below the litter. Beneath these is darker reddish brown deep peat (Martin 1971).

Unfortunately recognition of redox zonation did not occur until 1966 and much of the older work has only sought a correlation of different factors with depth and has not taken into account the redox status of the peat in the sampling position. Moreover the seasonal and within-site variations of the redox profile are probably considerable. Martin (1971) has observed that oxidation of the anaerobic zones is reversible, thus seasonal variation is apparently possible. Limited repeated sampling by Collins and D'Sylva (1972) at Bog End site also indicated that seasonal variation in the redox profile did occur (Table 5a). My own work (p.19) and that of Martin (p.17) indicated that great within-site variation of redox profile characteristics occurs.

One cannot therefore at present correlate data collected at one time with observations of the redox zonation at a later date or different position on the same site; hence the lack of explanation of the various characteristics examined, on a functional basis.

5.2.2 General characteristics and intersite comparisons

The descriptive work on the peat profile has mainly involved definition of a range of parameters at a particular point in time. The scattered nature of most of the information, both as regards sampling times and coincidence of sites, makes it difficult to conclude anything from these data. However Bog End site has been investigated more fully (Table 5b) and it is possible to draw some general conclusions on the variation at this site of different factors with depth in the profile. It must be borne in mind that some of these conclusions may not be generally applicable to all the blanket bog sites. A certain amount of intersite comparison is also possible, particularly on the basis of the documentation of redox zonation and other parameters which I carried out recently on a range of sites.

Water table

Water levels of each site, measured in pits, were followed by G. I. Forrest (pers. comm.) during selected periods. A plot of these results for a summer sampling period (Fig. 5d) shows several interesting features. The Cottage Hill A site has a much higher water table than any other. Otherwise the picture is less clear with the relationships between the sites varying with time of sampling. In general the Green Burn site is the next wettest followed by Cottage Hill B and Bog End which are similar. Driest is the Sike Hill (dry) site, then Sike Hill (wet) and Bog Hill (Fig. 5d). The Sike Hill (dry) site shows greater range of water table variation than other sites, suggesting perhaps that the pit is in a hollow and surface runoff is important at this site; expected in view of its low Sphagnum cover, this species acting as a sponge and absorbing runoff. However a similar water table relationship exists for Green Burn which is a site with a high Sphagnum cover, runoff therefore is not the main factor influencing water table dynamics on all sites. Also important will be the local micro-topography of the bog surface around the pit and factors (such as the peat conductivity) affecting the rate of equilibrium of the free water table with that in the complete profile. Boelter (1965) found hydraulic conductivity was maximal for Sphagnum dominated peat; least for that composed mainly of herbaceous species. Hydraulic conductivity also decreased with depth. Conway (1956) found, using cores from Moor House, that vertical conductivity was much greater in Sphagnum peat than humified 'cheesy' peat.

G. I. Forrest (pers. comm.) also investigated the within-site variation of water table level and found that this was quite considerable (Table 5c). The extent of variation was however fairly similar on each site.

The rate of response of the pit water table following precipitation would appear to be relatively rapid, a rise of 18 cms to a maximum occurring at Sike Hill (dry), after only one day, following a rainfall of 3.3 cms. The rate of fall of the water table under conditions of little or no rainfall is about 1.4 cms per day, averaged over the period. As would be expected the greatest rates of fall are at the beginning of the period.

To what extent however the water table as measured in a pit bears any direct relationship to the water table in the complete profile is doubtful. This latter variable probably is meaningful but may only represent a difference of a few percent in the water content of the peat; a completely arbitrary position at the boundary of capillary and gravimetric water. Its relationship to the measured water table is probably highly complex and depends principally on the same factors which influence the dynamics of the measured water table (i.e. surface vegetation, microtopography, and local peat conductivity). The variation of the last factor with depth is a particularly important influence on the relationship of measured to actual water table. A marked change in peat conductance may result in the water table variation being buffered, with a tendency for the water to settle out at this level (R. S. Clymo, pers. comm.). Such a discontinuity in conductance may well be present at the 'change of state' position (p. 21) where there is a striking change in bulk density and peat consistency.

Morphological zonation

The morphological zones at Bog End have been examined briefly by N. J. Martin (pers. comm.) and P. M. Latter (pers. comm.), who concluded that there was no constant pattern within the site, the zonation at any particular point reflecting the sequence of vegetation and the conditions of topography under which the deposit was laid down.

Johnson and Dunham (1963) have examined the morphological zonation of Bog Hill and Hard Hill. The peat at the latter site is much deeper than at the former, but although there are differences in the early deposits (p. 27), the upper regions of the profiles on both sites show a succession of zones reflecting varying dominance of Calluna, Eriophorum and Sphagnum (Figs. 5e, 5f and 5g).

Redox zonation and related variables

The position of the coloured redox zones is extremely variable, (Table 5b), even within a site (Bog End) at one sampling time (Fig. 5h) (N. J. Martin, pers. comm.). One way of quantifying and comparing the colour of these zones is the use of Munsell's colour chart; colour matching however is still subjective, but differences between the three main zones are detectable (Collins and D'Sylva 1971). The explanation of these differences in terms of redox potential or other factors is however somewhat hypothetical.

The relationship between colour zonation and past and present vegetation was investigated by Martin (1971). He found that the depth of the zones above the rust horizon was unrelated to the degree of humification or the surface vegetation but there was a correlation with the original peat forming vegetation, the dark brown zone being shallower where Sphagnum remains dominated. This Martin ascribed to higher water table in the wetter Sphagnum areas; however it would be expected that if this were the case the correlation of zone position would be even greater with present day vegetation.

Data on the colour zonal characteristics of four IBP sites has been collected by Collins and D'Sylva (1972) and recently I have also sampled these and a further six sites, noting colour zone depths, and investigated the location of sulphide deposition using silver wires.

The results of Collins and D'Sylva (Table 5d) do not show any obvious differences between the ranges of the coloured redox zones at the four sites sampled. However these sites were sampled at two different times, thus making comparisons difficult.

position, on these sites, since a deep green zone was found at Burnt Hill and Green Burn, where *Sphagnum* remains dominated in the peat, and a shallow zone at the sloping but equally wet Cottage Hill A site, where non-*Sphagnum* remains were dominant.

However probably the most striking feature of the results of Table 5e was the great within-site variation of redox zonal characteristics and thus probably redox potential, dependent on the microhahabitat into which the core was taken. At certain sites, even wet ones, a green zone was absent from one or more samples. This was the case at Cottage Hill A, a very wet site with deep green zones of 13 and 9 cms at two sampling positions, but at the remaining positions, where *Trichophorum cespitosum* was dominant, no green zone was present. The existence of significant within-site variation of redox potential is also indicated by the finding of G. I. Forrest (pers. comm.) of differences in the water table, measured at ten positions on one site (p. 16).

Urquhart (1969) found a zone of sulphide deposition within the profile at most sites he investigated. Martin (1971) suggests that this zone is located within and below the green zone. This conclusion is however based only on observations at Bog End by P. M. Latter (pers. comm.), that a smell of H_2S was sometimes detectable in this region of the profile. However this suggestion is also supported by the localisation of sulphate reducing bacteria mainly in this zone (Collins and D'Sylva 1971), and by the findings of Urquhart (1969) of correspondence of the zone of silver wire blackening to the redox potential dip, with more uniform blackening deeper in the profile.

However a more detailed investigation was made on several sites, into the relationship between the region of sulphide deposition, the water table, and the redox zonation at a particular site. I examined the first two parameters at several sites during October 1971; silver wires were used to detect sulphide deposition. These results (Table 5f) show that in general the depth of commencement of the sulphide deposition was correlated with water table depth. However coincidence was not very precise, there being differences of up to 3.3 cms; this could be because the water table was measured in a pit which was also some distance from the sampling positions.

A subsequent investigation of the position and intensity of sulphide deposition was carried out using longer wires than previously, at the same time as the documentation of redox zonation. The results of these investigations (Table 5e) carried out during very dry conditions, show that, although wetter sites had in general shallower and more intense deposition than drier locations, there was less coincidence of deposition and water table than previously. However on several sites no deposition was observed on one or more wires and the depth of sulphide deposition for these sites is a maximum value since it is the mean of results only from those wires where deposition had occurred. This consideration, together with the problem of the relationship between the water table as measured in a pit with that in the complete profile some distance away (p. 16), probably particularly tentative with positions of very low water table, means that it is difficult to conclude whether the observed discrepancy between water table and sulphide deposition is meaningful in this case. However Clymo (1965) showed that at Thursley Bog, Surrey, the water table fluctuated more rapidly and by larger amounts than the top of the sulphide zone. The results of my investigation (Table 5e) also show that the position of sulphide deposition at Moor House was definitely not related to that of the green zone.

Again a striking characteristic of these results is the great within site variation of sulphide deposition. Even wires only a few inches apart showed very different deposition characteristics; for example at Bog End one wire had a zone of heavy sulphide deposition from 8-9 cms deep to the wire base (13.0 cms) after seven days whereas a wire placed only 4 inches away, at the same distance from the water table pit, showed no discolouration after the same time period.

It would thus seem that the intensity and position of sulphide deposition is influenced to a large extent by the position of the water table at a particular time. Clymo (1965) demonstrated seasonal fluctuation of the position of sulphide deposition at Thursley Bog, Surrey. The location and thickness of the green zone is more stable, and it is situated higher in the profile than sulphide deposition, which is apparently confined mainly to the rust horizon. However both the sulphide and the green zones probably represent areas of reducing redox potential. The reducing conditions almost certainly result from a combination of the presence of stagnant water and an active microbial population. The zones above the sulphide layer are apparently oxidising, probably with the iron in the ferric state; that below is largely reducing (Urquhart 1969) but less so than the sulphide layer. Clymo (1965) showed that at Thursley Bog breakdown of *Sphagnum* material was less in the sulphide zone than at the surface, and lowest below the permanently sulphidic level. However in deep peat there are probably few micro-organisms (Waksman and Purvis 1932) and the problem of the maintenance of reducing conditions in this region is discussed by Urquhart (1969). He suggests that this is a result either of localisation of micro-organisms in the rhizosphere of deep-rooting species (e.g. *Eriophorum vaginatum*), or of diffusion of reduced substances downwards from the sulphide zone.

Thus on all sites it is possible to recognise to a greater or lesser degree a series of biologically meaningful colour zones which are definable, albeit somewhat subjectively. Thus repeated sampling can be carried out within the same biological entity and between site comparisons made of other properties of analogous regions of the peat profile, impossible where sampling points are defined by depth.

Peat accumulation

The rate of peat formation, which is still occurring actively on much of the Moor House blanket bog, is obviously inversely related to its rate of decomposition and this latter process would seem to be dominantly aerobic in character. Clymo (1965) postulates that the main factor determining the rate of peat accumulation is the rate of incorporation of material into the sulphide zone where decomposition is much reduced. This depends largely on the depth of the zone which is related to the water table depth (p. 19), and thus to the rainfall and drainage conditions of the site, and varies greatly within a site dependent on local hummock:hollow topography. The rapidity of peat accumulation is also very dependent on the rate of dry matter production by the bog surface vegetation.

Physical factors

In the upper profile at Bog End physical factors generally show little variation with depth (Table 5b). There was a slight increase of density and decrease of moisture content/g. d.wt., below about 30 cms. Similar results were obtained for bulk density at Burnt Hill by R. S. Clymo (pers. comm.). Examining successive 1 cm slices of *Sphagnum magellanicum* cores he found (Fig. 5k) a gradual increase of density to a point 28 cms below the surface where there was a marked increase which correlated with an observable 'change of state'. Below this level no individual *Sphagnum* leaves were identifiable.

These factors (bulk density, moisture content/g d. wt.) reflect principally the degree of humification and compression of the different horizons. Thus it seems that little compression takes place above a depth of 30 cms at these two sites. The density at Bog End was higher than that at comparable depths at Burnt Hill, doubtless because the cores at the latter site were chiefly of *Sphagnum magellanicum*. However determinations of moisture content/g d. wt. by Collins and D'Sylva (1972) at Sike Hill, Cottage Hill A and B, and Green Burn showed no decrease with depth (Table 5d), and data on this parameter by the same workers at Bog End showed a decrease only at two sampling times from a total of five (Table 5a). There was little seasonal variation in this parameter at Bog End (Table 5a).

Further determinations of bulk density are being carried out at Green Burn by R. S. Clymo (pers. comm.) and also by H. E. Jones (pers. comm.) at this site and at Valley Bog, Bog Hill (decomposition site), and Sike Hill (dry). The latter worker is determining the bulk density in cores to the peat base in the last two sites, and to the depth of the birch layer at Green Burn and Valley Bog.

pH

Values for the pH of the upper regions of the blanket bog peat at Bog End, measured by homogenisation of the peat with distilled water, range from 3.0-4.2 (Table 5b). The pH of peat samples has usually been measured using this technique and the validity of this approach was examined in detail by R. M. MacDonald (pers. comm.) who also measured the pH of expressates and peat homogenised with distilled water and 1M KCl. He thus split the total acidity into three components; that of the expressate, that liberated by water, and that liberated by KCl. The last, which was the exchangeable component, was about six times the sum of the other two components, and thus a large proportion of the total acidity is not being assessed by distilled water measurement. MacDonald did not find any variation of pH, measured either in KCl or distilled water, down the profile, but other workers using distilled water have found an increase of pH in deep peat.

Collins and D'Sylva (1972) examined the pH in the four colour zones at Sike Hill, Cottage Hill A and B, and Green Burn. Their results (Table 5d) show few between-site differences except for a rather higher pH in all zones at Cottage Hill B. The same workers showed (Table 5a) that there was no seasonal variation in pH at Bog End.

Chemical analyses

Chemical analyses have been carried out on the four superficial horizons under *Calluna*, *Eriophorum vaginatum* and *Sphagnum* at Bog End, (Table 5b). Several constituents, particularly iron, and also potassium, calcium and phosphorus, are concentrated in the black brown layer. High nutrient contents in this layer may be a result of mineralisation in the litter, followed by leaching and uptake by the high concentration of roots in the dark brown layer (Martin 1971). There may also be immobilisation in microbial populations (Martin 1971); this may also partly explain the high level of potassium in the litter layer. The high nutrient concentration in the black-brown zone may also partly be a reflection of the high cation exchange capacity of this zone (Martin 1971). Iron may also be concentrated here, possibly because of upward movement from the green zone of ferrous iron with the water table, and deposition as ferric iron in the relatively oxidising conditions of the black brown layer. Results of recent analyses of vegetation and soils from a range of sites are given in Tables 5g and 5h.

Limited sampling under the range of vegetation types detailed above has revealed few differences except for lower nitrogen content and higher C/N ratio in and under *Sphagnum* than under *Calluna* or *E. vaginatum*.

5.3 Non-Blanket Bog Sites

5.3.1 Introduction

These are principally Rawes et. al. sites on the Agrosto-Festucetum, Nardetum and Juncetum squarrosi. Although few of the descriptions of soil profiles given by Hornung (1968) refer to the exact sites examined by Rawes et. al., the generalised structure of each soil type is fairly constant. It can thus probably be assumed that the descriptions abstracted from Hornung and given in the following sections are a fair representation of the soil profile at the appropriate sites of Rawes et. al. Ranges of chemical analyses are given for soils under each vegetation type in Table 5i and more detailed analyses are to be found in Hornung (1968).

5.3.2 Juncetum and Nardetum sites

The Juncetum squarrosi sub-alpinum and Nardetum sub-alpinum are the vegetation types dominant on the mineral soils of the Reserve. The former association is commonest on peaty gleys, the latter on peaty gleyed podsols and may sometimes also be found on acid brown earths or brown podsols. All Rawes et. al. Juncetum sites were on peaty gleys and two of their Nardetum sites were on gleyed alluvium (N_1 and N_4). N_2 and N_3 were on peaty podsols.

Peaty gleys

The peaty gley is a very widespread soil type and is characteristic of gentle slopes, often forming an intermediate band between blanket peats and peaty gleyed podsols. The development of a peaty gley is caused by the presence of a high ground water table leading to gleying of the deeper horizons with reduction of ferric iron to ferrous and a resultant blue/grey colouration. The surface horizons are also often gleyed because of the sponge effect of the thick mor humus surface layer. Both this soil type and the peaty gleyed podsols are developed on a superficial layer of material. The surface humus layer of the peaty gley is always very acid (pH 3.5-4.0) and the underlying gleyed A horizon may show redistribution of iron. The appearance of the B and deeper horizons is largely dependent on the ground water table level; if this is very high these layers may be a uniform blue grey colour, if not then they may show oxidised ochreous mottled areas, particularly along the line of root channels. Peaty gleys are acid leached soils with a low percentage base saturation. Table 5j shows a typical profile.

Podsols

In better drained, usually steeper sloping, situations leaching becomes a dominant influence and a podsol profile is developed. Where the surface layers remain gleyed because of a water saturated humus layer, the soil is classed as a peaty gleyed podsol. The gleyed layer is usually blue-grey in colour and there is normally mobilisation and leaching of the ferrous iron present here. Beneath this the profile is better drained and iron enriched. An impervious iron pan may be present at the upper boundary of the better drained region or sometimes at a lower level. All these soils are heavily leached and acid. A typical profile is illustrated in Table 5k. With increasing depth of the surface humus mat this soil type intergrades directly to blanket peat. Where there is no gleying of the surface horizons the term peaty podsol would probably be a more appropriate definition. The Nardetum sites N_2 and N_3 of Rawes et. al. fall into this category.

5.3.3 Festucetum sites

Humus iron podsols

The soil type characteristic of the Festucetum is a humus-iron podsol which is typically derived from underlying sandstone in situ. It has very stony upper horizons with the sandstone boulders projecting through the vegetation and showing stone striping and other cryoturbation phenomena. The humus layer is of the mor type and generally shallow (5-7 cms) and is underlain by a sandy A_2 horizon beneath which is a black B_{1H} horizon which contains redeposited organic material. A less well defined layer of iron deposition is present beneath this. This soil type is usually very acid with a surface pH of 4.0-4.4, and extensively leached surface horizons. A typical profile is listed in Table 5l. Site F1 of Rawes et. al. lies on this soil-type, site F2 is described (Rawes and Welch 1969) as being situated on a 'solifluction creep-soil complex'.

5.3.4 Agrosto-Festucetum sites

Most (A4-A7) of Rawes et. al. productivity sites on the Agrosto-Festucetum (Table 1a) are to a varying degree under the influence of underlying limestone deposits. The remainder of the sites (A1-A3) are on silty alluvium.

The soil type developed on limestone is variable and according to Hornung (1968) can vary from rendzinas through brown calcareous soils to acid brown earths and possibly to brown podsols, depending on the depth of cover of superficial material (Fig. 5b). However Agrosto-Festucetum is found most commonly on the first two soil types, where the limestone is still sufficiently near the surface for the plants to be able to obtain nutrients from this source, thus counteracting leaching. It is also found occasionally on acid brown earths, usually with more Nardus stricta than normal.

Acid brown earths

Acid brown earths are found both associated with deeper drift over limestone, and with alluvial deposits. Only the former are described by Hornung (1968), however sites A1-A3 of Rawes et. al. are on the latter formation where the soil type may be slightly different. The acid brown earths associated with limestone are characteristically 30-60 cms deep with three horizons developed. There is a thin layer of acid humus distinct from the underlying mineral soil. The latter can be divided into a narrow A horizon (5 cm), and a well drained uniform red-brown B horizon overlying a firm C horizon. The pH varies from 5-6, increasing with depth, the base saturation is 12-13%, and a little free calcium carbonate may be present near the bedrock. Table 5m shows a typical profile.

Brown calcareous soils

Brown calcareous soils are developed on limestone sites with a rather deeper covering of superficial material than that which characterises rendzina development. Three horizons are developed although often the B is barely distinct from the A horizon above, with a gradual colour change between them. The rooting zone is concentrated in the A horizon which is dark-brown and has a well developed mull humus. The B horizon is poorer in organic matter and as a result is rather lighter in colour. Although they are situated on limestone the depth of intervening material causes these soils to be relatively acid but they do contain some free calcium carbonate, although less than in a rendzina. The base saturation is 50-70% and a typical profile is given in Table 5n. Sites A4, A6 and A7 of Rawes et. al. are regarded as falling into this soil group, as also are parts of the site A5, although rendzinas are developed in places on this site.

Rendzinas

Rendzinas are usually found associated with flat limestone outcrops. They are extremely shallow (→ 25 cm) dark soils with limestone fragments throughout the profile. They usually have a stable crumb structure and show development of distinct A and C horizons, the former consisting of a dense mixture of roots, mull humus and limestone fragments, with a basal root mat resting on the underlying shattered limestone of the C horizon. Although the soil is much influenced by limestone, the calcium content of the fine earth fraction is relatively low as a result of leaching, and the cation exchange complex is rarely completely saturated; the dominant cation is calcium. Some free calcium carbonate is however present. Often the Agrosto-Festucetum found on this soil type belongs to the Sesleria facies (p. 32). A typical profile is illustrated in Table 5c. Parts of site A5 of Rawes et. al. represent this soil type.

6 POST-GLACIAL HISTORY

6.1 Introduction

The detailed post glacial history of a site can be traced by morphological and palynological examination of the soil profile. This has been carried out by Johnson and Dunham (1963), on several blanket bog sites on the Reserve and much of the following is summarised from their account and those of Hornung (1968) and Rawes and Welch (manuscript).

6.2 Post-glacial frost effects

After the retreat of the ice sheets about 13,000 BC, vast areas of ground were covered in unsorted glacial drift which was bare of vegetation. This was subject to widespread cryoturbation and solifluction during the time immediately following the glaciation, and also in the Preboreal and Boreal periods (8,300-5,500 BC). In the intervening Allerød period (10,000-8,800 BC) some climatic amelioration took place. The occurrence of these phenomena of cryoturbation and solifluction is reflected in the presence, beneath the peat deposits, of a sandstone blockfield in the upper layer of the mineral soil, which is composed of glacial drift.

6.3 Vegetation colonisation

Vegetative recolonisation of the area commenced about 10,000 BC, and continued during the Allerød and Preboreal periods. It probably consisted of a scattered tundra flora. Further climatic amelioration during the Boreal period led to the development of a more luxuriant vegetation and stunted forest of birch, plus willow and juniper, later developed. This is indicated by the presence of a basal forest layer beneath the peat over much of the Reserve, below about 760 m, the suggested altitudinal limit for the boreal forests.

6.4 Peat deposition

In most places the deep deposit of organic peat was laid down from the time of the Boreal/Atlantic transition (5,500 BC) with the onset of a warmer climate with higher rainfall, increased precipitation/evaporation ratio, and more vigorous growth of peat forming species. These factors, combined with the presence of impervious drift deposits, led to a general water-logging of conditions and the accumulation of undecomposed organic matter as peat. The deposition began on lower ground and spread to higher altitudes later. The remains indicate that the dominant peat forming species was *Eriophorum vaginatum*. This is in contrast to the situation today where *Sphagnum* spp. and *Calluna vulgaris* are the most important species, but it is possible that *E. vaginatum* is preferentially preserved because its shoot base is deep in the peat and at death is close to or within the zone of reduced decomposition (Clymo 1965) (p. 20).

In some places deposition of peat commenced in the drier Boreal period but this was probably only in valleys where there was marked influence of ground water in the form of springs. Since the Atlantic period peat deposition has probably been fairly continuous because the succeeding sub-Boreal and sub-Atlantic periods were characterised by a cooler climate. There have however been some periods of cessation of peat accumulation, as shown by the presence of thick layers of *Rhacomitrium lanuginosum* in the peat profiles (Rawes and Welch manuscript). At the present time the combination of an annual rainfall of over 1900 mm, low average temperatures throught the year, (which reduce decomposition rate and water loss by evaporation and transpiration), plus low utilisation of the plant production by herbivores, is sufficient to allow peat accumulation.

Johnson and Dunham (1963) have carried out a detailed examination of sections of the blanket peat, including ones from Hard Hill and Bog Hill. These showed that deposition at the former site commenced during the Boreal period, probably because of the presence of springs. The deepest zone was of tree remains, reflecting the stunted birch forest of this period. Above this zone both sites show a similar succession of layers (Figs. 5e, 5f, 5g) dominated by variable proportions of oligotrophic species (Eriophorum, Sphagnum, Calluna) in differing stages of humification. Recently J. Turner (pers. comm.) has commenced radiocarbon dating of the Valley Bog profile.

As the organic matter accumulates it is gradually humified, largely anaerobically because of the waterlogged conditions. A depth of 4 m of peat has accumulated on some parts of the Reserve and these deposits were apparently formerly more widespread than at the present day, since erosion has removed much of the peat above about 760 m.

6.5 Peat erosion

Erosion is believed to have been initiated by the climatic deterioration at the beginning of the sub-Atlantic period. The cooler conditions caused dieback and discontinuity in the vegetation cover and this, coupled with increased rainfall, led to the development of erosion channels in the inherently unstable deep unconsolidated peat deposits, (Johnson and Dunham 1963). These authors consider that in many cases these channels develop first at the base of the peat, and reach the surface by collapse from above forming peat potholes and then open gulleys or hags which gradually enlarge by wind and water erosion facilitated by frost action. However Bower in her detailed studies of peat erosion in the Pennines regards the hags as developing by dissection from the surface (Bower 1960a and b, 1961, 1962). The effects of man by forest clearance and burning, mainly in the sub-Atlantic period, also probably accelerated peat erosion (Conway 1954). Erosion is still widespread but continues at a slow rate nowadays. 11-16% of the blanket bog area on the eastern plateau is eroded (Crisp 1966). In some areas it proceeds to the mineral substratum before any recolonisation occurs, in other cases recolonisation takes place before the complete depth of peat has been removed (Johnson and Dunham 1963).

Conway (1960) tried several methods of arresting the erosion of blanket bog on Bog Hill including diversion of water flow, turfing, and construction of dams on the lower side of eroded areas. After seven years the most successful technique was the last, with development of secondary bog proceeding over the eroded surface. A. J. P. Gore (pers. comm.) also used experimental trials to investigate the possibility of artificially reclaiming these areas of eroded peat.

Surface runoff from a non-eroded Sphagnum dominated blanket bog catchment (Bog Hill) was continuous, but from a burnt eroded catchment (Burnt Hill) it was discontinuous (Conway and Millar 1960), reflecting the storage capacity of Sphagnum for water.

Of the IBP study sites Burnt Hill is particularly affected by erosion; R. S. Clymo (pers. comm.) and M. Rawes (pers. comm.) have observed erosion within the past fifteen years. The topography at Burnt Hill consists of a series of partly interconnecting bog pools on level ground, with a radiating series of eroding hags on the surrounding slopes. The study area was entirely situated on the level pool complex. Most of the other IBP sites were on non-eroded blanket bog, but the ancillary sites of Rawes et. al. included sites on recolonised eroded peat, (p. 33).

6.6 Types of peat deposit

The deposition of peat may be initiated under conditions of actual standing water or under waterlogged soil conditions. The former situation produces a valley bog, the latter blanket bog. In both cases the initial phase of deposition is under relatively eutrophic conditions forming soligenous bog where the plants obtain nutrients from the mineral substrate and/or ground water. As the deposit deepens conditions gradually become more oligotrophic, the supply of nutrients is solely via rainwater, and a uniform deposit of ombrogenous peat is the result (Jessen 1949). This may be modified by the influence of moving ground water causing secondary enrichment of conditions producing flush-peat. This however does not occur in any of the experimental sites except possibly at Green Burn; elsewhere the deposit is true ombrogenous blanket bog with more or less static ground water. The lack of horizontal ground water movement in such a situation even on sloping ground was demonstrated by Smith who showed that titrated water injected into the sloping blanket bog deposit moved only a mean distance of 1 m down-slope in 21 months, but penetrated the whole depth of the profile (70 cm) into the underlying clay (Smith 1968).

7 VEGETATION COMPOSITION

7.1 Introduction

The vegetation of the Moor House National Nature Reserve consists of a rather limited spectrum of plant communities, the vegetation developed on a particular site depending to a large extent on underlying soil type, altitude, and management. Generally speaking most of the communities are extremely species poor, and are either dominated by ericaceous plants or grasses. Most of the Reserve lies c. 100 m above the present day tree line of about 600 m; consequently the plant communities represent climax development modified to a varying extent by management factors. Below 600 m much of the grassland represents a management induced seral stage or anthropogenic climax, the natural climax being woodland or scrub.

7.2 Previous research

Eddy, Welch and Rawes (1969) mapped and classified the extent and nature of each vegetation type on the Reserve, using the techniques of phytosociology which have been so extensively applied by continental workers. They used the scheme of Ellenberg (1963) and based their units on those developed by McVean and Ratcliffe (1962) for the Scottish Highlands. The distribution on the Reserve of each vegetation unit is shown in Fig. 7a, and the extent of each in Table 7a. Eddy, Welch and Rawes also compiled complete species lists for each vegetation unit. The vegetation of the IBP blanket bog sites has been more fully investigated by Forrest (1971 and Forrest and Smith, in prep.) and Clymo (Clymo, Jones and Smith, 1971; Clymo and Reddaway, 1971, 1972).

7.3 Distribution of vegetation types

As well as topographical and edaphic differences, the western and eastern slopes and summit plateau of the Pennine ridge are very distinct from each other floristically. The western slopes consist largely of poor grassland dominated by *Juncus squarrosus* and *Nardus stricta*, the summit ridge of these communities plus Festucetum and the eastern slopes of blanket bog colonised by *Calluna vulgaris*, *Eriophorum vaginatum* and *Sphagnum* spp. Interspersed in these areas are localised patches (usually less than a hectare in extent) of *Agrostis/Festuca* grassland, developed on more base-rich sites.

7.4 Blanket bog communities

The blanket peat is probably the most extensive edaphic formation of the Reserve, and its vegetation cover has been modified by different management practices (p. 42) and the effects of erosion and altitude.

7.4.1 Calluneto-Eriophoretum

The most widespread association of the blanket bog is the Calluneto-Eriophoretum . Here *Calluna vulgaris* and *Eriophorum vaginatum* are co-dominant and frequent species include *Eriophorum angustifolium*, *Empetrum nigrum*, *Rubus chamaemorus* and various *sphagna* of which *S. rubellum* is the commonest. Eddy et. al. also recognise a *S. recurvum* facies of this association on gentle slopes below about 550 m, and a burnt facies with more *Eriophorum* spp.

The IBP sites at Sike Hill, Bog Hill and Bog End fit into the Calluneto-Eriophoretum vegetation unit (Forrest and Smith, in prep.). The Cottage Hill sites, although dominated by *Eriophorum* spp. in fact represent a seral stage of Calluneto-Eriophoretum, modified (in 1961) by burning.

7.4.2 Trichophoro-Eriophoretum

The wetter deeper peat on more or less flat areas at a lower altitude has a Trichophoro-Eriophoretum vegetation cover in which *Trichophorum cespitosum* is an important constituent in addition to *C. vulgaris* and *E. vaginatum*, with *Erica tetralix* a constant species. This association is represented by the IBP site at Green Burn (Forrest and Smith in prep.). The peat of this association is believed to be under the influence of slight flushing from the surrounding blanket bog; thus the vegetation is somewhat richer than on the Calluneto-Eriophoretum. Two facies are recognised, one with more *Calluna*, the other with much *E. tetralix* and *T. cespitosum*. The almost complete absence at Moor House of *Molinia caerulea*, normally a diagnostic constant of this association, is possibly because of the relatively high altitude of the association on the Reserve (Eddy, et. al. 1969) or because of the general waterlogging of the blanket bog (Gore and Urquhart 1966).

7.4.3 Information-analysis and ordination of the vegetation of IBP sites

The vegetation within 10 m of the seven sites of Forrest (in prep.) (Table 1a) and the Burnt Hill sites of Clymo (1965, 1970) was compared by Clymo (Clymo, Jones and Smith 1971; Clymo, pers. comm.; Clymo and Reddaway, 1971, 1972). Frequency figures obtained during this work for each species on all sites are listed in Table 7b. The vegetation was classified using normal and inverse monothetic divisive information analyses (Williams, Lambert and Lance 1966, Lambert and Williams 1966, Lance and Williams 1968). Inverse analysis into species groups does not give a readily interpretable classification. However normal analysis into groups of quadrats (Fig. 7b) is more useful. Primary division is on the basis of *Eriophorum angustifolium*, secondary division on *Erica tetralix* in both primary hierarchies. A plot of this classification for each site as numbers of quadrats separated by each division (Fig. 7c) indicates that the primary division reflects differing wetness of the sites, the Bog End, Sike Hill and Bog Hill sites being separated from those at Cottage Hill, Burnt Hill and Green Burn. The Burnt Hill site however has a wide spectrum of variation, reflecting its diversity of habitats ranging from relatively dry blanket bog, through *Sphagnum* lawns to pools. The inclusion of Green Burn with the wet sites is principally due to the presence there of *Sphagnum magellanicum*. Deletion of this species from the analyses (Fig. 7d) shows Green Burn to have clear affinities with the drier sites on the absence of *E. tetralix* and *E. angustifolium* from a high proportion of the samples. The relative positions of the other sites remain largely unaltered (Fig. 7e).

Within the drier sites, with the exception of Green Burn, little meaningful pattern emerges. Green Burn is distinct from the other sites on account of the absence of Rubus chamaemorus. There is also little pattern within the wetter sites, Cottage Hill B being only slightly distinct in lack of Erica tetralix. Generally speaking there seems to be reasonable floristic similarity between samples from the one site (Clymo, Jones and Smith, 1971).

Classification of samples within the highly variable Burnt Hill site, described by Clymo and Reddaway (1971 and 1972) produced a more meaningful inverse analysis (Fig. 7f). They suggest that the presence of Cladonia arbuscula in a separate group to E. tetralix, C. vulgaris and E. vaginatum, may represent blanket bog sites with large Calluna bushes, the lichen preferring the shelter afforded by these. The presence of Sphagnum cuspidatum in association with the rare species reflects its floristic isolation, it being usually the sole coloniser of pools.

Ordination (principal components analysis) of the above data showed little of interest since the first axis only removed 18% of the variance, and even the first five removed only 43%.

7.4.4 Point quadrat analysis of vegetation of IBP sites

Forrest (pers. comm.) examined the floristic composition of four of his sites using point quadrats (p. 34). Cover values for different species, derived from the percentage of pins contacted, are listed in Table 7c. Green Burn again emerges as very distinctive with a relatively low cover of E. vaginatum, little Empetrum nigrum, and no Vaccinium myrtillus, Listera cordata or R. chamaemorus. Instead the Green Burn site has E. tetralix, and some E. angustifolium, Drosera rotundifolia, and Vaccinium oxycoccus. It is also characterised by very high Sphagnum cover with S. magellanicum and S. papillosum replacing S. recurvum and S. rubellum which are dominant on the other sites. There are fewer differences between the other three sites; the main feature is the relatively low cover of Sphagnum spp. and other mosses on the Sike Hill (dry) site, and the correspondingly higher lichen cover. The species which most account for these differences are Plagiothecium undulatum and Cladonia impexa.

7.4.5 Eriophoretum

On the western scarp, central ridge and localised areas elsewhere, Eriophoretum is characteristic, and is believed to be derived from Calluneto-Eriophoretum by grazing. In this association Eriophorum vaginatum and E. angustifolium are characteristic and Calluna has only low cover. At a higher altitude Calluna is replaced by Empetrum nigrum. The Eriophoretum lacks a Sphagnum carpet so characteristic of the other blanket bog vegetation types. It may be actively colonised by circular patches of Juncus squarrosus and this is recognised as a separate facies, as also are the intensively grazed areas where grasses such as Deschampsia flexuosa and Festuca ovina come in with Juncus squarrosus.

7.5 Grassland communities

The grassland communities of the Reserve constitute a high proportion of the ground cover of the central ridge and western scarp. Several distinct associations have been recognised by Eddy et. al. (1969). The classification of some of these grassland communities is complicated by the fact that often their distribution interdigitates. This is particularly true for communities dominated by Nardus and Juncus and to a lesser extent those by Festuca. Juncus often forms circular patches representing areas of vegetative colonisation and incipient dominance; other mosaic areas represent variable site conditions or result from the overlap of habitat preferences of Nardus and Juncus.

7.5.1 Species poor Juncetum squarrosi sub-alpinum

Eddy et. al. recognise a species poor Juncetum squarrosi sub-alpinum which contains varying amounts of Juncus squarrosus. This association commonly occurs on peaty gleys and it is believed that these areas would be Callunetum were it not for grazing pressure (Ratcliffe 1959). Festuca ovina and Deschampsia flexuosa, which grow between the clumps of Juncus, are the species most favoured by sheep (p. 47), and other common species are Galium saxatile and various hypnoid mosses.

7.5.2 Species poor Nardetum sub-alpinum

Species poor Nardetum sub-alpinum has also been recognised and this is distinct in clear dominance of Nardus stricta. It is characteristic of alluvial terraces on the eastern side and of steep drift soils on the central ridge and western scarp. Grasses such as Agrostis tenuis and Anthoxanthum odoratum typically have considerable cover. This association grades into 'species poor Juncetum sub-alpinum' (where Juncus is co-dominant a Juncus facies is recognised), Festucetum and Agrosto-Festucetum. A 'species rich Nardeto-Juncetum sub-alpinum' is also distinguished on flushed gleys.

7.5.3 Festucetum

The Festucetum is probably derived from other associations by grazing. It is typical of somewhat podsolised soils at high altitudes on the central ridge and consists of a sward, largely of Festuca ovina, beneath which is a thick bryophyte ground layer. At higher levels a Carex bigelowii facies is characteristic.

7.5.4 Agrosto-Festucetum

On the shallow limestone soils and some of the alluvial terraces and shingle, Agrosto-Festucetum is the most frequent association, but only covers 4% of the total Reserve area (Rawes 1971a). The soil types are mainly brown earths or brown limestone soils with some rendzinas, and this community is heavily grazed. On the rendzinas Sesleria caerulea is often an important species and a Sesleria facies has been separated. The Agrosto-Festucetum is a species-rich association, but the bryophyte and lichen ground layer generally has little cover. Agrostis tenuis, Festuca rubra, Carex caryophyllea, Cerastium holosteoides, Euphrasia confusa, Prunella vulgaris, Thymus drucei and Trifolium repens are all constants.

7.6 Communities of recolonised eroded peat

Eddy et. al. (1969) also examined the recolonisation of the eroding peat. The communities here were characterised by Eriophorum spp., Festuca ovina, Juncus squarrosus, Nardus stricta and Deschampsia flexuosa. The species occurring in a particular area probably depend largely on the depth to which the peat has been eroded and thus the degree of flushing from the underlying mineral substratum. The Juncus squarrosus sites of Rawes et. al. (Table 1a) in some cases represented areas of eroded blanket peat or areas of distubed peat (e.g. site of an old trackway).

7.7 Vegetation of Rawes et. al. sites

Most of the other foregoing vegetation types were also represented in the sites used by Rawes et. al. (Table 1a) but the work done on the detailed definition and comparison of the vegetative composition of these sites (Rawes 1961, 1963, Rawes and Welch 1964, 1966, 1969, Welch and Rawes 1964, 1965, Park, Rawes and Allen 1962) is not relevant to the present summary description of the sites.

8 VEGETATION STRUCTURE

8.1 Introduction

This is a very important consideration, particularly for the interpretation of the primary production and micro-climatic data.

Vegetation structure can be considered from a number of aspects, principally the vertical, horizontal, and age structure of the plant community. Horizontal structure includes the definition of any pattern in the vegetation and the scale of this pattern if present. Unfortunately few data are available on these aspects. Age structure should be related if possible to the management history of the particular site.

8.2 Vertical structure

Vertical structure of the blanket bog dwarf shrub community above and below ground has been examined by only a few workers. The point of separation of these two components is questionable because of the dynamic nature of the Sphagnum dominated surface. Some workers have defined the above/below ground boundary as the top of the peat deposit, others have related it to the morphology of the vascular plants, whereas all the IBP studies have defined this important parameter as the surface of the moss carpet.

8.2.1 Above ground

Grace (1970), in connection with measurement of light intensity profiles of dwarf shrub canopies (p. 12), examined the vertical structure of a Calluna model stand comprising 6 cm long cuttings. He noted that the short shoots mostly make an angle of 45-60° with the long shoots and this pattern remains constant with height. The biomass distribution (Fig. 8a) reflects the concentration of shoots at 2-3 cm height in this model, which is difficult to extrapolate to the field situation, except in those few areas of young dense Calluna (e.g. following a recent burn).

The vertical structure of the blanket bog vegetation above ground in the field situation has been studied by Forrest (pers. comm.) on four of his primary production sites; Sike Hill (wet) and (dry), Bog Hill and Green Burn. He used point quadrats with the pins marked at 10 cm intervals. The number of contacts of each species per pin in each interval or stratum were recorded. The mean number of hits per pin were then calculated for each component and these have been plotted as a percentage of the total hits for that species on each site (Figs. 8b-8d). Thus a measure has been obtained of the proportional representation of living and dead components of each species in a stratum.

Fig. 8b compares the Calluna profile at the four sites and it is apparent that the vertical structure of the dwarf shrub canopy is remarkably similar at the Sike Hill sites and Bog Hill. Green Burn however is distinct with a much larger proportion of the biomass between 0 and 10 cms than on the other sites. Also the standing dead in the upper strata on Green Burn is a lower proportion of the total Calluna biomass than on the other sites. These figures are probably explicable on the basis of the vigorous Sphagnum growth on this site, burial of Calluna being rapid and resulting in a high biomass of densely packed young branching shoots near the bog surface (Forrest and Smith, in prep.). Conversion to standing dead is probably reduced because of the active rejuvenation.

Consideration of the E. vaginatum profile for live and dead components (Fig. 8c), reveals a lower proportion of live components and a higher proportion of dead at Green Burn than at the other sites. The profile distributions however are fairly similar on all sites for both the live and dead components.

The graphs (Fig. 8d) for Empetrum nigrum and Rubus chamaemorus, indicate that E. nigrum is taller growing at Sike Hill (dry) than Bog Hill or Sike Hill (wet), and this is also the case for R. chamaemorus at Bog Hill which is almost as frequent in the 10-20 cm stratum as in the lower one, in contrast to its low frequency in the upper stratum at the Sike Hill sites.

Thus a general picture emerges of a remarkably similar dwarf shrub canopy structure on the blanket bog at all four sites examined. The community comprises an upper open Calluna canopy, beneath, and inter-digitating with which, is a discontinuous intermediate stratum of E. vaginatum tussocks, Empetrum nigrum, Rubus chamaemorus and on one site Erica tetralix. Below this is a discontinuous carpet of pleurocarpous mosses and a ground stratum, continuous in some sites, of Sphagnum. Hence, although there may be considerable intersite differences in community composition, the above ground growth form of each species is relatively constant between sites.

8.2.2 Below ground

Forrest (1971) cropped the below ground component of Calluna biomass in connection with his productivity studies, and observed that most of this component comprised buried stems. Small adventitious roots develop on the stems. Gimingham (1964) notes that in heaths developing on peat most of the Calluna roots are restricted to 5-10 cm in depth, but species such as E. vaginatum root to 50 cm or more. The Calluna roots however spread vigorously horizontally; Gimingham suggests their downward penetration may be limited by the anaerobic conditions below the water table, and Urquhart (1969) suggests the critical factor may be 'the soil conditions which caused the dip in the redox profile'. Gimingham (1972) reviews the work on the root distribution of heathland species.

Boggie, Hunter and Knight (1958) investigated the root distribution of species growing on deep peat at three sites in Scotland, using radioactive tracers. The classified the species as surface rooters (Calluna vulgaris, Erica tetralix and Narthecium ossifragum), an intermediate category (Molinia caerulea) and deep rooting species (Trichophorum cespitosum, Eriophorum vaginatum and E. angustifolium).

Gore and Urquhart (1966) investigated experimentally the root distribution of Eriophorum vaginatum and Molinia caerulea under waterlogged and non-waterlogged conditions. The results (Fig. 8e) indicate that E. vaginatum rooted throughout the pot depth of 12.5 cms under both treatments; more roots in fact penetrated deeply under waterlogged conditions, than non-waterlogged. This indicates the adaptation of E. vaginatum to the waterlogged conditions commonly characteristic of blanket bog and suggests that it normally roots to a fairly deep level in these conditions. M. caerulea is only found (as an introduced species) on one site (Cottage Hill) at Moor House; it would appear to be limited by the stagnant waterlogged conditions, rooting depth being exceedingly shallow in this treatment. Armstrong and Boatman (1967) suggest that Molinia is limited by the reducing conditions of stagnant sites, and presence of H_2S. They postulate that other species tolerate this environment because of vigorous oxygen diffusion from their roots. However Ingram (1967) suggests that plants characteristic of slightly flushed sites are limited more by nutrient supply rate than aeration conditions.

The below ground structure of E. vaginatum in the field was examined by Forrest (1971) during his determinations of below-ground biomass. His data are plotted in Figure 8f, the biomass of the live and dead components being expressed as a percentage of the total root yield. Most of the live roots are less than 10 cms below the bottom of the shoot base layer, with the maximum biomass within this layer, but some do penetrate as deep as 30 cm below this level. The biomass of dead roots is much higher than that of live; the former are probably persistent for a number of years following death before conspicuous humification takes place. This is supported by the fact that the maximum biomass of dead roots is at a deeper level than that of live, indicating that to some extent it represents fossilised roots derived from the time when the bog surface was lower than at present.

8.3 Age structure

The age structure of Calluna populations at the IBP sites have been investigated (Forrest, 1971, Jones, Forrest and Gore, 1971, Forrest and Smith, in prep.). Ages were determined directly by annual ring counts on limited Calluna samples, and then from regressions of age against mean basal diameter were extrapolated to large samples of populations. Additional studies were made on tussock size distribution in E. vaginatum.

8.3.1 Calluna vulgaris

Effect of Sphagnum overgrowth

Consideration of Forrest's Calluna age structure data reveal several interesting features. The data for the site at Green Burn (Fig. 8g), for areas with and without active Sphagnum growth, indicate that where Sphagnum is present there is a higher density of stems of the younger age groups. This is due to Sphagnum overgrowth of the stems causing continuous rejuvenation of Calluna, the effective age of the plants measured at the bog surface remaining more or less constant with time. Moreover the Sphagnum overgrowth results in an increase in stem number per unit area since the branching points are buried.

Vegetation dynamics

The presence of active upward growth of Sphagnum, and absence of burning, differentiates Moor House from the other main British heathland productivity sites in Dorset and the Cairngorms, and it results in an ecosystem characterised by highly complex vegetational dynamics. Lack of burning produces a Callunetum dominated by old plants with long straggly stems. The weight of snow and high winds causes the stems to become decumbent (p. 4) and they are buried by the upward growth of Sphagnum. The buried stems usually root adventitiously into the enveloping Sphagnum carpet and die back behind because of conversion of their wood to heartwood (Forrest 1971). These characteristics, plus the continual death of whole plants, and upper shoots (mainly by desiccation when exposed in winter (p. 4)), led Jones, Forrest and Gore (1971), Forrest (1971) and Jones and Gore (1972) to regard the ecosystem at Moor House as being in a steady state, and thus representing a climax system.

Comparison of IBP sites, and effects of burning

Comparison of the age structures of Calluna at the five primary production sites of Forrest (Forrest and Smith, in prep.) which have not been burnt in the last 30 years (M. Rawes, pers. comm.) (Fig. 8h), illustrates again the effects of Sphagnum overgrowth. The sites at Bog End, Bog Hill and Sike Hill (dry) are relatively dry with little Sphagnum cover except at Bog Hill (Table 8a), and with presumably relatively moribund Sphagnum growth. The age structure curves of Bog Hill and Sike Hill (dry) are characterised by a peak density at 8-9 years believed to be the result of profuse branching of the youngest plants near the base; thus only a little upward growth is sufficient to cause a large increase in apparent stem density of younger stems, with little alteration of the stem basal age and a consequent reduction of older stem density (Forrest 1971). With older stems rapid conversion to standing dead also occurs. The graph for Bog End does not show a peak, in this case possibly the youngest plants do not branch profusely near the base. On all these relatively dry sites the mean age is relatively high (Table 8a). Sike Hill (wet), with a greater Sphagnum cover (Table 8a), has an age structure curve characterised by a relatively high density of young plants, a result of Sphagnum overgrowth which has also caused the low mean age. These characteristics are further accentuated at Green Burn, which has a large cover of actively growing Sphagnum.

The age structure of Forrest's primary production site, Cottage Hill, differs from those detailed above very strikingly (Fig. 8i), with a spectacularly high stem density of the younger age classes (Forrest and Smith, in prep.). This site was however burnt in 1961 which would cause rejuvenation either by killing of stems to the bog surface with re-sprouting, or by seedling regeneration. Since a number of stems older than nine years were found it is probable that the temperature of the fire was insufficient to kill all the original root stocks. Since this site is very wet Sphagnum overgrowth will also have overemphasised the rejuvenating effects of fire.

However a better indication of the effects of burning management is obtained by comparison of a burnt area with an adjacent area that has not been burnt. Fig. 8j (Jones, Forrest and Gore 1971) shows the results of such a study on a site burnt 12 years ago. The burn caused a lowering of Calluna mean and modal ages. Unfortunately no details of Sphagnum cover or vigour following the burn are available from this site, and it is thus not possible to assess to what extent the age characteristics of the burnt site reflect the history of regeneration following burning, or the effects of Sphagnum overgrowth. The maximum age was only 13 years indicating that regeneration was principally by seedlings in this case. This is supported by observation (Rawes 1962). The modal age was 6 years suggesting that most regeneration was delayed until some years after the burn, this fits with the observation that Eriophorum spp. dominate for several years on blanket bog following a burn (p. 43).

Cyclical Succession

The Moor House blanket bog ecosystem does not show any of the features of the classic cyclical succession of Calluna as described by Watt (1955) for Lakenheath Warren, Breckland. In the latter area there is no continuous rejuvenating influence of Sphagnum overgrowth, but death of plants when they reach about 25 years with regeneration from seedlings which initiate the cycle once again. The system is thus, like Moor House (p. 37), in a steady state condition.

At both Moor House and Lakenheath there is a range of physiological ages within each stand. This is in contrast to the situation in the Cairngorms, where burning is a common management practice and thus rejuvenation of the system takes place every 8-15 years. Regeneration is either from old root stocks or seedlings depending on the temperature of the fire, the result being blocks of even aged stands, adjacent blocks having a different mean age.

8.3.2 Eriophorum vaginatum

Eriophorum vaginatum tussock size distribution was sampled only at the Sike Hill (dry) site (Forrest 1971). The data were plotted directly in Fig. 8k, and in Fig. 8l on a log transformed basis to obtain a more normal distribution. From these graphs it is evident that over 50% of the tussocks were less than 50 cm^2 basal area, ($\log_{10}$ area = 1.7), although the maximum size sampled was 1115 cm^2. There were few tussocks less than 4 cm^2 in area; this was possibly more a reflection of subjective sampling excluding aggregates of shoots of less than a certain size as not representing a tussock, than of a true decrease in numbers of small tussock sizes. Shoot density was very variable and independent of tussock size and there was no apparent relationship between size of tussock and distance to the next. Lacking data on tussock ages it is impossible to formulate any conclusions on the dynamics of this species within the blanket bog community.

8.4 Pool/hummock succession

It was previously believed that the differentiation of the vegetation of the blanket bog ecosystem into a pattern of pools (or hollows) and hummocks, represented a cyclical succession, with the *Sphagnum* dominated pools or hollows growing upwards more rapidly than the *E. vaginatum* and *Calluna* dominated hummocks, which became engulfed and converted to hollows, (Tansley, 1939). However evidence for this type of succession elsewhere is scanty, and is non-existent for Moor House; current opinion seems on the whole more in favour of positional persistence of the system with only small scale fluctuations in the relative extent of the pools and hummocks, over a long period of time, until the sequence is interrupted by a large scale climatic upheaval.

9 EFFECTS OF MANAGEMENT PAST AND PRESENT

9.1 Historical aspects

The earlier historical aspects of man's settlement of the area have been well summarised by Johnson and Dunham (1963) and Welch (manuscript).

9.1.1 Stone - Iron Ages

The first evidence of man's activity in the Moor House area date from the Stone Age, tools fashioned by Mesolithic peoples being found by Johnson and Dunham during their survey of the region. The implements were probably left by wandering hunters rather than being an indication of an actual settlement of the peoples within the area. Their main influence was probably initiation of forest clearance in the Atlantic Period. No legacies of the succeeding Bronze or Iron Age cultures have been found on the Reserve, although these peoples may have been present, and remains have been found nearby. During all these ages there is evidence, from the remains of horn sheaths, that races of wild cattle of the oxen type were roaming the fells and grazing the vegetation, and these were probably the prey of the hunters. From late in the Stone Age the cattle were domesticated and probably were kept at relatively low altitudes.

9.1.2 Roman - Norman Periods

The Roman occupation was the next important event, but there is no definite evidence of settlement on the Reserve. Following this period was successive colonisation by the Picts and Wallaces, Anglo-Saxons, Norsemen and the Normans. The Anglo-Saxons are believed to have formed the first settled communities in the region, but their influence did not extend onto the marginal land of the Reserve, since they farmed the valley bottoms. The Norse introduced black-faced sheep into north-west England and were the first people to graze them on the fells; first the western side of the Pennine scarp and then later the whole area, was used as summer grazing, and has been more or less continuously since.

9.1.3 Medieval Times - Present Day

Rawes (1971a), Rawes and Gore (manuscript), and Welch (manuscript) have discussed the later influences of man and his management practices on the vegetation of the Reserve. In Medieval times the Monastic Houses were an important influence with herds of sheep, cattle and horses on the fells. However, although of only very localised influence on the vegetation, the development which probably had the most influence on the settlement of the area was mining which had its heyday in the early 19th Century. This industry resulted in the creation of several villages, and many farms and roads; in fact Moor House itself was originally a miner's shop or bothy. Often the miners were part-time farmers and their sheep grazed the common fell land. The old mine tracks caused significant changes in the vegetation (p. 33), and the contaminated waste tips support a very distinctive and specialised flora.

Until quite recently the flocks of sheep were kept largely for their wool, but with the development of alternative synthetic fibres, production aimed less towards the wool market. Emphasis changed to meat production and thus the winter fattening of lambs on low ground became important. Recently however even this is no longer an attractive economic proposition and the future for the hill farmer, whose flocks are virtually the only crop supported by the area, looks uncertain. Some changes seem inevitable in the near future.

However throughout these changes in the aims of sheep production there has been little significant effect on the associated management practices as they directly affect the vegetation of the region. Flocks have continued to graze the fells of the Reserve mainly during the summer and autumn. At present there are about 8500 sheep in summer, which represents a three-fold increase over the past 200 years (Welch, manuscript). Most of the twenty-two flocks are Swaledales but in the last year (1972) there has been an increase in cross-bred sheep.

Horses were an important influence in the area during mining times and many of the present tracks were originally defined by horses. At the present day there are no horses on the blanket bog, although some are grazed on the crest and western side of the Pennine scarp. Cattle have never grazed on the Reserve but have however recently increased in number, being mainly localised within enclosed land at a relatively low altitude (< 700 m), and have no influence on any of the IBP experimental sites. Geese were grazed on the fells in the 19th Century.

The other important anthropogenic factor influencing the vegetation of the area is the recreational use of the moors for the hunting of game. This included deer until the middle of the 18th Century, which time saw the extinction from these fells of the herds that once roamed them. Grouse have been shot on a large scale since the 18th Century. Although numbers have decreased over the last 50 years or so, they have however continued to influence the region, both directly, and in their associated management practices of burning and drainage, used extensively to maintain canopy diversity with the aim of supporting maximum numbers of birds. Active management of the Reserve area has, however, been almost entirely discontinued since its acquisition in 1951, and no grouse have been shot since then. However the direct influence of the bird population is still present and shooting takes place on surrounding estates.

9.2 Present-day management

9.2.1 Introduction

The present day effects of management at Moor House have been investigated over a long period by Rawes and others. The following account is drawn largely from these findings, which have been documented in many published papers including Rawes and Welch (1964, 1966, 1969), Welch and Rawes (1964, 1965, 1966), Rawes and Gore (manuscript), and Rawes (1961, 1963, 1971a), of which the last is a useful summary of some of the more important conclusions.

Current management practices influence the different vegetation types of the Reserve to a varying extent. Blanket bog is mainly utilised by grouse, Calluna vulgaris being the preferred food plant of this species. Sheep are selective for the grassland areas and exert little effect on the blanket bog vegetation (p. 45). On the whole traditional management practices, which aim towards maximum food production (Calluna and grass) for grouse and sheep respectively, are at a low intensity, and are characterised by extraction with almost complete lack of nutrient replacement either by fertilisation or liming. However these losses are insignificant compared with those by other agencies, and considerable replacement by rainfall input also occurs (p. 47). Often different management practices interact producing effects distinct from those of each singly (p. 48).

9.2.2 Direct effects of grouse

The production and biological effects of the grouse population at Moor House were studied by Taylor (Evans and Taylor 1971, Taylor 1972a and b, Taylor and Rawes, in press). These birds probably have little direct impact on the blanket bog vegetation, their consumption in a good grouse year at Moor House being only 2.3-4.6% of the Calluna green shoot production (Taylor 1972b). However locally they may consume a significant proportion of Calluna shoots, particularly in areas exposed above the snow during the winter. Although grouse have not been shot or managed at Moor House since 1951 there is no evidence of decline in the population size or alteration of the age structure since shooting ceased; there are however large yearly fluctuations in the population, 1971 and 1972 being particularly good years.

9.2.3 Effects of grouse management practices (drainage and burning)

Grouse management practices, drainage and burning, also have little direct effect on the blanket bog vegetation of the Reserve at present.

Drainage

Drainage by means of ditches, has been little practised on blanket bog and where it has been carried out (e.g. Sike Hill) there has been no detectable change in the vegetation.

Burning

Burning has a more significant effect than drainage, but has not been practised on the Reserve with any regularity since 1951. Any burning that has taken place since has been experimental, accidental or to aid neighbouring estates. The scale of recent burns, and therefore associated vegetational changes, has been much smaller than in the past; nowadays burns are only about 0.5-10 ha in extent compared with a maximum of about 120 ha early in the century. The effect of burns which took place before 1951 is still probably evident also.

Burning usually kills the old *Calluna* stems and stimulates new growth either from the stem bases buried in the peat or from seedlings, depending on the temperature of the fire. If this exceeds 290°C in the region of the perennating buds, death of the old root-stock occurs and death of the old stem bases also normally occurs if the plants are more than 15-20 years old (Whittaker and Gimingham 1962). At Moor House the effects of burning have been assessed both by observation, and by experiments with long and short rotation burn plots which also allowed evaluation of the interactions of grazing effects with those of burning. These experimental plots, planned by R. J. Elliott, were situated on Hard Hill. They were first burnt in 1954 and the short rotation treatments were reburnt after 11 years. The results have been assessed by a series of students.

Forrest (1961) carried out a botanical analysis of the control plots and those burnt seven years previously. He found that regeneration of *Calluna* was entirely from seed, and that cover of *Calluna*, *Empetrum* and *Sphagnum* decreased on the burnt areas, and *E. vaginatum* and *Rubus chamaemorus* increased, the latter species being taller growing also. Forrest suggested a scheme of succession after burning. The pioneer stage was mainly of bryophyte and lichen species favouring a high light intensity, e.g. *Coriscium viride*. This was succeeded by *E. vaginatum* dominance and gradual elimination of the pioneer species by shading and competition. The development of luxuriant *Sphagnum* dominated areas then followed, succeeded or accompanied by increase of *Calluna* and pleurocarpous mosses with corresponding decrease of *Eriophorum* spp.

Regeneration of *Calluna* from seed is probably fairly slow at Moor House, particularly in the wetter areas. The dominance of *E. vaginatum* probably results from destruction of *Calluna* and burning of old *E. vaginatum* leaves, thus stimulating the latter species since its growing point is protected within other leaves at the ground surface, and regenerative tissue is in the form of underground rhizomes. The resting buds of *Rubus chamaemorus* are also undamaged by fire allowing this species to increase after burning (Marks and Taylor 1972). The normal period of *E. vaginatum* dominance is c. 6 years, but if the area is heavily grazed dominance of this species may be maintained permanently, although Studley (1967) observed that little grazing of the regenerating *Calluna* plants occurred. At Moor House *Calluna* generally returns to its co-dominance with *E. vaginatum* within 10 years under the relatively low grazing pressure on the blanket bog, except at higher altitudes where *Calluna* recovery is slower. The bryophyte cover usually initially appears to be little affected by a burn, but after a few months it may become moribund and some of the species may die out.

Studley (1967) also assessed the results of the experimental plots. She found that standing crop was reduced under both treatments but in the long rotation plots after 13 years regeneration the percentage of green shoots and the percentage of dead wood were similar to the controls, although the standing crop was still less (Fig. 9a). Studley also found that bare areas liable to erosion were created beneath the dead root stocks.

Gore and Olson (1967) investigated the probably succession following a burn at Moor House by clipping an area of blanket bog at Bog End. They then simulated this succession by using modelling techniques with successive approximation of the modelling to the field results. Jones, Forrest and Gore (1971) also used a computer simulation of the recovery of blanket bog vegetation after a fire.

Data from various workers of total standing crop recovery following a burn at Moor House, Banchory and Dorset have been plotted (Fig. 9b). In the latter are dry Calluneta at 170 m and 15 m O.D. respectively and are normally managed by regular burning. A levelling off of total standing crop occurs after 20 years at Moor House, much earlier than at Dorset and Banchory. This presumably is because the burial of decumbent Calluna stems by Sphagnum overgrowth at Moor House causes a more rapid attainment of equilibrium here than at the drier sites where there is little or no Sphagnum present.

Burning also results in some nutrient loss from the ecosystem, the importance of which is debateable. Elliott (1953) and McVean (1959) found that nutrient loss by burning, particularly of potassium, was serious. More recent work is however contrary to this and showed that the soluble ions were retained by the peat and the nutrients driven off in smoke (including about half the carbon, nitrogen and sulphur in the vegetation) would be, except for nitrogen, all replaced by rain input in a short period (Allen 1964, Evans and Allen 1971). The replacement of nitrogen took longer and mobilisation of soil nitrogen by micro-organisms may be an important contributory factor in any replacement.

9.2.4 Influence of sheep

Behaviour

On all vegetation types except the blanket bog the most important management factor is sheep grazing, and it probably is the main factor determining the community composition, particularly on drier sites. Each ewe tends to keep within its own territory which overlaps with that of others, and as new lambs are born they continue the traditions. A ewe will normally be on the fell for only three years. Since the western side and the crest of the Pennine ridge is largely grassland and the eastern side mainly blanket bog, there are fewer flock territories on the eastern side than on the remainder, the sheep tending to favour the grasslands. The type of community favoured by sheep is also influenced by where they were raised.

Efficiency of production

The fell sheep is a very inefficient animal, with a slow growth rate, each animal producing little in any one year. The efficiency of animal production:food intake is only 2.2% (Rawes 1971a) compared with 10.9% for beef cattle on lowland areas (Phillipson 1966). The annual net production of sheep at Moor House is only 22.8 kg/ha fresh weight (Rawes and Welch 1969) and much of the annual primary production is not utilised by the herbivores. Rawes and Welch (1969) have also examined the sheep density, herbage production and intake over a six month growing season, on 16 different sites representing the six most important sward types. The average intake of a sheep was 1.5 kg/day. The production of the swards was generally low and not directly related to their utilisation by sheep, since the most favoured Agrostis/Festuca grasslands had a higher productivity than the lesser used vegetation types (Table 9a). Altitudinal variation also caused large differences in the production of the communities.

Botanical effects of grazing

Grazing management may change by increase or decrease of grazing, seasonal differences in grazing intensity, or differences in the age-class of the flocks.

The effects of removal of grazing on the botanical composition of the vegetation have been assessed by Welch and Rawes (1964), using charting methods and 1000 permanent point quadrats at three grassland sites. These changes have now been followed for sixteen years although the later results have yet to be published. In general removal of grazing led to greater differentiation of swards with less interdigitation of growth of adjacent plants and reduced cover of unpalatable species. Later work by Rawes et. al. assessed the effects of a range of grazing intensities at different seasons of the year.

The small influence of the present grazing regime on the blanket bog vegetation is illustrated by the effect of fenced exclosures at Bog Hill; even after 16 years there was little change in the vegetation which is therefore probably approaching a climax. Trampling by sheep may however have more significant effects (Forrest 1961), by reducing Sphagnum cover. Sheep density on the blanket bog may be as low as 0.025 sheep/ha (Welch and Rawes 1966) but it is normally about five times this. Any increase in the number of sheep on the fell would cause greater utilisation of the blanket bog areas. Particularly important would be increased use of the fells for winter grazing; the blanket bog is relatively more attractive at this time of the year because of the winter browning of grassland. At present Calluna and Eriophorum vaginatum are utilised to a certain extent during this season, the latter being a species capable of growth at low temperatures. Trichophorum cespitosum, Narthecium ossifragum, Eriophorum angustifolium and Rubus chamaemorus are also utilised, particularly in late summer. Taylor and Marks (1971) investigated the effects of sheep grazing on the growth of Rubus chamaemorus and concluded that the sheep sought out and closely grazed the young shoots and flowers of this species and E. vaginatum. Welch and Rawes (1966) compared three areas of blanket bog just outside the Reserve, which were subjected to different grazing intensity. An increase of grazing intensity on blanket bog causes, on the drier areas, decrease of Calluna and increase of Deschampsia flexuosa and Festuca ovina, and on the wetter sites dominance of Juncus squarrosus. Thus the value of the community for grazing has been enhanced by increased grazing pressure (Rawes 1971a). More recent work at House Hill showed early elimination of Calluna from blanket bog subjected to heavy grazing, (Rawes and Williams, in press). At higher altitudes Calluna is replaced by Empetrum nigrum as a result of grazing and possibly also climate. The effects on the blanket bog vegetation of winter versus summer grazing are being assessed at House Hill, and have yet to be evaluated. The change under grazing to a largely hemicryptophytic vegetation, is mainly a result of the ability of this vegetation type to withstand cropping, since the growing point remains undamaged.

The non-blanket bog vegetation types are utilised by sheep to a variable degree dependent on a number of factors. These include, apart from the botanical composition and therefore palatability of the herbage, factors such as exposure, sheltered communities being preferred. Also important in determining utilisation are the altitude of the community, the number of sheep available, the wetness of the vegetation, and the presence of alternative more palatable communities.

All the grassland communities reflect only the effects of sheep, there being no grouse, or management practices such as burning or drainage, on these areas. All these communities are apparently at equilibrium, there being no evidence of change in botanical composition under the present grazing regime, except in certain overgrazed Agrostis/Festuca swards (see below). Trees would probably be the climax vegetation on many of these areas below 600 m altitude.

The plant community most readily digested and therefore preferred by sheep is the Agrostis/Festuca grassland, characteristic of shallow limestone soils. On the west side of the Reserve this vegetation type is overgrazed in some areas, unpalatable species such as bryophytes and Cirsium spp. having increased. On the east side, where this community is more localised by streams and sink holes, no overgrazing occurs, since the area is rested in winter when the sheep are removed from the fells. The sheep on this side of the fell put on 3 kg more weight by July than on the west side, probably because of the lighter grazing pressure on the food sources, (Rawes and Welch 1969). The Agrostis/Festuca grassland is very palatable and 50% of the above-ground herbage production is utilised (Rawes and Welch, 1969), compared with only 14% by beef cattle in a pastoral system in England (MacFadyen 1964). Grazing density on the Agrostis/Festuca community is usually 5-13 sheep/ha. Some of the flowering plants (e.g. Myosotis alpestris) have evolved dwarf ecotypes, increasing their ability to withstand grazing (Elkington 1962). Removal of grazing (Welch and Rawes 1964) in general leads to decrease of bryophytes and lichens and many flowering plants at present characteristic of the Agrostis/Festuca grassland, and increase in species such as Deschampsia caespitosa, Achillea millefolium, Agrostis tenuis and Festuca ovina. Many of these areas would probably revert to tall herb, scrub, or fern communities, in the absence of grazing.

It is believed that there is a maximum acceptable density of sheep on an area of Agrostis/Festuca grassland, and this is determined by the number of sheep with territories which include the particular sward, which will be actively defended. If this density is exceeded any extra animals will move onto other adjacent vegetation types such as Nardetum, Juncetum (these two communities together occupy 20% of the Reserve area), Festucetum, and to a lesser extent blanket bog.

Within the Juncetum Juncus squarrosus itself is little grazed, except in spring when it is one of the few remaining green plants, but the grass species are utilised more fully. The production of this community as a whole is relatively high in comparison to other grasslands and the blanket bog, and the proportion consumed is also relatively large. However the Juncetum is little grazed during the late summer when the main vegetation type utilised is Nardetum. The latter has a lower productivity, of a more fibrous and mineral poor herbage than the Juncetum, although its utilisation by sheep is more than that of the latter community. Removal of grazing on these two communities, and on Festucetum (Welch and Rawes 1964) leads to increase of Deschampsia flexuosa and decrease of Nardus and Juncus.

Other effects of grazing

However in addition to direct botanical change alteration of the grazing regime has other effects, chief effects of which are on nutrient distribution. Crisp (1966) constructed a balance sheet for a catchment on the east side of the Reserve and found that the actual nutrient loss from the ecosystem by cropping is very low in comparison to the total loss which is mainly by erosion and solution, and the input in rainfall (Table 9b). Nitrogen has the highest loss through cropping but this is only 0.5% of the total, and phosphate with the highest proportionate loss is only 1% of the total. However the total loss from the catchment is not entirely replaced by rainfall input, and there is a continuous small scale nutrient loss from this ecosystem of original low fertility.

More important than nutrient loss via sheep cropping is probably redistribution of nutrients, both between and within plant communities, by defaecation and urination (Table 9c). Rawes and Welch (1969) regard between site transfers as non-significant, but there may be nutrient enrichment of night resting sites with a concomitant impoverishment of day-time feeding sites, mainly Agrostis/Festuca grassland. There is probably significant within sward transfer (Hilder 1966) and defaecation may increase biological activity and thus nutrient availability.

Botanical change resulting from alteration of grazing management may cause nutrient effects and changes in litter type and decomposition rate. The nutrient effects mainly result from the different rooting depths of each species. For example Eriophorum vaginatum, can obtain 70% of its phosphorus supply from below 15 cms (Boggie et. al. 1958) and thus burning and the resulting E. vaginatum dominance may lead to increased phosphorus availability to the succeeding shallower rooted species. Also the decreased Sphagnum cover caused by grazing and burning may reduce the nutrient absorptive capacity of the ecosystem (Gore and Allen 1956).

The amount of litter accumulating may be altered if grazing is removed from an area. Welch and Rawes (1964) in their studies of three grassland exclosures (p.45) observed increased accumulation of organic matter following removal of grazing, a distinct litter layer being formed. This accumulation was greatest on the highest site (Great Dun Fell), there being nearly twice as much litter after seven years exclosure, as on the grazed sward (Table 9d). This litter accumulation may cause acidification of the soil. The Great Dun Fell site was on a sandstone soil, at Knock Fell the exclosure was on a brown calcareous soil and here there was a decrease in accumulated litter over the season. This suggests a more rapid breakdown than at the other two sites studied, possibly because of the more fertile soil at Knock Fell (Rawes and Welch. 1964). Change in species forming the litter may also occur following grazing removal, with consequent change in decomposition rates (Heal and Latter 1971). The decomposition of litter is also influenced by compaction and puddling produced by sheep trampling.

The changes in litter characteristics and absorption capacity are most marked on peat soils, whereas nutrient effects are dominant on mineral soils.

9.2.5 Interaction of several management practices

Moor House National Nature Reserve is thus an area consisting of a mosaic of different plant communities, upon each of which the various management practices have different effects. Little is known however about the interacting effects of a combination of several management practices on productivity, fertility, and botanical composition, or of applying these practices in an extreme form, important in view of their low intensity of operation at present. The effects of the interaction of burning and grazing have been assessed at House Hill and preliminary results are discussed in Rawes and Williams (in press). Burning prior to heavy grazing caused few effects additional to those of heavy grazing alone, except for earlier reduction of Calluna. The interaction of burning and grazing has also been studied on the Hard Hill experimental plots (p. 43) and the effects of this interaction on Calluna productivity are described in Rawes and Williams (in press) and on Rubus performance in Taylor and Marks (1971) and Marks and Taylor (1972).

9.2.6 Reversibility of management practices

The whole question of the reversibility of management induced changes is also extremely important and has rarely been investigated experimentally. It is believed that the dominance of E. vaginatum in the southern Pennines is due to grazing, burning (Pearsall 1941, 1950) and pollution, and is possibly a non-reversible change (Rawes and Gore, manuscript). Jones (1967) working in Wales, found the effects of exclosure still apparent in swards that had been re-opened to grazing 25 years previously.

9.2.7 Possibilities of upgrading and other land-use options

There is a possibility that this relatively unproductive land could be upgraded by fertilisation and reseeding. Limited fertilisation experiments have been tried and on blanket bog there was no response to calcium or phosphate application (Gore 1961a and b, 1963), and only a small response to nitrogen (Gore 1961b, 1963). It would thus appear that there is probably no one limiting factor to growth on blanket peat at Moor House. On Eriophoretum nitrogen applied at 43 kg/ha doubled grazing (Rawes and Gore, manuscript), and on Agrostis/Festuca grassland Rawes (1963) showed that the standing crop of 2400 lb/acre was doubled by the application of NPK fertiliser and ground limestone. However there was little response on Nardetum (Rawes 1965), it being thought that mechanical action was required first in this case. Reseeding has been tried on blanket bog, good yields being obtained with grasses under heavy fertilisation.

The principal alternative land use for this marginal land is forestry, and the feasibility of this on blanket bog has been assessed by trials of different tree species (Miller 1958, Carlisle et. al. 1959-71, Brown, Carlisle and White 1964). On the whole the Pinus spp. (P. sylvestris, P. contorta and P. mugo var. rostrata) performed best; Picea sitchensis (Alaskan provenance) and Larix eurolepis also grew quite well. These workers also applied a range of fertiliser treatments to one species (Pinus contorta) growing on blanket peat at Bog End and showed that phosphorus and potassium were limiting but mineralisation of nitrogen was adequate to maintain growth.

These large areas of blanket peat are also useful as a medium for water storage, buffering the effects of heavy rain storms and prolonged droughts.

10 FAUNA AND MICROFLORA

10.1 Introduction

The invertebrate fauna, especially the soil fauna, has been extensively studied at Moor House with less attention paid to the microflora and to vertebrates. In the present paper a detailed description of the fauna and microflora is not attempted, only a brief comment on some of the general features is given. A summary of the main invertebrates studied, with references, is given in Table 10a and a full bibliography in Rawes (1971b). A review and discussion of the invertebrate fauna was published in 1961 by J. B. Cragg who supervised most of the fauna research. The research has continued for another decade and the broad characteristics which he describes have been confirmed although many details have been refined.

10.2 Vertebrates

There is a restricted range of vertebrates at Moor House (Table 10b) and few species have been studied intensively. The general impression is that on the blanket bog, grouse are the only vertebrate present in large numbers. Taylor and Rawes (in press) report numbers over the range 0.39 to 5.55 birds/ha in autumn, 1971 and 1972 being years with very high population densities. Low densities of sheep (0.01 to 0.71/ha) and *Microtus* (c. 1.0/ha) are reported by Rawes and Welch (1969) and Evans and Evans (1971) respectively.

On the *Festuca*/*Agrostis* and *Juncus squarrosus* grasslands, sheep, in summer, are present in numbers between 0.6 and 13.3/ha. *Microtus* reaches 90 individuals/ha in sheep exclosures where vegetation is taller than on grazed grasslands (Evans and Evans 1971). Of the birds, the meadow pipit (*Anthus pratense*) is common (0.5/ha) along the stream banks where it feeds on tipulids and aquatic insects (Coulson 1956). A very low rate of predation on the chicks of the meadow pipit compared with lower altitudes (Coulson 1956) and the low proportion of the *Tipula subnodicornis* population consumed by the pipits - and by spiders (Cherrett 1961) - supports the subjective impression that there is a restricted trophic pyramid at Moor House. Some observations on the gut content of *Rana temporaria* and *Sorex* spp. are given by Houston 1970.

10.3 Invertebrates

Cragg (1961) emphasised that the invertebrate fauna of Moor House proved more complex than was expected when the site was selected, in 1952, for intensive study. Since 1961 an extensive study of invertebrates produced a list of 637 species (Nelson 1971). This, with previous studies, brings the number of identified species of invertebrates to just over 1000 for the Reserve.

In a comparison of the fauna of the different soil types Cragg showed that the biomass was greatest in limestone grassland, intermediate in *Juncus* moor and low in *Calluna* moor. The grasslands are dominated by earthworms, the peaty soils by Enchytraeidae. Further analysis by MacFadyen (1963), Springett (1967) and more recent studies on enchytraeids and tipulids confirm the broad pattern indicated in the earlier calculations. A summary, from Springett (1967), is given in Table 10 c.

The species composition of the invertebrate fauna varies greatly between the soil and vegetation types (Nelson 1971, and specialist papers). However the total number of species does not differ markedly between sites, with the exception of the very wet Valley Bog (Table 10d). The amount of structural diversity, the number of plant species, and the soil conditions appear to influence the number of species present (Nelson 1971, Cherrett 1964). One feature of the fauna is that, in many taxonomic groups, the species composition shows similarities to arctic-alpine and Fennoscandian faunas, probably reflecting the climatic conditions at Moor House.

Within each major plant community, the individual groups of soil fauna have usually been shown to be aggregated in numbers and to have micro-habitat separation of species related to moisture conditions and plant composition, (e.g. Peachey 1963, Cherrett 1964, Hale 1966). Studies of the vertical distribution of soil fauna show that on the blanket bog the majority of individuals of all groups are restricted to the upper 5 cms of the litter and peat, presumably because of the waterlogged conditions. A greater depth distribution sometimes occurs in the podsols and brown earths of the alluvial and limestone grasslands.

The population dynamics of a number of species indicate the importance of climatic factors in controlling populations. Predators and parasites, as an influence on populations, are less important than in lowland Britain, and density related mortality has been indicated only rarely, (Cragg 1961, Whittaker 1971, Hadley 1971, Horobin 1971).

The trophic relations of the soil fauna are little understood in comparison to population characteristics. MacFadyen (1963) on the basis of data in Cragg (1961) and knowledge of the organisms, gave a quantitative assessment of the main trophic levels of the soil fauna of the limestone and Juncus grassland, (Table 10e). Herbivores contribute little on these sites and on the blanket bog (Heal, 1972). The majority of soil fauna is involved in detritus or microbial feeding and carnivores, both invertebrate and vertebrate, are largely dependent on a detritus rather than a herbivore food chain.

10.4 Microflora

The soil microflora is characterised by increasing numbers of species and individuals and rates of activity over the series bare peat, blanket bog, Juncus moor and limestone grassland (Fig. 10a) (Latter, Cragg and Heal 1967). The levels in each soil type are not detectably different from those in similar lowland soils. As with the soil invertebrates there are marked patterns of micro-habitat and vertical distribution.

Intensive studies of bacteria on the blanket bog by V. G. Collins and B. T. D'Sylva, A. J. Holding, N. Martin and E. MacEvoy, are in preparation for publication, but a summary of estimates of different bio-chemical groups of bacteria, is given in Table 10f. Lists of fungal species are given in Latter, Cragg and Heal (1967) and a more recent list of 48 species of basidiomycetes was compiled by Houlton (1972).

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TABLES

FIGURES

Table 1a. *Moor House IBP and other primary production sites*

(R = Rawes; W = Welch; A = Allen; P = Park)

Name of site	Grid reference	Altitude (m)	Aspect	Slope (°)	Principal worker(s) & references	Detail of present survey	Vegetation Association	Main primary production study species
Sike Hill (dry)	NY 769331	550	-	0	Forrest (1971)	Very detailed	Calluneto-Eriophoretum	All species
Bog Hill	NY 767326	550	NE	5	Forrest & Smith (in prep.)	detailed	"	"
Green Burn	NY 774323	515	-	0	Forrest & Smith (in prep.)		Trichophoro-Eriophoretum	"
Bog End	NY 764329	556	-	0	Forrest & Smith (in prep.)		Calluneto-Eriophoretum	"
Cottage Hill A	NY 752335	561	E	10	Forrest & Smith (in prep.)		Calluneto-Eriophoretum Grazed Facies	"
Cottage Hill B	NY 753335	558	E	10	Forrest & Smith (in prep.)			"
Sike Hill (wet)	NY 770331	550	SE	5	Forrest & Smith (in prep.)		Calluneto-Eriophoretum	"
Burnt Hill	NY 754328	575	-	0	Clymo and Reddaway (1971, 1972)		"	*Sphagnum* spp.
Hard Hill	NY 742329	610	SE		Taylor & Marks (1971), Marks & Taylor (1972)		"	*Rubus chamaemorus*
B1	NY 747342	566-549			Rawes & Welch (1969)	summary	"	all species
B2	NY 752334	566-555			R & W (1969)		"	"
B3	NY 756329	566-550			R & W (1969)		"	"
B4	NY 762330	524			R & W (1969)		"	"
B5	NY 770326	535			R & W (1969)		"	"
B6	NY 774323	518			R & W (1969)		"	"
B7	NY 773325	518			R & W (1969)		"	"
B8	NY 759336	535			R & W (1969)		"	"
B9	NY 742331	600-590			R & W (1969)		"	"
B10	NY 738332	640-652			R & W (1969)		"	"
B11	NY 771317	535			R & W (1969)		"	"
B12	NY 724318	688			R & W (1969)		"	"

Table 1a (continued)

Name of site	Grid reference	Altitude (m)	Aspect	Slope (°)	Principal worker(s) & references	Detail of present survey	Vegetation Association	Main primary production study species
E1	NY 751341	551			Rawes & Welch (1969)	summary	Calluneto-Eriophoretum	All species
E2	NY 752335	566-555			R & W (1969)		(Grazed Facies)	"
E3	NY 772323	535			R & W (1969)		"	"
E4	NY 712308	680			R & W (1969)		Eriophoretum	"
E5	NY 716315	765			R & W (1969)		"	"
F1	NY 726329	678			R & W (1969)		Festucetum	"
F2	NY 704331	840-822			R & W (1969)		"	"
Little Dun Fell	NY 704332	823	E		R & W (1964) W & R (1964) W & R (1965)		"	"
Hard Hill	NY 730332	678	-		P, R & A (1962)		"	"
A1	NY 745346	555			R & W (1969)		Agrosto-Festucetum	"
A2	NY 746346	550			R & W (1969)		"	"
A3	NY 774323	510			R & W (1969)		"	"
A4	NY 717311	747			R & W (1969)		"	"
Knock Fell	NY 717311	747			P, R & A (1962), W & R (1964, 1965) R & W (1964, 1966)		"	"
A5	NY 700297	480			R & W (1969)			
	NY 700297	480	W		W & R (1965)		"	"
					W & R (1966)		"	"
A6	NY 756327	560			R & W (1969)		"	"
A7	NY 713313	747-716			R & W (1969)		"	"
Tees	NY 774328				R (1963) W & R (1965) R & W (1966)		"	"
-	NY 772330	518			R (1961)		Nardetum	"

Table 1a (continued)

Name of site	Grid reference	Altitude (m)	Aspect	Slope (°)	Principal worker(s) & references	Detail of present survey	Vegetation Association	Main primary production study species
N1	NY 748345	549			R & W (1969)	summary	*Nardetum*	All species
N2	NY 699298	470-459			R & W (1969)		"	"
N3	NY 705297	575-550			R & W (1969)		"	"
N4	NY 774325	512			R & W (1969)		"	"
J1	NY 757336	549			R & W (1969)		Juncetum squarrosi	"
J2	NY 758337	549			R & W (1969)			"
J3	NY 702297	548			R & W (1969)		"	"
J4	NY 718311	748			R & W (1969)		"	"
M1	NY 774324	518			R & W (1969)		Soligenous bog meadow	"
-	NY 757328	563			R & W (1969)			"

Table 2a Selected climatic parameters for Moor House 1968-72, with 10-year means

Year	Parameter	JAN.	FEB.	MAR.	APR.	MAY.	JUNE	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
1968	½(Max.+Min.) Temperature °C	0.3	-3.0	1.5	3.7	4.9	10.3	10.2	10.9	9.3	(8.5)	(2.8)	-0.7
	Highest Maximum Temperature °C	7.8	6.1	12.2	13.9	17.2	21.1	18.3	21.7	16.7	15.6	9.4	6.7
	Lowest Minimum Temperature °C	-12.8	-11.7	-9.4	-8.9	-4.4	0.6	0.6	1.7	-0.6	-0.6	(-6.1)	-7.8
	Temperature Sum (>5.6°C)C°	0.0	0.0	0.0	0.0	0.0	141.0	142.6	164.3	111.0	89.9	0.0	0.0
	Rainfall (mms)	204.5	146.8	305.8	108.2	124.5	123.4	132.6	58.4	285.0	242.1	100.6	144.3
	Days with snow lying	14	28	14	8	2	0	0	0	0	0	2	14
	Days with air frost	19	29	19	11	14	0	0	0	1	2	8	26
	Days with ground frost	23	29	25	21	18	8	5	7	5	3	15	25
	Total sunshine (hrs)	19.9	83.2	65.7	160.0	126.9	209.7	85.7	128.1	70.1	34.5	26.5	12.6
	Average wind speed (knots)	20.6	13.2	20.1	13.4	9.8	9.5	8.1	9.7	12.0	14.2	14.7	13.1
1967	½(Max. + Min.) Temperature °C	1.1	-4.2	-1.9	2.2	6.2	9.5	12.0	12.3	9.4	9.2	0.5	-0.2
	Highest Maximum Temperature °C	7.8	3.9	5.0	14.4	14.4	19.4	23.3	21.7	17.8	19.4	11.7	6.7
	Lowest Minimum Temperature °C	-10.6	-18.3	-11.7	-8.3	-2.8	-4.4	2.8	1.7	0.0	0.0	-8.3	-8.3
	Temperature Sum (> 5.6°C)C°	0.0	0.0	0.0	0.0	18.6	117.0	198.4	207.7	114.0	111.6	0.0	0.0
	Rainfall (mms)	149.4	142.2	125.7	135.6	118.4	114.1	64.5	78.2	143.3	87.4	350.0	162.6
	Days with snow lying	11	28	31	8	0	0	0	0	0	0	20	12
	Days with air frost	20	27	30	21	7	2	0	0	1	1	24	23
	Days with ground frost	20	28	30	23	12	11	3	1	6	4	25	24
	Total sunshine (hrs)	(11.5)	57.3	55.3	147.1	97.5	228.1	170.2	161.1	73.8	103.7	32.4	22.1
	Average wind speed (knots)	13.5	17.7	15.6	11.9	9.7	9.7	12.9	10.8	12.1	15.9	17.3	14.3
1970	½(Max.+Min.) Temperature °C	-0.5	-2.5	-0.9	1.3	8.3	11.3	10.5	11.7	10.1	6.3	2.9	0.9
	Highest Maximum Temperature °C	6.1	5.6	6.1	10.0	18.3	23.3	22.8	21.1	20.0	16.1	11.7	7.2
	Lowest Minimum Temperature °C	-14.4	-15.0	-10.6	-8.3	-1.7	0.0	2.2	2.2	-0.6	-1.7	-5.6	-6.1
	Temperature Sum (>5.6°C)C°	0.0	0.0	0.0	0.0	83.7	171.0	151.9	189.1	135.0	21.7	0.0	0.0
	Rainfall (mms)	157.0	280.2	154.0	203.0	61.2	95.8	170.4	185.2	154.7	266.7	240.5	172.7
	Days with snow lying	14	26	6	14	0	0	0	0	0	0	12	8
	Days with air frost	18	26	25	20	3	0	0	0	1	3	12	20
	Days with ground frost	24	28	30	23	8	7	3	3	3	10	20	27
	Total sunshine (hrs)	25.9	64.5	107.5	109.5	171.0	234.3	121.5	174.2	91.0	80.6	23.1	36.2
	Average wind speed (knots)	(13.2)	(20.0)	(16.9)	(17.0)	13.0	(10.0)	15.0	(10.7)	(16.9)	(18.4)	(17.6)	(15.2)

1971	½(Max. & Min.) Temperature °C	1.2	1.2	0.9	3.5	7.0	7.5	12.3	11.1	10.2	7.3	2.1	3.3
	Highest Maximum Temperature °C	10.2	8.2	7.0	14.7	15.7	16.3	22.8	18.6	19.8	13.5	11.0	10.3
	Lowest Minimum Temperature °C	-12.4	-10.2	-10.5	-5.2	-2.8	-2.8	-0.9	3.3	-3.5	-5.5	-8.4	-3.6
	Temperature Sum (≥5.6°C)C°	0.0	0.0	0.0	0.0	43.4	57.0	207.7	170.5	138.0	52.7	0.0	0.0
	Rainfall (mms)	138.8	154.1	127.2	53.6	76.4	129.1	63.7	186.6	41.1	140.2	172.7	61.6
	Days with snow lying	7	12	13	1	0	0	0	0	0	0	7	4
	Days with air frost	15	18	22	17	7	2	1	0	2	3	19	11
	Days with ground frost	24	20	21	19	16	8	6	2	5	10	21	15
	Total sunshine (hrs.)	21.8	50.0	68.6	122.9	220.0	114.0	227.9	109.3	140.4	82.0	41.0	9.3
	Average wind speed (knots)	14.6	13.2	12.3	10.6	10.7	11.5	8.6	11.1	10.4	17.7	19.6	21.1
10-YEAR MEAN 1961-70	½(Max. + Min.) Temperature °C	-0.4	-1.3	0.6	3.4	6.5	9.9	10.6	10.7	9.3	6.8	2.1	-0.2
	Highest Maximum Temperature °C	6.6	6.5	8.8	14.3	17.6	20.0	19.9	20.3	17.8	15.2	10.0	8.2
	Lowest Minimum Temperature °C	-11.6	-11.8	-9.3	-6.8	-3.1	-0.7	1.2	0.5	-0.3	-2.1	-7.7	-10.6
	Temperature Sum (>5.6°C)C°	0.0	0.0	6.0	0.0	29.8	127.8	153.5	158.7	112.2	39.1	0.0	0.0
	Rainfall (mms)	185.2	155.5	159.5	144.8	131.1	114.1	135.9	177.8	185.7	189.2	207.8	194.3
	Days with snow lying	18.6	19.1	13.5	7.3	0.7	0.0	0.0	0.0	0.0	0.4	8.7	14.1
	Days with air frost	23.1	22.3	21.2	14.7	7.0	1.1	0.3	0.5	1.6	3.4	15.3	22.3
	Days with ground frost	26.0	24.7	25.0	20.8	12.0	5.9	3.4	3.7	4.7	8.3	21.0	25.4
	Total sunshine (hrs.)	30.9	47.9	83.0	110.5	143.1	173.4	122.1	128.6	91.8	76.7	39.8	33.5
	Average wind speed (knots)	15.8	17.1	17.8	14.7	12.4	11.7	12.0	11.5	13.7	14.7	15.4	16.0

Bracketted figures indicate incomplete record, but for more than half the mouth

Table 2b Coefficients for the regressions of radiation on sunshine duration (A. D. Bailey, pers. comm.)
Regressions in the form $y = a + bx$. $y = Q$ or Q/Q_A and $x = n$ or n/n_A where Q - actual radiation (gcal. cm^{-2}); Q_A - total possible radiation for period (gcal. cm^{-2}); n - actual sunshine (hrs); n_A - total possible sunshine for period (hrs).

	Reg. Q on n			Reg. Q/Q_A on n/n_A		
Month & Year	a	b	r	a	b	r
October '71	56.744	20.608	0.869	0.156	0.571	0.906
November '71	30.323	15.044	0.914	0.158	0.642	0.889
December '71	18.082	11.620	0.667	0.145	0.696	0.693
January '72	21.159	19.920	0.811	0.136	0.811	0.806
February '72	52.952	19.637	0.802	0.187	0.631	0.796
March '72	102.971	25.649	0.882	0.208	0.592	0.928
April '72	141.042	31.169	0.921	0.197	0.582	0.929
May '72	145.098	36.448	0.944	0.159	0.634	0.945
June '72	171.204	34.917	0.962	0.170	0.589	0.963
July '72	188.027	31.172	0.958	0.194	0.530	0.959
August '72	142.248	31.958	0.935	0.172	0.594	0.949
September '72	120.229	24.787	0.933	0.209	0.501	0.946

Table 3a Grant temperature probe positions on Sike Hill

Probe No.	Probe height (cm)	Probe position
1	- 25	Peat under *Calluna*
2	- 10	Peat under *Calluna*
3	- 6	Peat under *Calluna*
4	- 3	Peat under *Calluna*
5	- 1	In *Calluna* litter
6	- 1	In *Calluna* litter
7	+ 4 approx.	*Rubus* zone (*Calluna* enclosure)
8	+ 4 approx.	*Rubus* zone (*Eriophorum* enclosure)
9	In stream	In Dodgen Pot Syke
10	In stream	In Dodgen Pot Syke
11	- 1 (arbitrary)	In *Eriophorum* litter in tussock
12	- 1 (arbitrary)	In *Eriophorum* litter in tussock
13	+ 18	In *Calluna* canopy
14	+ 152	Above *Calluna* canopy
15	+ 152	Above *Calluna* canopy
16	+ 18	In *Calluna* canopy
17	- 0.5	In *Sphagnum*
18	- 0.5	In *Sphagnum*
19	- 5.0	In *Sphagnum*
20	- 5.0	In *Sphagnum*
21	+ 2	In *Juncus* vegetation
22	+ 2	In *Juncus* vegetation
23	- 1	In *Juncus* litter
24	- 1	In *Juncus* litter
25	- 3	Peat under *Juncus*
26	- 6	Peat under *Juncus*
27	10	Peat under *Juncus*
28	- 25	Peat under *Juncus*

Table 3b Accumulated temperature sums for 1969 for range of litters examined

Litter Type and Probe Position	Accumulated Temperature Sum (Day Degrees Above 0°C) Replicate 1	Replicate 2	Mean
Calluna - 1 cm	1954	1982	1968
Sphagnum - 5 cm	2127	2069	2098
Sphagnum - 0.5 cm	2123	2123	2123
Eriophorum - 1 cm	2228	2077	2153
Juncus - 1 cm	2238	2181	2210

Table 3c Predicted and actual temperatures for probe 3 (-6 cm) for 1970.

Prediction based on **conversion for probe** 20 (-5 cm) (J. A. Webster, **pers. comm.**) i.e. if met. difference 1969/70 > 1° reduce this difference by 1° and use resulting figure to correct probe Fourier values for 1969. (Any values < -1°C are taken as -1°C)

Temperature (°C)

Week	1st harm. prediction	3rd harm. prediction	Actual
1	- 1.0	- 1.0	- 1.3
2	- 0.4	- 1.0	- 0.8
8	- 1.0	- 0.5	- 1.0
13	- 1.0	- 1.0	- 1.0
17	3.9	2.6	3.5
20	6.3	6.7	7.7
22	8.9	10.2	10.4
26	9.4	10.6	9.3
27	10.7	11.5	12.2
32	11.6	10.9	11.6

Table 3d Grant temperature probe positions on Burnt Hill (Clymo pers. comm)

Probe height (cm)	Probe position
+ 152	Stanchion
+ 10	Stanchion
+ 1	Stanchion
0	Lawn (2 sites)
0	Hummock top
0	Hummock, N. face
0	Hummock, NW face
0	Hummock, SW face
0	Pool (2 sites)
- 1.5	Below lawn
- 5	Below lawn
- 29	Below lawn
- 29	Below hummock top
- 29	Below pool bottom

Table 3e Temperatures (°C) in different *Sphagnum* microhabitats. (Clymo and Reddaway, 1968)

Time (1st May) hrs.	Microhabitat Pool	Lawn	Hummock
13.00	14.0	13.0	11.5
14.00	15.5	14.5	12.5
15.00	16.0	14.0	13.0
16.00	13.3	11.0	11.0
17.00	11.0	9.0	9.0

Time (1st May) hrs.	Hummock aspect SW	N	NW	Top
13.00	13.5	11.0	10.5	11.5
14.00	15.8	12.0	12.3	12.5
15.00	18.5	11.0	12.0	13.0
16.00	13.3	9.0	10.0	11.0
17.00	10.0	7.5	8.3	9.0

Weather conditions - partially overcast

These figures represent only a small sample of reliminary results.

Table 3f Grant temperature probe positions for Hard Hill (Marks, pers. comm.)

Treatment	Probe No.	Height relative to bog surface (cm.)	Probe position
	6*	+ 152	Reference at Stevenson screen height
Burnt 1965	8*	+ 20	Above *E. vaginatum* canopy
(*E. vaginatum*	7*	+ 8	Within *E. vaginatum*
dominant)	1	0	Litter layer (bog surface)
	2	- 6	In peat
	5*	+ 20	Top of *Calluna* canopy
Burnt 1954	4*	+ 8	Within *Calluna*
(*Calluna* dominant)	3	0	Litter layer (bog surface)
	9	- 6	In peat

probes marked * were equipped with a radiation shield

Table 5a Seasonal variation of redox zonation, pH and moisture content at Bog End, (Collins and D'Sylva, 1972)

Horizon	Range of depth (cm)	pH Dist. water	pH 1M KCl	Moisture content % dry wt.
September 1970				
Litter	0- 4	3.88	-	1264.7
Black brown	2-12	3.50	-	1099.6
Green brown	7-22	3.41	-	959.7
Red brown	22+	3.40	-	909.9
October 1970				
Litter	0- 9	3.70	3.25	806.6
Black brown	4-16	3.71	3.20	1084.2
Green brown	10-27	3.60	3.03	1044.2
Red brown	27+	3.60	2.98	869.9
February 1971				
Litter	0-12	3.33	2.90	1289.1
Black brown	2.5-14	3.20	2.73	1069.4
Green brown	11-19	3.06	2.58	1073.4
Red brown	19+	2.93	2.61	833.5
April 1971				
Litter	0- 9	3.50	3.00	798.2
Black brown	2-16	3.53	2.85	1097.9
Green brown	6-23	3.36	2.71	873.5
Red brown	23+	3.19	2.66	854.8
June 1971				
Litter	0-10	3.46	2.83	926.0
Black brown	4-20	3.56	2.85	1124.0
Green brown	11-28	3.36	2.68	866.3
Red brown	28+	3.33	2.66	1026.0

Results are the means of 3 samples

Table 5b

Range of Peat profile parameters at Bog End

	Colour (Munsell's Chart)	Depth of Horizon Commencement (cm)	Thickness of Horizon (cm)	Density (g cm-3)	Ash Content (% dry wt)	Moisture (% dry wt)	pH (dist H2O)	pH (KCl)	E4 (mv)	Na	K	Ca	Mg	Fe	P	N	C	C/N	Total H (% d wt)	CEC (meq/100g dry wt)
Litter Horizon																				
Parameter (range)		0-2	1-15	0.03	1.75-2.79	614-2028	3.1-4.2	2.6-3.4	560-610	0.019-0.024	0.056-0.103	0.12-0.22	0.041-0.075	0.12-0.16	0.045-0.067	0.64-1.45	48.4-51.9	36-76		199
Source of reference		1, 2, 3, 4, 6	1, 2, 3, 5, 6	6	7	1, 2, 4, 6, 8	1, 2, 3, 4, 9, 10	2, 4	9	7	7	7	7	7	7	7	7	7		8
Black-Brown Horizon																				
Parameter (range)	5 YR/2/2	1-15	1-10	0.07	2.85-4.29	525-1900	3.2-4.0	2.5-3.4	460-520	0.016-0.021	0.059-0.088	0.19-0.27	0.025-0.069	0.35-0.55	0.081-0.131	0.85-1.69	48.1-52.8	31-52	5.66	246
Source of reference	2	1, 2, 3, 4, 6	1, 2, 3, 5, 6	6	7	1, 2, 4, 6, 8	1, 2, 3, 4, 9, 10	2, 4	9	7	7	7	7	7	7	7	7	7	7	8
Gren Horizon																				
Parameter (range)	5 Y/2/2	2-20	3-24	0.09	2.42-3.78	733-2400	3.0-3.9	2.4-3.1	320-530	0.015-0.026	0.024-0.040	0.17-0.31	0.039-0.059	0.13-0.21	0.055-0.089	0.99-1.58	49.6-53.0	33.7-47	5.33	188
Source of reference	2	1, 2, 3, 4, 6	1, 2, 3, 5, 6	6	7	1, 2, 4, 6, 8	1, 2, 3, 4, 9, 10	2, 4	9	7	7	7	7	7	7	7	7	7	7	8
Red Brown Horizon																				
Parameter (range)	5 YR/3/2	12-36	9-36	0.10	2.68-4.47	537-1150	3.2-4.6	2.4-3.0	240-280	0.011-0.029	0.016-0.028	0.24-0.31	0.019-0.053	0.12-0.18	0.047-0.076	0.91-1.78	48.5-54.3	30.5-53.7	5.25	157
Source of reference	2	1, 2, 3, 4, 6	1, 2, 3, 5, 6	6	7	1, 2, 4, 6, 8	1, 2, 3, 4, 9, 10	2, 4	9	7	7	7	7	7	7	7	7	7	7	8

References

1 B. D'Sylva (pers. Comm.)
2 Collins & D'Sylva (1971)
3 N.J. Martin & P.M. Latter (pers. comm.)
4 R.M. McDonald (pers. Comm.)
5 Martin (1971)
6 Latter, Cragg & Heal (1967)
7 N.J. Martin & P.M. Latter (pers. comm.)
8 Holding, MacDonald, Martin & McEvoy (1970)
9 Urquhart (1969)
10 P.M. Latter (pers. comm.)

Table 5c

Within-site variation of water table at seven sites 14th August 1970
G. I. Forrest (pers. comm)

SITE.	Pit No. 1	2	3	4	5	6	7	8	9	10	Mean watertable ± 95% C.L.
	WATER TABLE DEPTH (cm)										
Sike Hill Wet	10.8	10.5	10.8	12.3	6.3	7.9	9.0	8.6	11.0	9.9	9.7±1.3
Sike Hill Dry	12.6	9.7	13.1	13.0	10.5	12.5	8.5	7.8	9.8	14.2	11.2±1.6
Bog Hill	9.3	14.1	11.6	8.3	12.7	13.7	11.7	10.3	10.9	14.9	11.8±1.5
Green Burn	9.3	7.5	7.0	10.6	7.8	8.1	10.0	8.8	9.8	6.7	8.6±1.0
Bog End	6.5	8.0	4.0	6.2	5.4	6.8	4.0	7.5	7.0	6.5	6.2±1.0
Cottage Hill A	-0.2	1.8	1.9	1.6	0.7	3.0	1.1	1.3	2.7	2.8	1.7±0.7
Cottage Hill B	6.4	2.5	2.3	0.7	4.4	5.8	3.8	4.6	3.0	4.3	3.8± 1.2

Table 5d Redox zonation, pH and moisture content at four Moor House sites (Collins and D'Sylva 1972)

Site and sampling date	Horizon	Range of depth (cm)	pH		Moisture content
			dist. water	1M KCL	% dry wt.
Sike Hill	Litter	0-15	3.30	2.77	1237.0
September 1971	Black brown	2-19	3.26	2.71	930.0
	Green brown	10-27	3.30	2.67	1037.5
	Red brown	27+	3.41	2.71	918.9
Cottage Hill B	Litter	0- 9	3.73	3.04	1488.0
September 1971	Black brown	6-19	4.06	3.23	1180.0
	Green brown	14-25	4.28	3.55	1261.4
	Red brown	25+	4.63	3.87	1082.8
Cottage Hill A	Litter	0- 8	3.31	3.21	1218.6
April 1972	Black brown	3-16	3.45	2.83	1089.8
	Green brown	7-23	3.53	2.81	1091.0
	Red brown	23+	3.64	2.90	1180.0
Green Burn	Litter	0-11	3.47	2.80	1018.2
April 1972	Black brown	1-23	3.50	2.70	1597.0
	Green brown	12-29	3.53	2.69	1710.0
	Red brown	29+	3.51	2.73	1654.0

Results are the means of 3 samples

Table 5e

Mean depth and thicknesses of redox zones on ten sites, measured with reference to bog surface

	Litter and/or living Sphagnum			Black-Brown			Green-Brown			Rust (pale)			Rust (pale) and/or lower red			Silver Wires	
Site	Mean depths of top and base of zone	Mean zone thickness	No. of samples in zone	Mean depths of top and base of zone	Mean zone thickness	No. of samples in zone	Mean depths of top and base of zone	Mean zone thickness	No. of samples in zone	Mean depths of top and base of zone	Mean zone thickness	No. of samples in zone	Mean depths of top of zone	No. of samples in zone	Mean Water Table over sampling period w.r.t. bog surface (cms)	Mean depth of commencement of blackening w.r.t. bog surface (cms)	Mean intensity of blackening (1-5 scale)
Cottage Hill A	0-1.4	1.4	4	1.4(0.6)-10.3(9.5)	8.9	4	6.0(4.5)-17.0(15.5)	11.0	2	16.0(15.0)-22.7(21.7)	6.7	3	15.8(15.0)	4	20.4	9.6	4.1
Cottage Hill B	0-2.3	2.3	4	2.3(0.8)- 6.0(4.5)	3.8	4	6.0(4.5)-14.0(12.5)	8.0	4	14.0(21.5)-22.5(21.0)	8.5	4	14.0(12.5)	4	18.8	16.1	3.7
Hard Hill	0-1.4	1.4	4	1.4 - 9.3	7.9	4	5.0-8.0	3.0	1	10.0-27.3	17.3	4	10	4	nd	17.9	2.3
Burnt Hill	0-4.5	4.5	4	4.5(0.3)-12.8(8.5)	8.3	4	11.3(7.0)-31.6(27.3)	20.3	3	17.0(13.0)-37.0(33.0)	20.0	1	28.0(23.8)	4	nd	11.3	4.2
Gren Burn	0-6.8	6.8	4	6.8(0.5)-14.0(7.8)	7.3	4	14.0(7.8)-27.3(21.0)	13.3	4			0	27.3(21.0)	4	18.1	16.5	4.5
Bog Hill (decomp)	0-3.0	3.0	4	5.0(0.5)-10.0(5.5)	5.0	4	4.7(1.7)-11.3(8.3)	6.6	3	10.5(8.3)-28.8(26.5)	18.3	4	10.5(8.3)	4	nd	18.9	2.5
Bog Hill (Forrest)	0-8.3	8.3	4	8.3(2.5)-13.5(7.8)	5.3	4	13.5(7.8)-21.0(15.3)	7.5	4	21.0(15.3)-34.3(28.5)	13.3	4	21.0(15.3)	4	28.8	18.7	3.6
Bog End	0-3.8	3.8	4	3.8(0.5)- 9.8(6.5)	6.0	4	9.0(4.7)-17.7(13.3)	8.7	3	17.7(13.3)-27.0(22.7)	9.3	3	16.5(13.3)	4	24.3	16.1	3.6
Sike Hill (wet)	0-5.3	5.3	4	5.3(2.3)-10.5(7.5)	5.3	4	10.5(7.5)-20.3(17.3)	9.8	4	20.3(16.3)-27.3(23.3)	7.0	3	20.3(17.3)	4	26.3	21.4	3.5
Sike Hill (dry)	0-2.8	2.8	4	2.8 - 8.8	6.0	4	8.8-14.0	5.3	4	14.0-21.5	7.5	4	14	4	29.5	20.0	3.4

Results are means of 4 samples

nd = not determined

Bracketed figures are measurements with reference to base of living Sphagnum (where present)

Table 5f Positions of sulphide zone and water table at IBP sites

Site	Mean water table depth (cm) 1st day - 7th day	Mean depth of commencement of blackening (cm)	Whether blackening continuous to wire base (13-15 cms)
Sike Hill (dry)	12.6	None	-
Bog Hill	11.8	11.0	NO
Green Burn	8.6	9.2	YES
Bog End	7.2	8.9	YES
Cottage Hill A	0	3.3	YES
Cottage Hill B	10.4	11.2	YES
Sike Hill (Wet)	9.9	9.8	YES
Burnt Hill	7.0	4.6	YES

Table 5g

Chemical analyses of Moor House soils (ph, N, P, K, Ca, Mg & Na)

	Horizon colour (unless otherwise specified)	Cottage Hill A	Cottage Hill B	Hard Hill	Burnt Hill	Green Burn	Bog Hill (decomp)	Bog Hill (Forrest)	Bog End	Sike Hill (wet)	Sike Hill (dry)	Juncus moor	<u>Agrostis/Festuca</u> grassland (hummock)	<u>Agrostis/Festuca</u> grassland (hollow)
	Black-Brown	3.6	3.63	3.5	3.6	3	3.3	3.7	3.3	3.8	3.5	3.5	6.0 (2-6 cm)	5.4 (2-4 cm)
pH	Green	3.6	3.43	3.3	3.5	3.3	3.3	3.3	3.4	3.4	3.6	3.2(brown)	6.3 (7-13 cm)	7.0 (8-13 cm)
	Upper Rust	3.5	3.63	3.5			3.4	3.3	3.2	3.5	4.4			
	Lower rust/rust	4	3.93	3.5	4	3.5	3.5	3.5	3.5	3.6	3.6	3.8		
	Variance ratio and sig.		10.74											
Total N	Black-Brown	1800	1930	2000	1100	1200	2000	1700	1400	1900	1400	2900	1200 (2-6 cm)	990 (2-4 cm)
(mg/100g O.D. wt.)	Green	1500	1550	1400	1600	1100	1800	1300	2000	1400	1400	3400 (brown)	870 (7-13 cm)	840 (8-13 cm)
	Upper Rust	2000	1700	1800			2000	1900	2100	1900	1600			
	Lower rust/rust	1600	1680	1400	2200	810	1500	1900	1700	1600	1400	2800		
	Variance ratio and sig.		n.s.											
Total P	Black-Brown	58	78	94	45	50	97	100	81	100	66	140	170 (2-6 cm)	150 (2-4 cm)
(mg/100g O.D. wt.)	Green	48	54	55	45	50	84	66	66	55	75	130 (brown)	150 (7-13 cm)	140 (8-13 cm)
	Upper Rust	45	39.3	50			66	58	72	50	50			
	Lower rust/rust	31	35.5	34	33	28	39	53	41	36	38	49		
	Variance ratio and sig.		36.56											
Extractable P	Black-Brown	<0.4	<0.4	1.1	<0.4	<0.4	0.56	1.7	<0.4	0.46	<0.4	0.28	<0.4 (2-6 cm)	<0.4(2-4 cm)
(mg/100g O.D. wt.)	Green	<0.4	<0.4	0.81	<0.4	<0.4	1.1	1	0.75	0.86	1.14	<0.4 (brown)	<0.4 (7-13 cm)	<0.4 (8-13 cm)
	Upper Rust	<0.4	<0.4	<0.4			0.37	<0.4	0.44	<0.4	<0.4			
	Lower rust/rust	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4		
	Variance ratio and sig.		n.s											
Total K	Black-Brown	56	62.8	61	39	50	50	44	69	78	55	86	660(2-6 cm)	700 (2-4 cm)
(mg/100g O.D. wt.)	Green	41	45.5	23	28	23	34	19	25	16	36	44 (brown)	730 (7-13 cm)	810 (8-13 cm)
	Upper Rust	27	23.5	16			28	14	23	13	14			
	Lower rust/rust	28	16.8	6.2	22	7.8	4.6	6.2	3.1	6.2	6.2	60		
	Variance ratio and sig.		12.23											
Extractable K	Black-Brown	14	26	14	26	29	19	14	75	50	20	22	25(2-6 cm)	22 (2-4 cm)
(mg/100g O.D. wt.)	Green	14	14.3	5.4	6.6	8.7	3.8	4	3.8	3.2	18	13 (brown)	7.7 (7-13 cm)	17(8-13 cm)
	Upper Rust	9.5	4.63	4.1			5.8	3.1	3.6	1.6	4.3			
	Lower rust/rust	2.4	2.83	1.6	3.1	4.6	2	2.3	1	1.2	1.8	2.2		
	Variance ratio and sig.		10.86											
Total Ca	Black-Brown	260	280	230	210	220	230	230	280	250	230	94	630(2-6 cm)	370 (2-4 cm)
(mg/100g O.D. wt.)	Green	220	288	210	130	180	210	260	280	210	240	110 (brown)	790 (7-13 cm)	550 (8-13 cm)
	Upper Rust	220	250	150			250	280	280	280	220	160		
	Lower rust/rust	340	415	190	94	94	340	370	420	420	370			
	Variance ratio and sig.		4.16											
Extractable Ca	Black-Brown	178	215.3	151	142	110	130	197	232	162	101	53	539 (2-6 cm)	373(2-4 cm)
(mg/100g O.D. wt.)	Green	159	173.3	140	74	98	137	168	195	175	196	39 (brown)	642 (7-13 cm)	439 (8-13 cm)
	Upper Rust	162	189.5	109			132	164	197	188	252			
	Lower rust/rust	297	272.8	121	53	50	149	202	313	252	255	63		
	Variance ratio and sig.		4.03											
Total Mg	Black-Brown	130	112	68	94	90	65	45	53	88	73	19	630 (2-6 cm)	630 (2-4 cm)
(mg/100g O.D. wt.)	Green	110	114	73	78	86	58	49	48	64	83	13 (brown)	1050(7-13 cm)	910(8-13 cm)
	Upper Rust	98	99.5	54			68	40	34	51	59			
	Lower rust/rust	120	126	99	65	48	78	28	17	48	48	31		
	Variance ratio and sig.		n.s.											
Extractable Mg	Black-Brown	59	58.8	62	84	61	57	56	69	84	55	14	21 (2-6 cm)	19 (2-4 cm)
(mg/100g O.D. wt.)	Green	61	60	66	64	60	64	45	54	65	82	5.2 (brown)	16 (7-13 cm)	15(8-13 cm)
	Upper Rust	59	70.8	54			54	36	41	53	66			
	Lower rust/rust	82	67.5	58	72	40	57	25	14	44	58	3.6		
	Variance ratio and sig.		n.s.											
Total Na	Black-Brown	20	18.8	27	17	19	14	14	20	17	16	23	45 (2-6 cm)	54 (2-4 cm)
(mg/100g O.D. wt.)	Green	17	19	16	13	17	14	16	14	13	17	9.3 (brown)	44 (7-13 cm)	45 (8-13 cm)
	Upper Rust	14	13.5	16			16	13	14	14	11			
	Lower rust/rust	19	10.9	9.3	14	11	13	9.3	6.2	9.3	9.3	10		
	Variance ratio and sig.		4.84											
Extractable Na	Black-Brown	10	12.3	12	13	14	12	13	16	19	12	11	5.5 (2-6 cm)	4.1 (2-4 cm)
(mg/100g O.D. wt.)	Green	11	10.7	8.4	9	8.9	9.6	8.9	9.5	12	17	4.7 (brown)	3.9 (7-13 cm)	2.9 (8-13 cm)
	Upper Rust	10	10.3	9.6			10	7.8	10	10	13			
	Lower rust/rust	10	7.9	6.6	9.3	7.7	7	6	6.4	9.3	10	<0.37		
	Variance ratio and sig.		6.38											

Results from Cottage Hill B are means of 4 samples
Other values are analyses of bulked samples from 4 replicates

Table 5h. Between species comparisons of chemical analyses of vegetation at five sites

Species and components on blanket bog sites	Ash (% O.D. weight) Cottage hill B	Ash Hard Hill	Ash Burnt Hill	Total N (% O.D. weight) Cottage Hill B	Total N Hard Hill	Total N Burnt Hill	Total P (% O.D. weight) Cottage Hill B	Total P Hard Hill	Total P Burnt Hill	Total K (% O.D. weight) Cottage Hill B	Total K Hard Hill	Total K Burnt Hill
Calluna Green shoots	2.68	2.40	2.80	1.38	1.35	1.40	0.106	0.118	0.098	0.628	0.545	0.528
Live wood	1.39	1.45	1.65	0.545	0.585	0.675	0.039	0.049	0.043	0.268	0.273	0.260
Dead	1.88		1.75	0.743		0.948	0.038		0.035	0.168		0.115
Empetrum nigrum		2.03			0.740			0.079			0.258	
Erica tetralix			2.43			0.860			0.048			0.428
Erioph. vaginatum gn. lvs.	2.70(a)	1.93	2.00	2.10(a)	1.75	1.75	0.160(a)	0.153	0.115	0.840(a)	0.563	0.695
brown lvs.	0.760(a)		1.31	1.10(a)		0.928	0.067(a)		0.047	0.330(a)		0.198
E. angustifolium gn. lvs.	2.05		1.83	1.48		1.55	0.093		0.099	0.463		0.513
brown lvs.	1.28		1.05	0.833		0.935	0.105		0.039	0.090		0.113
Trichophorum cespitosum	3.13			1.53			0.110			1.02		
Rubus chamaemorus		4.93			2.43			0.158			0.928	
Narthecium ossifragum			4.78			1.95			0.062			1.33
Sphagnum papillosum	2.03		1.95	0.885		0.828	0.042		0.036	0.353		0.343
Variance ratio and sig.	15.7***	67.8***	31.1***	67.5***	82.3***	39.3***	N.S.	20.7***	31.7***	66.8***	69.9***	64.6***

Species and components on other sites	Ash Juncus moor	Ash Agrostis/Festuca grassland	Total N Juncus moor	Total N Agrostis/Festuca grassland	Total P Juncus moor	Total P Agrostis/Festuca grassland	Total K Juncus moor	Total K Agrostis/Festuca grassland
Juncus squarrosus	3.35		1.28		0.135		1.09	
Gramineae & Bryophyta	3.58		1.50		0.225		1.50	
Polytrichum commune	2.13		1.01		0.148		0.690	
Sphagnum recurvum	2.10		0.730		0.114		0.595	
All species Hummock		5.93		1.30		0.125		1.02
Hollow		5.78		2.03		0.168		1.55
Variance ratio and sig.	30.0***	N.S.	71.6***	132.8***	23.9***	N.S.	48.0***	78.8***

(a) Values from non-replicated samples

All other values are means of four replicates

Table 5h (continued) Between species comparisons of chemical analyses of vegetation at five sites

Species and components on blanket bog sites	Total Ca (% O.D. weight) Cottage Hill B	Hard Hill	Burnt Hill	Total Mg (% O.D. weight) Cottage Hill B	Hard Hill	Burnt Hill	Total Na (% O.D. weight) Cottage Hill B	Hard Hill	Burnt Hill
Calluna Green shoots	0.273	0.310	0.375	0.185	0.205	0.190	0.062	0.071	0.057
Live wood	0.157	0.128	0.178	0.060	0.070	0.075	0.044	0.060	0.037
Dead	0.200		0.210	0.075		0.062	0.036		0.031
Empetrum nigrum		0.445			0.150			0.008	
Erica tetralix			0.383			0.104			0.101
Erioph. vaginatum gn.lvs.	0.100(a)	0.161	0.135	0.150(a)	0.158	0.114	0.010(a)	0.015	0.018
brown lvs.	0.110(a)		0.138	0.075(a)		0.071	0.016(a)		0.018
E. angustifolium gn.lvs.	0.150		0.168	0.133		0.135	0.069		0.065
brown lvs.	0.218		0.120	0.052		0.049	0.021		0.020
Trichophorum cespitosum	0.130			0.183			0.022		
Rubus chamaemorus		0.837			0.713			0.035	
Narthecium ossifragum			0.608			0.203			0.126
Sphagnum papillosum	0.253(b)		0.105	0.098		0.068	0.109		0.119
Variance ratio and sig.	N.S.	61.5***	23.0***	71.3***	172.3***	52.0***	15.8***	41.5***	7.43***

Species and components on other sites	Ca: Juncus moor	Ca: Agrostis/Festuca grassland	Mg: Juncus moor	Mg: Agrostis/Festuca grassland	Na: Juncus moor	Na: Agrostis/Festuca grassland
Juncus squarrosus	0.080		0.215		0.220	
Gramineae & Bryophyta	0.168		0.160		0.046	
Polytrichum commune	0.099		0.091		0.064	
Sphagnum recurvum	0.150		0.086		0.076	
All species Hummock		0.703		0.153		0.019
Hollow		0.595		0.128		0.031
Variance ratio and sig.	N.S.	N.S.	35.2***	N.S.	162.3***	N.S.

(a) Values from non-replicated samples
(b) Value is mean of three replicates

All other values are means of four replicates

Table 5b. (cont.) Between site comparisons of chemical analyses of three vegetation components

Species and components		Total nutrients etc. (as % O.D. weight)	Cottage Hill A	Cottage Hill B	Hard Hill	Burnt Hill	Green Burn	Bog Hill (decomposition site)	Bog Hill (G. I. Forrest's site)	Bog End	Sike Hill (wet)	Sike Hill (dry)	Variance ratio and significance
Calluna	Green shoots	Ash	2.65	2.68	2.40	2.80	2.55	2.68	2.50	2.50	2.60	2.63	N.S.
	Live wood		1.60	1.39	1.45	1.65	1.45	1.53	1.28	1.45	1.58	1.38	N.S.
E. vaginatum	Green leaves			2.70(a)	1.93	2.00	2.33	1.93	2.43	1.95	2.28	2.28	2.83*
Calluna	Green shoots	N	1.45	1.38	1.35	1.40	1.28	1.23	1.30	1.35	1.40	1.35	N.S.
	Live wood		0.683	0.545	0.585	0.675	0.535	0.560	0.603	0.558	0.533	0.588	4.04**
E. vaginatum	Green leaves			2.10(a)	1.75	1.75	1.88	1.88	2.10	1.80	1.70	1.55	3.62**
Calluna	Green shoots	P	0.103	0.106	0.118	0.098	0.113	0.123	0.148	0.150	0.158	0.150	12.7***
	Live wood		0.043	0.039	0.049	0.043	0.039	0.051	0.070	0.063	0.061	0.061	9.82***
E. vaginatum	Green leaves			0.160(a)	0.153	0.115	0.150	0.178	0.245	0.185	0.185	0.150	6.07***
Calluna	Green shoots	K	0.618	0.628	0.545	0.528	0.590	0.530	0.513	0.608	0.600	0.543	2.43*
	Live wood		0.280	0.268	0.273	0.260	0.263	0.250	0.273	0.285	0.263	0.245	N.S.
E. vaginatum	Green leaves			0.840(a)	0.563	0.695	0.795	0.495	0.488	0.613	0.628	0.655	10.9***
Calluna	Green shoots	Ca	0.315	0.273	0.310	0.375	0.358	0.325	0.310	0.305	0.323	0.275	N.S.
	Live wood		0.160	0.157	0.128	0.178	0.130	0.193	0.130	0.115	0.118	0.110	N.S.
E. vaginatum	Green leaves			0.100(a)	0.161	0.135	0.188	0.138	0.230	0.143	0.135	0.148	N.S.
Calluna	Green shoots	Mg	0.198	0.185	0.205	0.190	0.170	0.200	0.210	0.185	0.193	0.195	N.S.
	Live wood		0.078	0.060	0.070	0.075	0.059	0.077	0.076	0.060	0.064	0.073	N.S.
E. vaginatum	Green leaves			0.150(a)	0.158	0.114	0.130	0.185	0.243	0.173	0.168	0.150	5.75***
Calluna	Green shoots	Na	0.068	0.062	0.071	0.057	0.051	0.080	0.062	0.054	0.059	0.070	N.S.
	Live wood		0.053	0.044	0.060	0.037	0.025	0.057	0.057	0.034	0.038	0.051	4.41**
E. vaginatum	Green leaves			0.010(a)	0.015	0.018	0.014	0.014	0.014	0.015	0.015	0.018	N.S.

(a) Values from non-replicated samples

All other values are means of four replicates

Table 5i. Ranges of chemical analyses of different soil types at Moor House 1960-1967

	pH	Loss on Ignition % O.D. wt.	Total N % O.D. wt.	EXTRACTABLE (mg/100 g O.D. wt.) K	Ca	Mg	P
1. Agrosto/festucetum	4.7-6.3	12.5-25.9	0.5-0.7	9-18	120-468	7-20	0.6-1.6
2. Nardetum	3.8-4.6	45.2-69.2	0.9-1.5	19-37	66- 82	-	0.8-1.6
3. Nardus/Agrostis/Festuca	4.6-5.6	11.5-35.5	0.3-0.7	8-26	86-130	16-22	0.8-1.4
4. Juncetum	3.4-4.4	53 -113	1.2-2.0	12-70	20-140	20-34	-
5. Calluna/Eriophorum	3.1-3.9	95 -99	0.9-1.9	12-52	81-160	28-69	0.8-1.4
6. Sphagnum	3.0-3.4	97 -99	1.0-1.4	42-78	90-130	30-50	-
7. Redistributed peat	3.6-3.3	83 -97	1.2-2.0	8-60	50-120	18-46	1

1. Brown earth; 2. Peaty podsol; 3. Podsol/gley; 4. Thin peat/peaty podsol/peaty gley; 5. Blanket peat;
6. Blanket peat; 7. Redistributed peat.

All analyses carried out by theChemical Service, Merlewood Research Station.

Sample depth usually 0-5 cm.

Large variation within and between sites, and the use of different extraction procedures allow only general interpretation

Table 5j. Peaty Gley-typical profile (from Hornung 1968)

Location :	Three-quarters of a mile north of Knock Ore Gill
Nat. Grid Reference:	695307
Altitude :	1700 ft. O.D.
Relief and aspect :	A slope of 6^{o} with a south westerly aspect
Geological data :	The soil is developed in a layer of superficial material overlying
Vegetation :	_Juncetum squarrosi sub-alpinum_

Horizon ins	
L	Trace
$3\frac{1}{2}$ - 3 F	Brown, wet, _Juncus_ and _Nardus_ leaves.
H	Black, greasy peaty humus.
0 - 8 A_G	Dark grey brown (10 YR 4/2), firm but plastic stony clay loam; weak, coarse blocky; frequent roots; low organic matter content; frequent medium, distinct, yellowish red (5 YR 4/6) mottles along root channels and frequent fine ones of the same colour elsewhere; merging regular boundary.
8 - 30 B_G	Dark grey (10 YR 4/1), very firm, stony clay loam; massive; occasional roots; low organic matter content; frequent, medium to large, distinct, yellowish red (5 YR 4/1) mottles; merging regular boundary.
30 - 40+ C_G	Dark grey (5 YR 4/1), very firm, stony clay loam; massive; frequent, medium, distinct, strong brown (7.5 YR 5/6) mottles, but restricted to root channels.

Table 5k Peaty Gleyed Podsol - typical profile (from Hornung, 1968)

Location	: Eighty yards south of Knock Ore Gill
Nat. Grid Reference	: 696298
Altitude	: 1250 ft. O.D.
Relief and aspect	: A 15° slope to the north west to Knock Ore Gill
Geological data	: A thick layer of superficial material overlies the Basement Series of the local Carboniferous
Vegetation	: Nardetum sub-alpinum

Horizon ins	
$9\frac{1}{2}$ - 9	
L	
9 - 8	Mainly Nardus leaves
F	
8 - 0	Black, wet, greasy peat; sharp regular boundary.
H	
0 - 6(8)	Brown (7.5 YR 5/2), firm, very stony loam; weak, moderated blocky; frequent live roots; almost a
A_{2G}	platform of large stones near the base of the horizon; low organic matter content; no mottles; sharp, irregular boundary.
B_{PAN}	Up to $\frac{1}{4}$" iron pan; root mat on the upper surface; very sinuous; continuous; sharp, irregular boundary.
6 - 7	Reddish brown (5 YR 4/4), firm, very stony clay loam;
B_2	weak medium blocky; no roots, low organic matter; no mottles; clear; irregular boundary.
7 - 11	Grey (5 YR 5/1), firm, stony clay; very weak coarse
B_3	blocky; no roots; low organic matter content; frequent medium distinct yellowish red (5 YR 5/8) mottles; gradual regular boundary.
11 - 24+	Grey brown (10 YR 5/2), firm, stony clay loam to clay;
C	structureless - massive; no roots; frequent medium, distinct, strong brown (7.5 YR 5/6) mottles.

Table 51 Humus Iron Podsol - typical profile (from Hornung, 1968)

Location	: Hard Ridge
Nat. Grid Reference	: 726331
Altitude	: 2300 ft. O.D.
Relief and aspect	: Bench on the E-W trending Hard Ridge, slight slope to the north.
Geological data	: Bedrock is the Quarry Hazle Sandstone
Vegetation	: Festucetum

Horizon. ins	
L	Few recent leaves
1.1/3 - 1½ F	Dark brown, plant remains recognisable, gradual, regular boundary.
1½ - 0 H	Black (2.5 YR 2/0), friable, peaty humus; a little mineral matter; moderate medium crumb; sharp regular boundary.
0 - 5 A_2	Grey brown (10 YR 5/2), loose, very stony, loamy sand; structureless - single grain to weak, fine crumb; abundant roots; low organic matter content; sharp regular boundary.
5 - 7 B_H	Black (5 YR 2/1), friable, very stony, loamy sand; weak medium crumb, frequent roots; low organic matter content; sharp regular junction.
7 -12 B_2	Dark brown (7.5 YR 4/4), friable, stony sandy clay loam; moderate medium crumb; occasional live roots; low organic matter content; merging regular boundary.
12 -18 B_3	Dark yellow brown (10 YR 4/4), friable, stony sandy loam; weak medium crumb; occasional roots, low organic matter content; merging regular boundary.
18 -43+ C	Yellowish brown (10 YR 5/6), compacted, stony sandy loam; structureless - single grain; no roots.

Table 5m Acid Brown Earth - typical profile (from Hornung 1968)

Location	: Northern slopes of Hard Hill
Nat. Grid Reference	: 726333
Altitude	: 2200 ft. O.D.
Relief and aspect	: Almost level bench on a north facing slope.
Geological data	: The underlying limestone is the Four Fathom.
Vegetation	: An association related to an Agrosto-Festucetum but with an unusually high content of Polytrichum spp.

Horizon ins	
A_1 0 - 1	Dark brown (10 YR 4/4) friable loam; moderate medium granular; high organic matter content; dense root mat; earthworms; clear and regular boundary.
(B) 1 - 6	Brown (7.5 YR 4/2), slightly stony, firm, silty loam; moderate coarse granular; frequent roots; earthworms; merging boundary.
(B)C 6 - 10	Brown (7.5 YR 4/4), very stony, firm silty clay, moderate coarse granular; frequent roots; many, highly weathered decalcified limestone fragments; merging boundary.
CD 10+	Bedrock limestone with some brown soil material along joint faces.

Table 5n Brown Calcareous Soil - typical profile (from Hornung 1968)

Location	: Northern end of Knock Fell
Nat. Grid Reference	: 716311
Altitude	: 2450 ft. O.D.
Relief and aspect	: A gentle slope to the north east
Geological data	: The Great Limestone is bedrock
Vegetation	: Agrosto-Festucetum

Horizon ins	
0 - 4 A	Very dark grey brown (10 YR 3/2), friable clay loam; strong fine crumb; abundant live roots; very few stones; moderate organic matter content; irregular gradual boundary.
4 - 8 (B)	Very dark brown (10 YR 2/2), friable to firm clay loam; strong medium crumb; frequent live roots; moderate organic matter content; few stones; sharp irregular boundary.
9 - 13+ C	Zone of fragmented limestone bedrock with clay loam between the boulders; the soil-limestone interface is stained black.

Table 5o Rendzina - typical profile (from Hornung 1968)

Location	:	North east edge of Knock Fell.
Nat. Grid Reference	:	716311
Altitude	:	2450 ft. O.D.
Relief and aspect	:	A gentle slope to the north east, to the col between Knock Fell and Green Fell.
Geological data	:	Bedrock is the Great Limestone.
Vegetation	:	Agrosto-Festucetum
Horizon ins		
A 0 - 2" (6")		Very dark brown black (10 YR 2/2), friable, stony loan strong medium to fine crumb; freely drained; dense mat of living roots; high organic matter content; earthworms present; sharp boundary.
C		Fragmented bedrock limestone with a trace of soil between the blocks.

Table 7a The extent of vegetation types on Moor House National Nature Reserve (after Eddy, Welch and Rawes, 1969)

Vegetation types	Area (ha) W	C	E	Total
Blanket bog				
Calluna-Eriophorum-Sphagnum	0	63	1137	1200
Trichophorum-Eriophorum and recolonised peat	80	264	340	684
Eroding bog	2	104	217	323
Total	82	431	1694	2207
Grasslands				
Juncus squarrosus	121	239	17	377
Nardus stricta	255	266	94	615
Festuca	35	147	1	183
Agrostis-Festuca	85	28	37	150
Scree, made ground etc.	100	33	21	154
Pteridium (Bracken)	34	0	0	34
Total	630	713	170	1513
Poor fens and flushes				
Total	18	49	55	122
Totals	730	1193	1919	3842

W = Western escarpment below 671m

C = Central ridge above 671m

E = Eastern plateau below 671m

Table 7b.

Frequencies of species at IBP sites (using 25 x 25 cm square quadrat)
(R. S. Clymo, pers. comm.)

Species	Sike Hill (dry)	Sike Hill (wet)	Bog Hill	Bog End	Cottage Hill B	Green Burn	Cottage Hill A	Burnt Hill
				SITES				
Calluna vulgaris	0.88	1.00	1.00	0.94	0.92	0.94	0.76	0.87
Drosera rotundifolia	-	-	-	-	-	0.02	0.20	0.24
Empetrum nigrum	0.62	0.64	0.68	0.50	0.02	0.44	-	0.06
Erica tetralix	-	-	-	-	-	0.10	0.22	0.78
Listera cordata	0.02	0.10	0.14	0.02	-	-	-	-
Narthecium ossifragum	-	-	-	-	0.08	-	0.14	0.47
Rubus chamaemorus	0.54	0.50	0.46	0.58	-	-	-	-
Vaccinium myrtillus	0.04	-	-	0.04	-	-	-	-
V. oxycoccus	-	-	-	-	-	0.60	-	-
Deschampsia flexuosa	-	-	-	0.02	-	-	-	0.01
Eriophorum angustifolium	-	0.10	-	0.02	1.00	0.04	0.92	0.64
E. vaginatum	0.94	0.90	0.84	0.90	0.88	0.80	0.28	0.75
Trichophorum cespitosum	-	-	-	-	0.28	-	0.78	0.42
Aulocomnium palustre	-	0.14	0.30	0.36	0.14	0.22	-	-
Blindia acuta	0.02	0.08	0.04	-	-	-	-	-
Campylopus flexuosus	-	-	-	-	0.02	-	0.04	-
Dicranella heteromalla	-	-	-	-	-	-	-	0.01
Dicranum scoparium	0.30	0.04	0.06	0.06	-	0.02	-	0.01
Hypnum cupressiforme	0.32	0.04	0.36	0.12	-	0.20	0.02	0.12
Mnium hornum	0.02	-	-	0.02	-	-	-	-
Orthodontium lineare	0.04	-	-	-	-	-	-	-
Plagiothecium undulatum	0.04	0.74	0.52	0.09	-	0.14	-	-
Pleurozium schreberi	0.18	0.40	0.60	0.18	-	0.36	-	-
Pohlia nutans	0.50	0.34	0.08	0.44	0.06	-	0.12	0.03
Polytrichum commune	-	0.08	0.22	0.04	0.02	-	-	-
P. juniperinum	-	0.08	0.02	-	-	-	-	-
Rhacomitrium lanuginosum	-	-	-	-	-	-	-	0.04
Rhytidiadelphus loreus	0.06	0.68	0.58	0.56	-	0.16	-	-
Sphagnum cuspidatum	-	-	-	-	-	-	-	0.16
S. magellanicum	-	-	-	-	0.08	0.92	-	-
S. papillosum	-	-	-	0.02	0.70	0.16	0.74	0.35

Table 7b (continued)

Species	Sike Hill (dry)	Sike Hill (wet)	Bog Hill	Bog End	Cottage Hill B	Green Burn	Cottage Hill A	Burnt Hill
S. plumulosum	-	-	-	-	0.02	-	0.08	-
S. recurvum	0.06	0.16	0.40	0.38	0.52	-	0.54	0.06
S. rubellum	0.68	0.80	0.72	0.76	0.72	0.70	0.50	0.76
S. tenellum	-	-	-	-	-	-	0.32	0.04
Barbilophozia floerkii	-	0.14	0.04	0.14	-	-	-	-
Cephalozia bicuspidata	0.86	0.64	0.44	0.84	0.68	0.50	0.72	0.60
C. connivens	0.02	0.06	-	0.04	-	0.02	0.02	0.06
Diplophyllum albicans	0.02	-	-	-	0.18	-	0.10	0.02
Lepidozia setacea	0.18	0.10	-	0.18	0.50	-	0.34	0.41
Lophozia spp.	0.40	0.52	0.58	0.64	0.32	0.08	0.06	0.06
Mylia spp.	0.48	0.28	0.58	0.78	0.52	0.24	0.40	0.75
Odontoschisma sphagni	0.48	0.72	0.70	0.76	0.44	0.64	0.30	0.76
Ptilidium ciliare	-	0.16	0.06	0.12	-	-	-	0.01
Cetaria islandica	-	-	-	-	-	-	-	0.01
Cladonia arbuscula	-	0.08	-	0.06	0.02	-	0.04	0.14
C. chlorophaea	-	-	-	0.04	-	-	0.02	-
C. fimbriata	0.28	0.10	0.08	0.42	-	0.08	0.08	0.03
C. furcata	-	-	-	0.02	-	-	-	-
C. impexa	0.30	0.18	0.08	0.32	0.02	0.04	0.12	0.47
C. squamosa	0.26	0.12	0.04	0.34	-	0.02	-	-
C. uncialis	-	0.02	-	-	0.02	-	0.02	0.13
Parmelia saxatilis	0.16	0.14	0.16	0.50	-	0.06	0.02	-

Table 7c Cover of vascular species at four IBP sites (Forrest, pers. comm.) (as % of pins contacted over all strata)

Species		Sike Hill (dry) 1968	Sike Hill (wet) 1970	Bog Hill 1970	Green Burn 1970
Calluna vulgaris	Live	68.9 ± 5.3	81.1 ± 5.6	80.6 ± 4.7	69.6 ± 9.4
	Dead	58.5 ± 7.6	74.4 ± 7.2	72.8 ± 5.4	47.1 ± 15.5
	Total	85.1 ± 3.3	90.5 ± 2.7	90.0 ± 2.6	82.6 ± 6.5
Eriophorum vaginatum	Live	68.4 ± 7.3	72.3 ± 6.4	63.4 ± 15.7	27.3 ± 10.6
	Dead	83.4 ± 4.3	79.9 ± 8.6	76.0 ± 8.3	49.4 ± 14.1
	Total	89.0 ± 4.3	87.1 ± 8.2	83.3 ± 9.0	53.5 ± 14.0
E. angustifolium		-	0.5 ± 0.6	-	3.1 ± 5.3
Empetrum nigrum		26.4 ± 6.2	26.3 ± 6.8	22.0 ± 6.1	0.1 ± 0.3
Erica tetralix		-	-	-	19.4 ± 15.7
Rubus chamaemorus		2.9 ± 2.7	6.5 ± 2.1	4.8 ± 2.4	-
Vaccinium myrtillus		0.3 ± 0.6	0.3 ± 0.6	0.1 ± 0.3	-
V. oxycoccus		-	-	-	1.8 ± 4.2
Listera cordata		0.4 ± 0.4	0.3 ± 0.4	0.6 ± 0.8	-
Drosera rotundifolia		-	-	-	0.3 ± 0.4
Σ Vascular species		99.4 ± 0.9	99.5 ± 0.6	99.4 ± 0.6	94.4 ± 4.9

Table 8a. *Calluna* parameters, *Sphagnum* cover, and burning history for seven sites (Forrest, pers. comm.)

	Calluna				
Site	Mean age (yrs.)	Modal age (yrs.)	Mean stem number per m^2	*Sphagnum* cover (%)	Yrs. since last burn
Sike Hill (dry)	11.54	8	110	15	< 30
Bog Hill	8.48	9	159	51	< 30
Green Burn	4.97	1	343	80	< 30
Bog End	10.21	6	107	17	< 30
Cottage Hill B	3.09	1	951	61	9
Sike Hill (wet)	6.26	5	173	16	< 30
Long Hill	5.44	6	173	N.D.	12
Long Hill	10.86	11	88	N.D..	< 30

Table 9a. Grazing pressure, intake, and primary production on different vegetation types (after Rawes, 1971a) Relative values are bracketted

Sward	Altitude m	Production g/m²	Intake g/m²	% utilised	Sheep - av. no./hectare
Agrostis-Festuca	555	174 (51)	110 (85)	63	3.7
Agrostis-Festuca	510	196 (57)	93 (72)	47	8.7
Agrostis-Festuca	747	85 (25)	61 (47)	73	2.5
Agrostis-Festuca	480	179 (52)	83 (64)	46	6.3
Festuca	678	90 (26)	50 (39)	55	2.0
Festuca	840	67 (18)	61 (47)	100	3.0
Juncus squarrosus	549	343 (100)	130 (100)	35	1.1
Nardus stricta	549	193 (56)	+	+	1.4
Blanket bog	560	154 (45)	+	0	0.02
Blanket bog (burnt)	560	69 (20)	+	0	0.04

+ small values

Table 9b. Outline of balance sheet of water and five elements for Rough Sike catchment (after Crisp, 1966)

	Water (10^3 m^3)	Sodium (kg/year)	Potassium (kg/year)	Calcium (kg/year)	Phosphorus (kg/year)	Nitrogen (kg/year)
Stream water output	1368	3755	744	4461	33	244
Evaporation	403	-	-	-	-	-
Peat erosion	-	23	171	401	37	1214
Drift of fauna in stream	-	0.004	0.011	0.003	0.010	0.118
Drift of fauna on stream	-	0.11	0.38	0.07	0.43	4.6
Sheep sales	-	0.16	0.19	1.58	0.98	3.88
Wool sales	-	-	0.25	0.005	0.002	0.55
Total output	1771	3778	916	4864	71	1467
Input in precipitation	1771	2120	255	745	38-57	681
Difference (= Net loss for catchment)	-	1658	661	4119	14-33	786
Net loss/ha.	-	20.01	7.97	49.68	0.17-0.40	9.48

Table 9c Nutrient cycling by sheep on two swards (after Rawes and Welch, 1969)

	Ca	N	P	K
			$g\ m^{-2}$	
Agrostis-Festuca grassland				
Intake	0.5	2.05	0.15	1.45
Dung	0.2	0.65	0.10	0.35
Urine	+	1.70	+	1.20
Amounts removed from sward	0.3		0.05	
Amounts added to sward		0.30		0.10
Juncus squarrosus sward				
Intake	0.1	1.8	0.2	0.7
Dung	+	0.1	+	0.1
Urine	+	0.3	+	0.2
Amounts removed from sward	0.1	1.4	0.2	0.4

Urine values estimated from:

Ca - based on data of Herriott and Wells (1963)
N - based on data of Wolton (1963) and Herriott and Wells
P - based on data of Wolton, Herriott and Wells, and Barrow and Lambourne (1962)
K - based on data of Wolton, Herriott and Wells, and Watkin (1954)

Table 9d. Dry weight and ash (including adhering soil) of the stubble-litter layers, under grazing and after 7 years' growth (Welch and Rawes, 1964)

	Little Dun Fell		Knock Fell		Hard Hill	
	7-year	Grazed	7-year	Grazed	7-year	Grazed
Total weight (g/m^2)	831.0 ± 73.5	480.8 ± 68.0	740.0 ± 53.6	621.8 ± 85.0	640.8 ± 61.6	480.0 ± 33.7
Ash (%)	7.23 ± 0.69	3.95 ± 0.14	13.85 ± 2.20	33.06 ± 3.54	3.70 ± 0.36	3.29 ± 0.10
Ash of the standing vegetation (%)			6.33 ± 0.24		3.57 ± 0.13	

Table 10a. Invertebrate groups studied at Moor House. A general invertebrate survey, especially of insects, was made by Nelson (1971)

Invertebrate group			References
Protozoa	- Testacea		Heal (1962)
Nematoda			Banage (1963)
Annelida			
	- Lumbricidae		Svendson (1957)
	- Enchytraeidae		Peachey (1963)
			Springett (1967)
Arthropoda	- Crustacea		Standen (in press)
		- Cladocera	Heal (1963)
	- Myriapoda		Nelson (1971)
	- Insecta		Nelson (1971)
		- Collembola	Murphy (1962)
			Hale (1966)
		- Ephemeroptera	Crisp and Nelson (1965)
		- Plecoptera	Crisp (1963)
			Brown, Cragg and Crisp (1964)
		- Hemiptera	
		(Corixidae)	Crisp (1962)
		(Auchenorrhyncha)	Whittaker (1964)
		(Psyllidae)	Hodkinson (1971, in press)
		Lepidoptera	Heath (pers. comm.)
		<u>Coleophora</u>	Jordan (1962)
			Reay (1964)
		- Coleoptera	
		(Carabidae)	Houston (1970, 1971)
		(Aphodidae)	White (1960)
		- Diptera	
		(Tipulidae)	Coulson (1959, 1962), Hadley (197[illegible])
			Horobin
		- Araneida	Cherrett (1964)
Arachnida		- Acarina	Block (1966)

Table 10b. Vertebrate species list

Vertebrate Group	Common name	Latin name	Breeds on Reserve	Reference to specific study
Fish	Brown trout	Salmo trutta	+	Crisp (1963)
	Bull-heads	Cottus gobio	+	Crisp (1963)
Amphibians	Palmate newt	Triturus helveticus	+	
	Frog	Rana temporaria	+	
Reptiles	Viviparous lizard	Lacerta vivipara	+	
	Adder	Vipera berus berus		
Birds	Heron	Ardea cinerea		
	Grey lag goose	Anser anser		
	Mallard	Anas platyrhynchos		
	Teal	A. crecca		
	Buzzard	Buteo buteo		
	Peregrine	Falco peregrinus		
	Merlin	F. columbarius		
	Kestrel	F. tinnunculus		
	Red grouse	Lagopus lagopus scoticus	+	Evans and Taylor (1971), Taylor (1972a and b) Taylor & Rawes (in press)
	Black grouse	Lyrurus tetrix		
	Oystercatcher	Haematopus ostralegus		
	Lapwing	Vanellus vanellus		
	Golden plover	Charadrius apricarius		
	Dotterel	C. morinellus	+	
	Snipe	Gallinago gallinago	+	
	Curlew	Numenius arquata	+	
	Common sandpiper	Tringa hypoleucos	+	
	Redshank	T. totanus		
	Greenshank	T. nebularia		
	Dunlin	Calidris alpina		
	Black-headed gull	Larus ridibundus		
	Barn owl	Tyto alba		
	Tawny owl	Strix aluco	+	
	Short-eared owl	Asio flammeus		
	Swift	Apus apus		
	Skylark	Alauda arvensis	+	
	Swallow	Hirundo rustica	+	
	Raven	Corvus corax		

Table 10b (continued)

Vertebrate Group	Common name	Latin name	Breeds on Reserve	Reference to specific study
Birds (cont.)	Carrion crow	C. corone corone		
	Wren	Troglodytes troglodytes	+	
	Dipper	Cinclus cinclus	+	
	Fieldfare	Turdus pilaris		
	Song thrush	Turdus philomelos		
	Ring ouzel	T. torquatus		
	Blackbird	T. merula		
	Wheatear	Oenanthe oenanthe	+	
	Whinchat	Saxicola rubetra		
	Robin	Erithacus rubecula		
	Meadow pipit	Anthus pratensis	+	Coulson (1956)
	Pied wagtail	Motacilla alba	+	
	Grey wagtail	M. cinerea	+	
	Yellow wagtail	M. flava		
	Greenfinch	Chloris chloris		
	Chaffinch	Fringilla coelebs		
	Snow bunting	Plectrophenax nivalis		
Mammals	Common shrew	Sorex araneus	+	
	Pygmy shrew	S. minutus	+	
	Rabbit	Oryctolagus cuniculus	+	
	Short-tailed vole	Microtus agrestis	+	Evans and Evans (1971)
	Wood mouse	Apodemus sylvaticus	+	
	Brown rat	Rattus norvegicus	+	
	Red fox	Vulpes vulpes	+	
	Stoat	Mustella erminea	+	
	Weasel	M. nivalis		
	Badger	Meles meles		
	Roe deer	Capreolus capreolus		
	Sheep	Ovis ammon		Rawes and Welch (1969)

(Source - Moor House Reserve Records - probably incomplete)

Table 10c Summary of the numbers, biomass (wet weight) and energy used in respiration, for various groups of soil fauna. From Springett (1967), based on Cragg (1961) and MacFadyen 1963).

	Juncus squarrosus moor	Nardus stricta grassland	Mixed moor	Limestone grassland	Bare peat
Acarina					
$10^3/m^2$	43	78	54	37	neg.
gm/m^2	0.9	1.9	1.1	0.9	
$Kcal/m^2/yr$	13	21	14	8	
Collembola					
$10^3/m^2$	13	-	32	56	neg.
gm/m^2	0.1	-	0.3	0.4	
$Kcal/m^2/yr$	4	-	10	15	
Lumbricidae					
nos/m^2	4	-	-	389	-
gm/m^2	1.2	-	-	137	-
$Kcal/m^2/yr$	5	-	-	333	-
Nematoda					
$10^6/m^2$	3.9	3.3	1.4	2.3	0.02
gm/m^2	1.0	-	-		
$Kcal/m^2/yr$	2.1	10	5	10	
Tipulidae					
nos/m^2	1389	-	371	49	-
gm/m^2	22	-	8	36	-
$Kcal/m^2/yr$	131	-	30	149	-
Enchytraeidae					
$10^3/m^2$	170	120	62	59	20
gm/m^2	24	20.5	12.5	26	4
$Kcal/m^2/yr$	235	140	86	76	27
Total					
$Kcal/m^2/yr$	409	171	145	591	27
% contribution of Enchytraeidae	57	82	59	13	ca 100

There is some doubt about the absolute values of respiration in this table. Revised estimates will be presented at the meeting 'UK Ecosystem Studies in the IBP' to be held at Liverpool in April 1973

Table 10d Numbers of species of various invertebrates groups identified from different vegetation and soil types

	Meadow	Limestone grassland	Alluvial grassland	*Juncus* moor	Blanket bog	Valley bog	Sources
All species	266	174	226	127	181	88	
Diptera	217	124	165	95	128	64	Appendix in
Hymenoptera	9	5	11	6	15	4	Nelson
Coleoptera	24	29	35	22	24	14	1971
Coleoptera	19	33	22	24	18	-	Houston 1970
Tipulidae (larvae)	-	4	6	8	9	-	Coulson 1959
Collembola	-	25	21	13	19	-	Hale 1966
Acarina	-	66	44	39	65	-	Block 1965
Areneida (Linyphiidae)	3	7	22	16	25	5	Cherrett 1964
Nematoda	-	17	15	11	7	-	Banage 1962
Enchytraeidae	16	15	11	9	5	4	Springett 1967

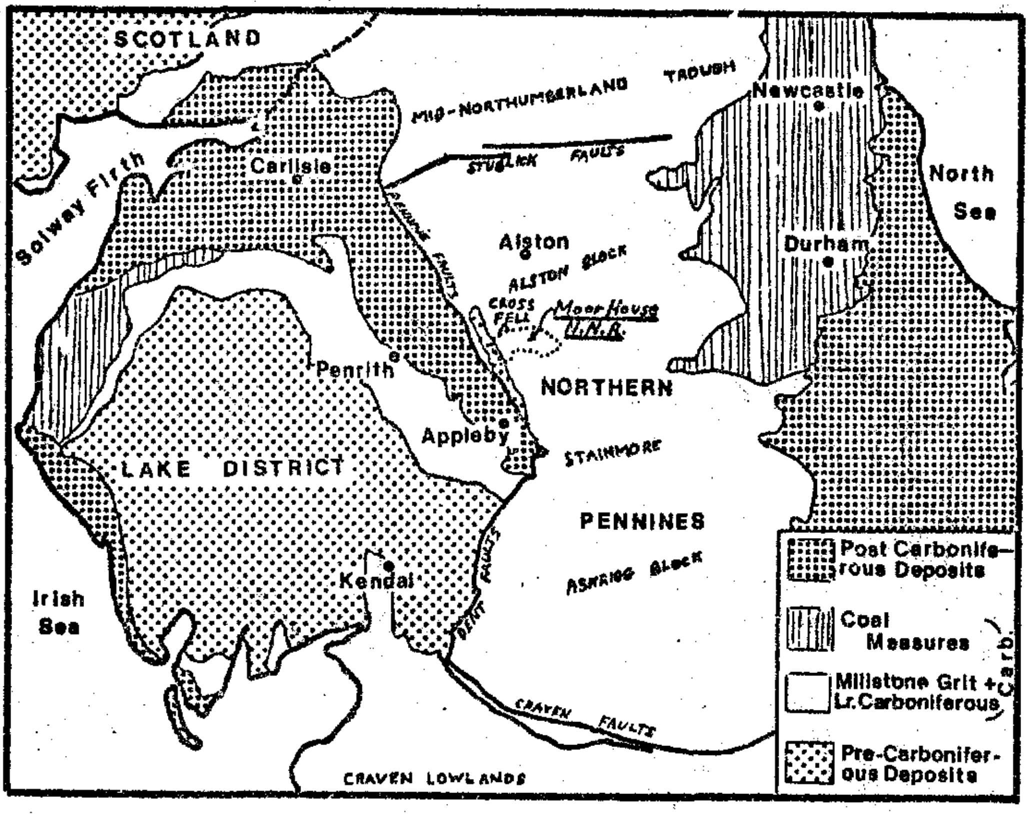


FIG.1a. LOCATION AND GEOLOGY OF MOORHOUSE NATIONAL NATURE RESERVE

[JOHNSON AND DUNHAM 1963]

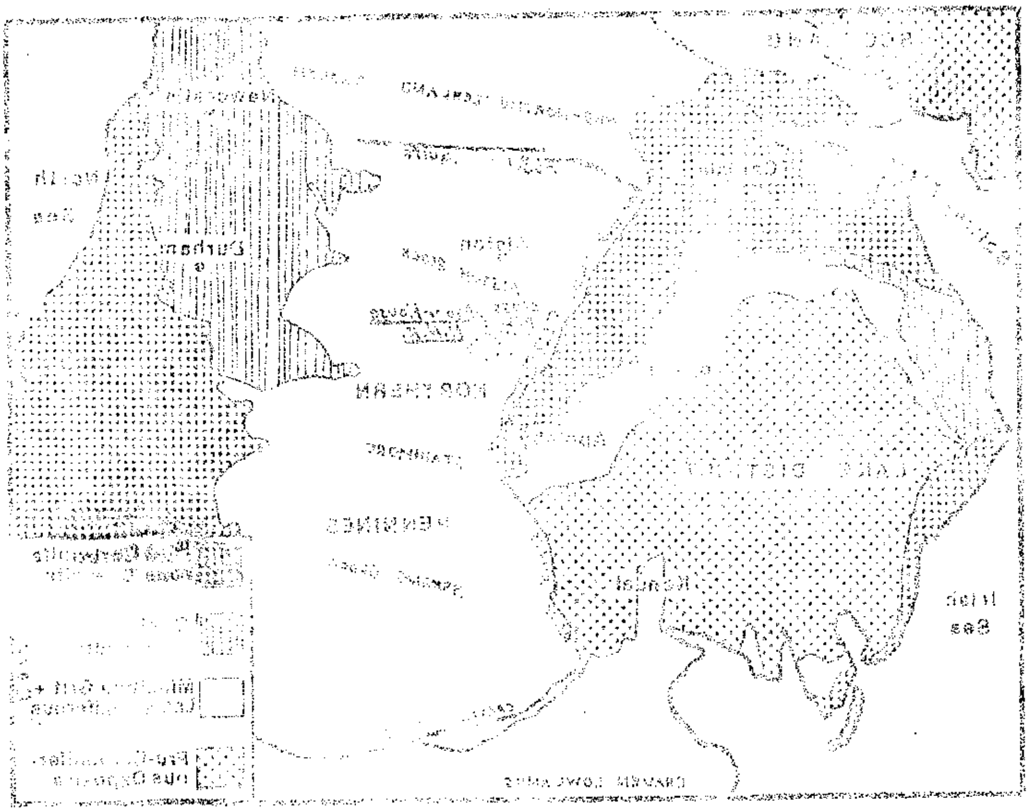
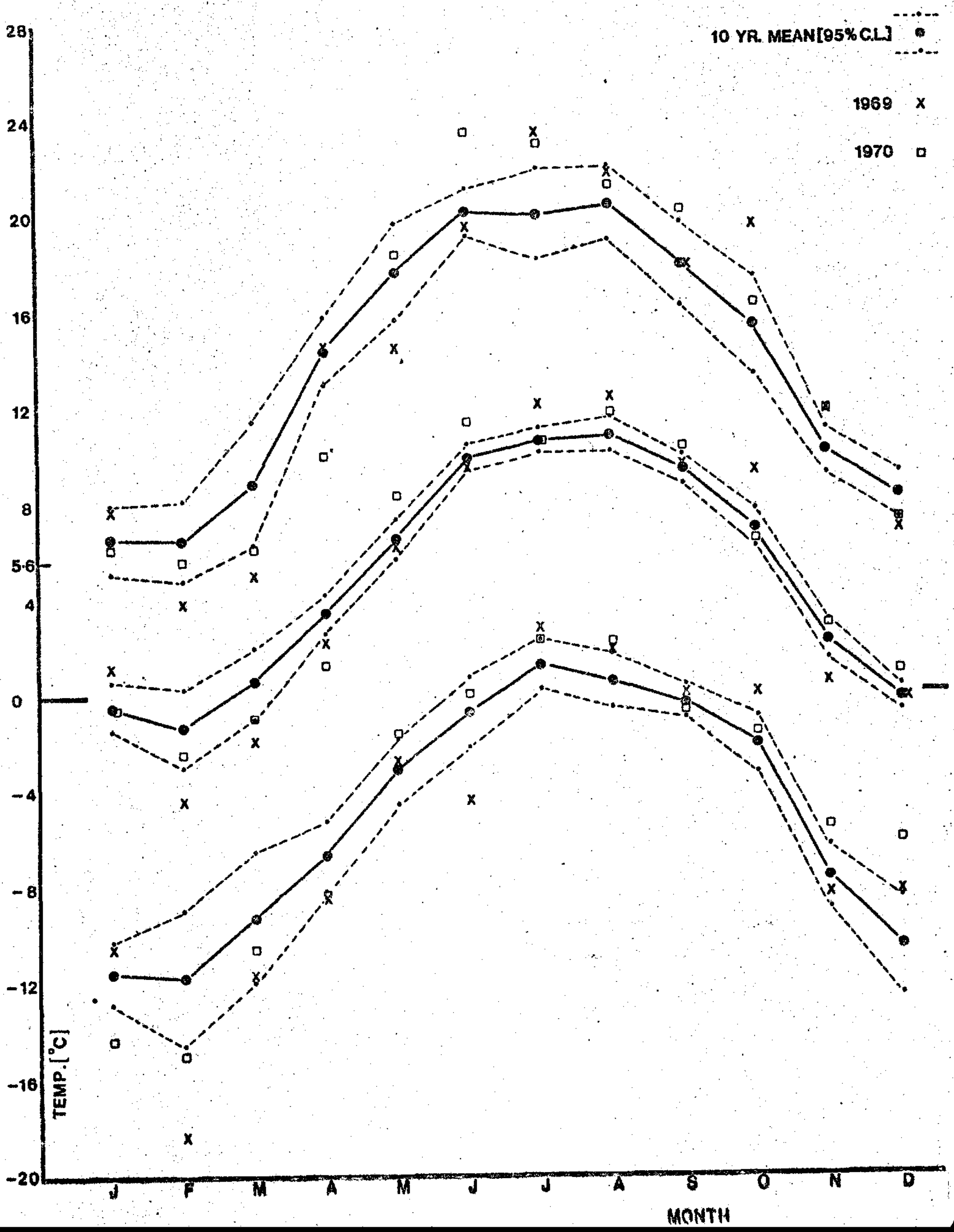


FIG.2a LOCATION AND GEOLOGY OF MOORHOUSE NATIONAL NATURE RESERVE

(JOHNSON AND DUNHAM 196

FIG 2a MEAN [½ MAX.+MIN.], HIGHEST MAX., AND LOWEST MIN. TEMPERATURES [°C]



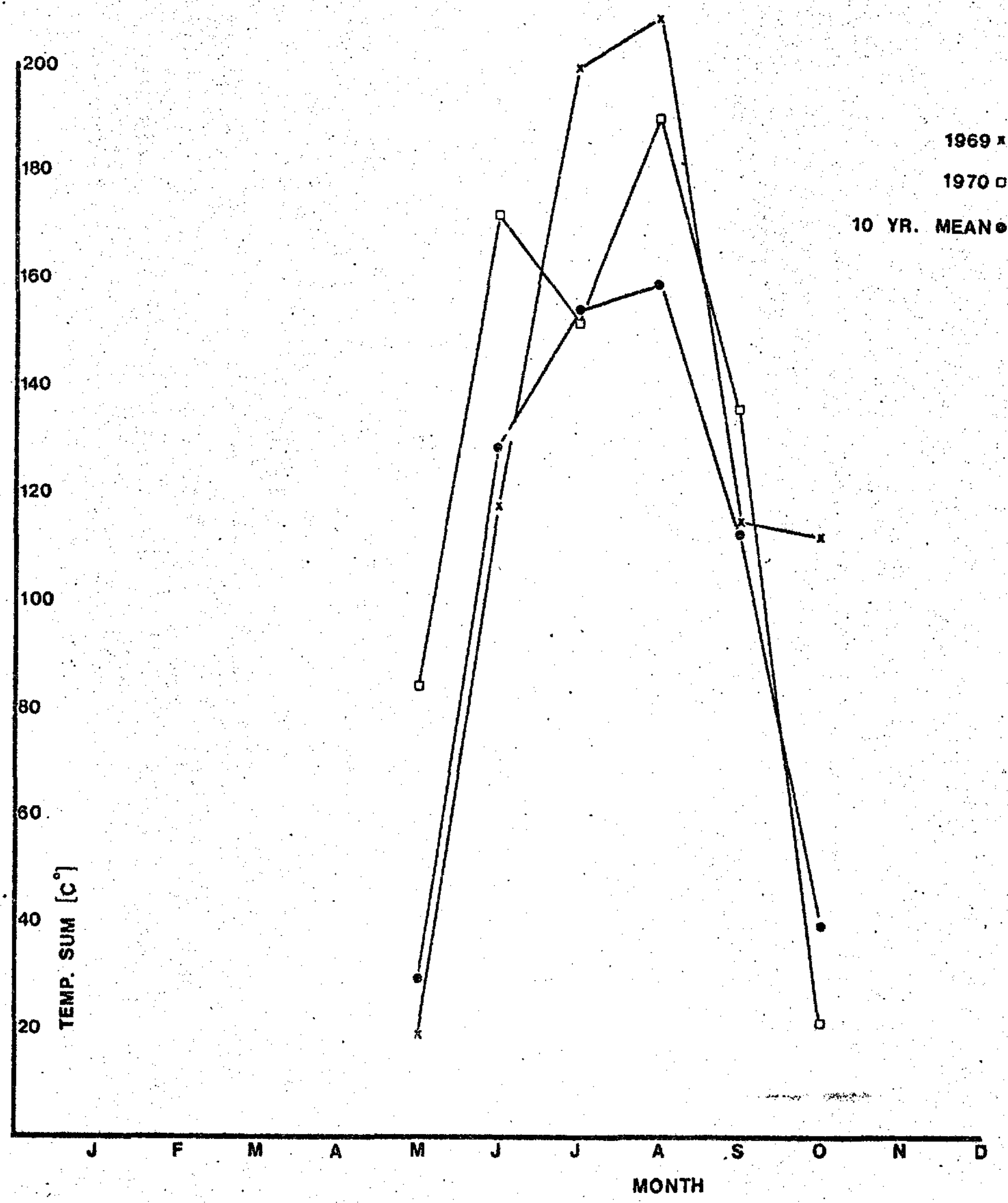


FIG. 2b TEMPERATURE SUMS > 5·6°C [C°]

FIG. 2c. DAYS WITH GROUND FROST

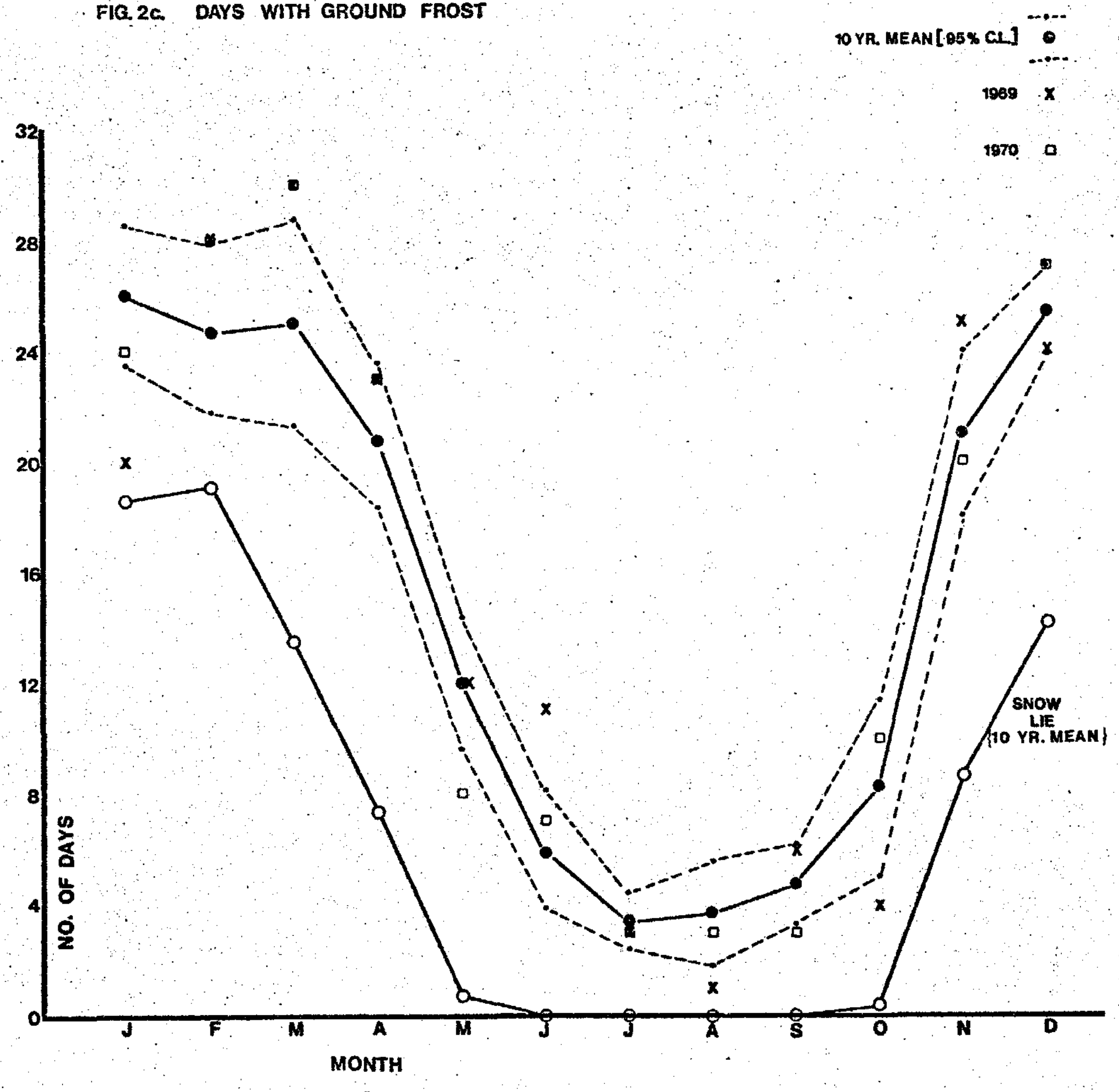


FIG. 2d. DAYS WITH AIR FROST

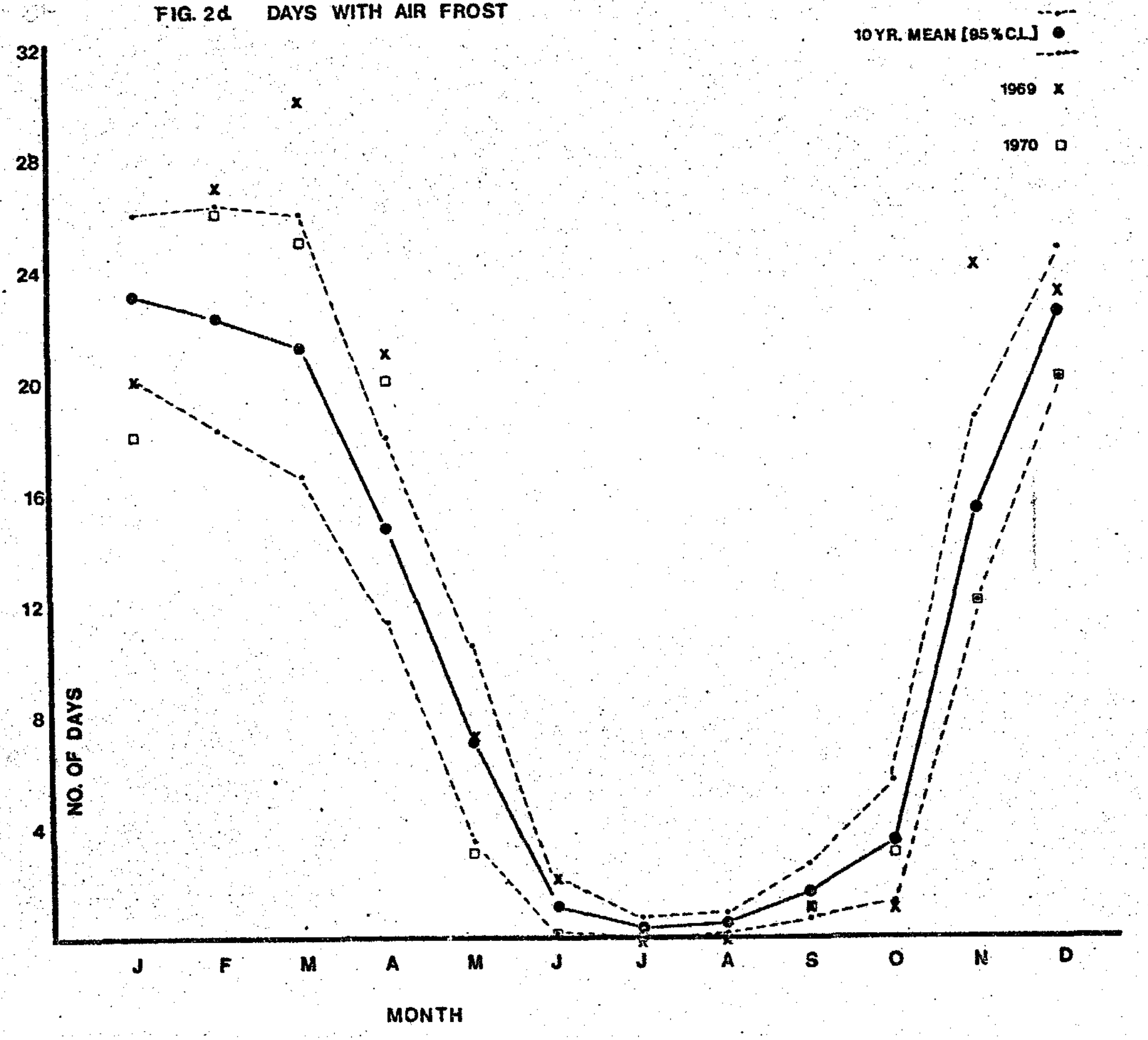


FIG. 2e DAYS WITH SNOW LYING [COVER > ½; EXCLUDING DRIFTS]

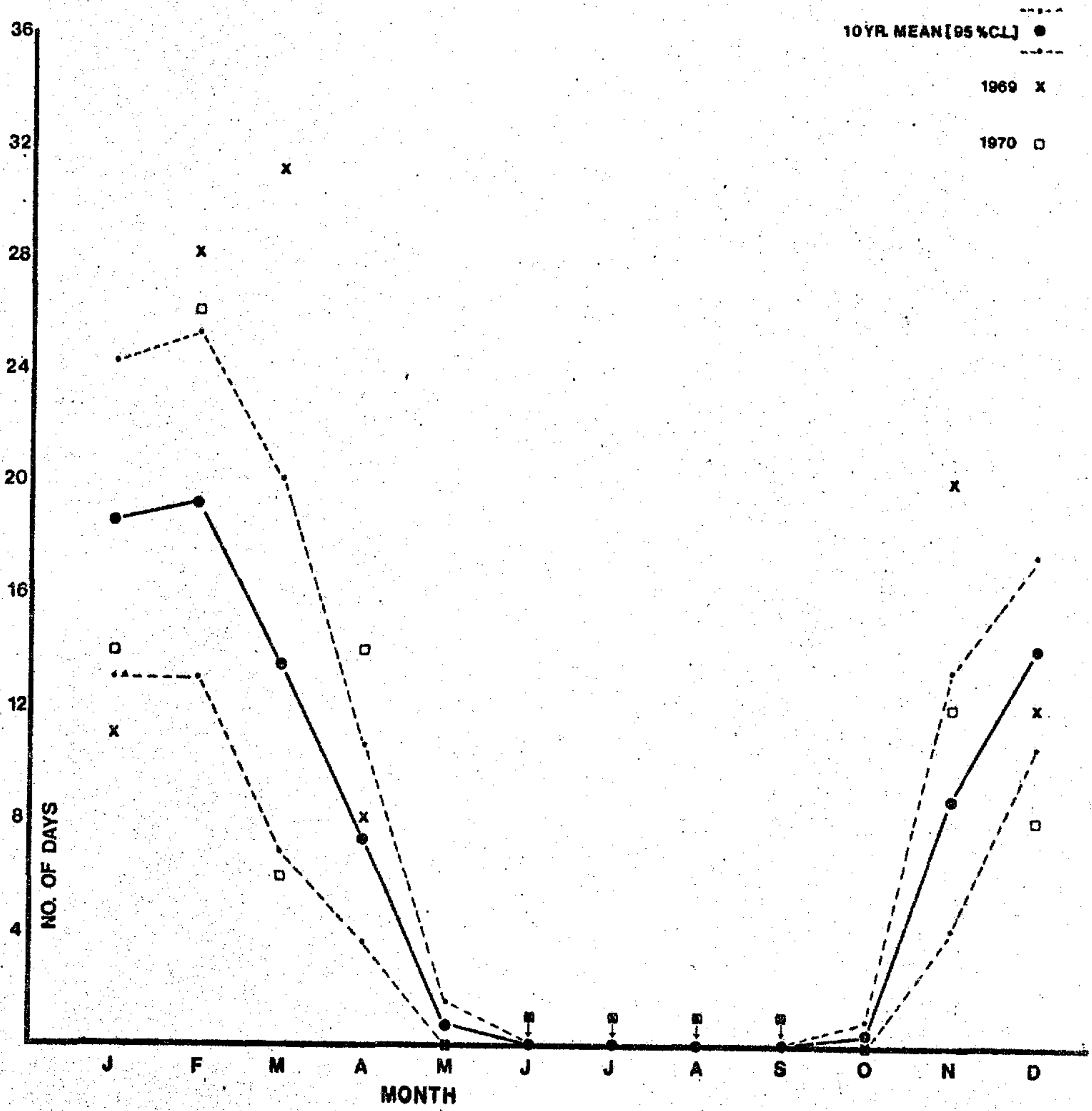


FIG. 21 TOTAL MONTHLY RAINFALL [MMS.]

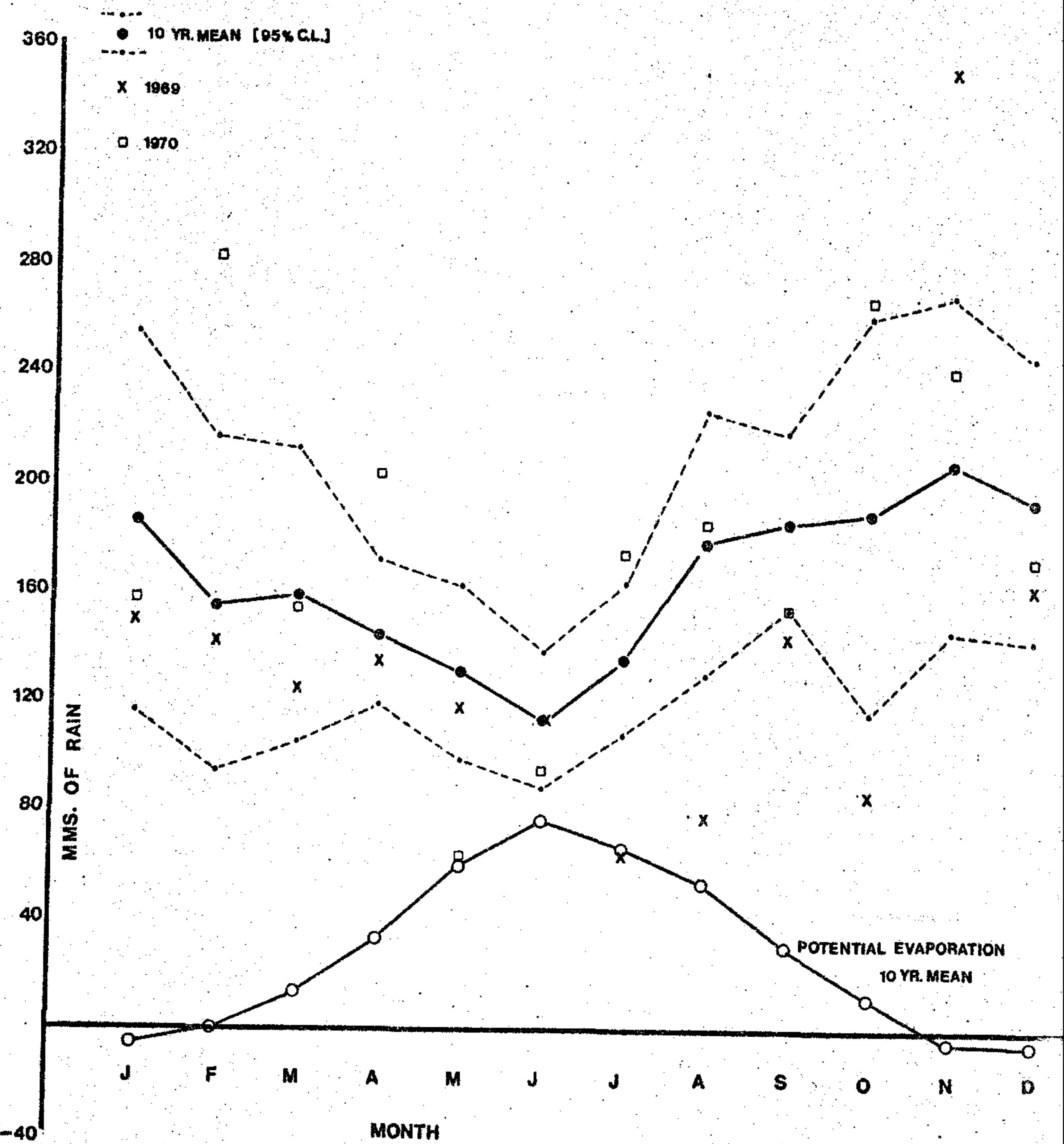


FIG. 2g. POTENTIAL EVAPORATION (MMS.)

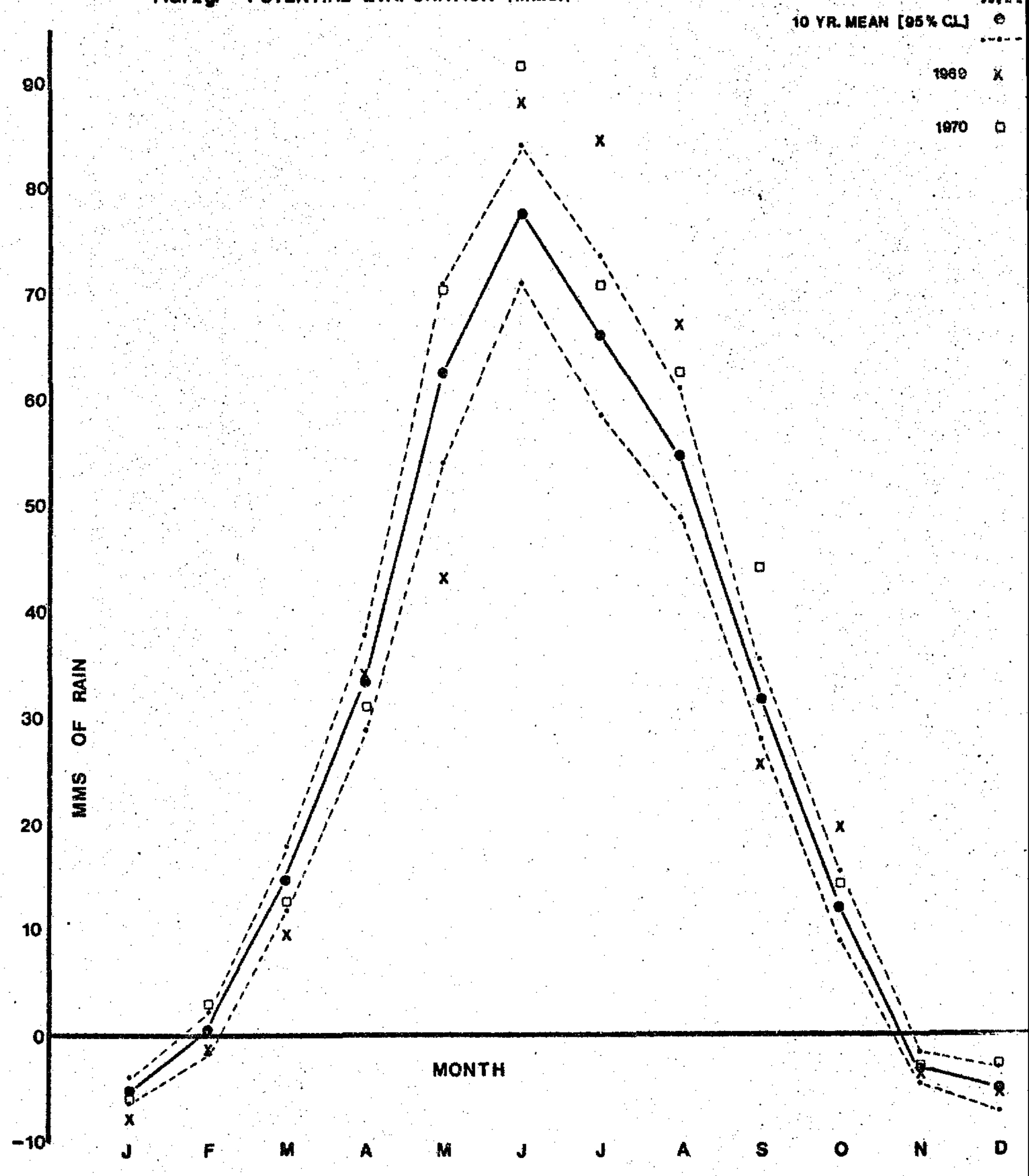


FIG 2h TOTAL MONTHLY SUNSHINE [HRS.]

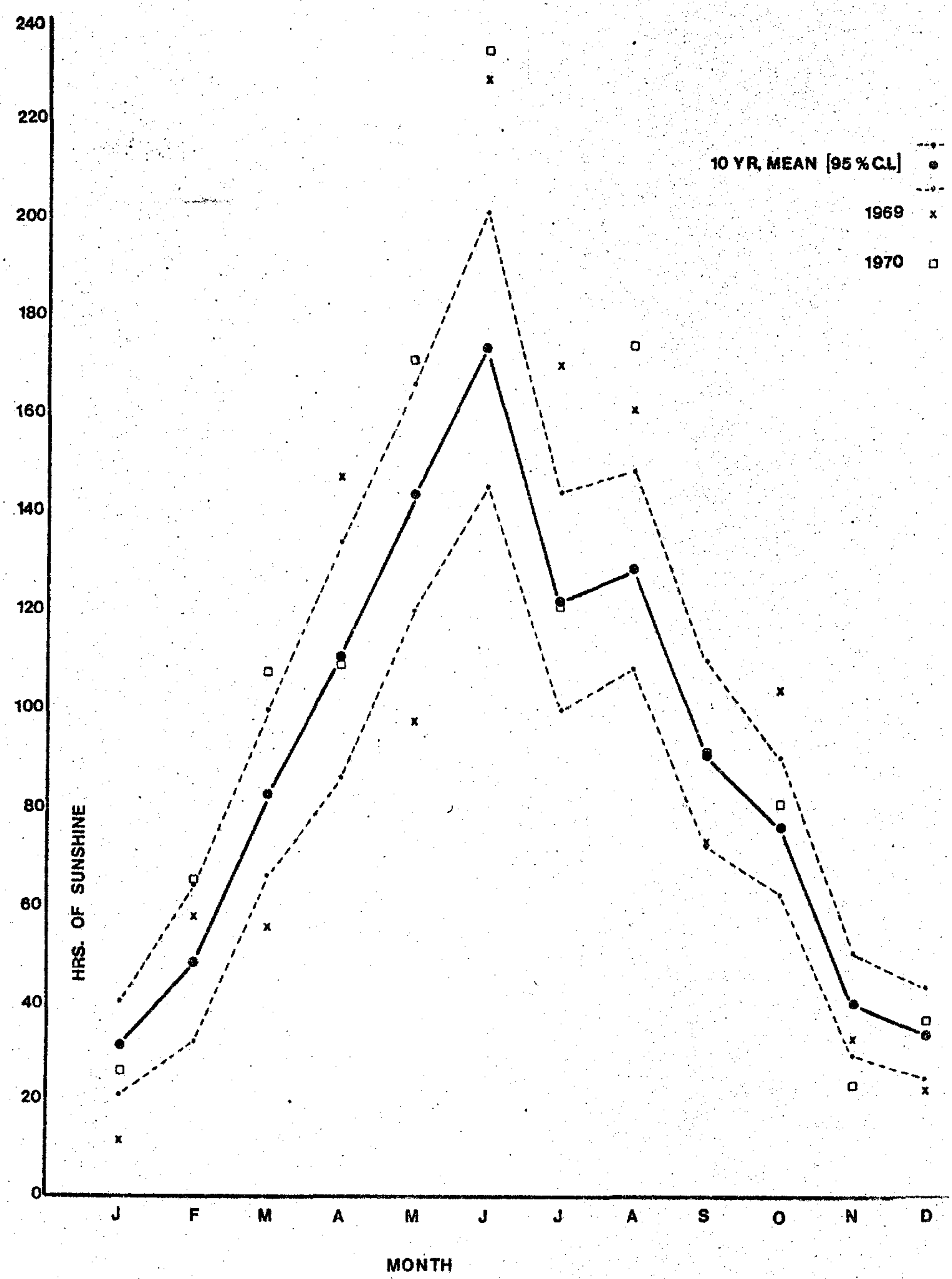
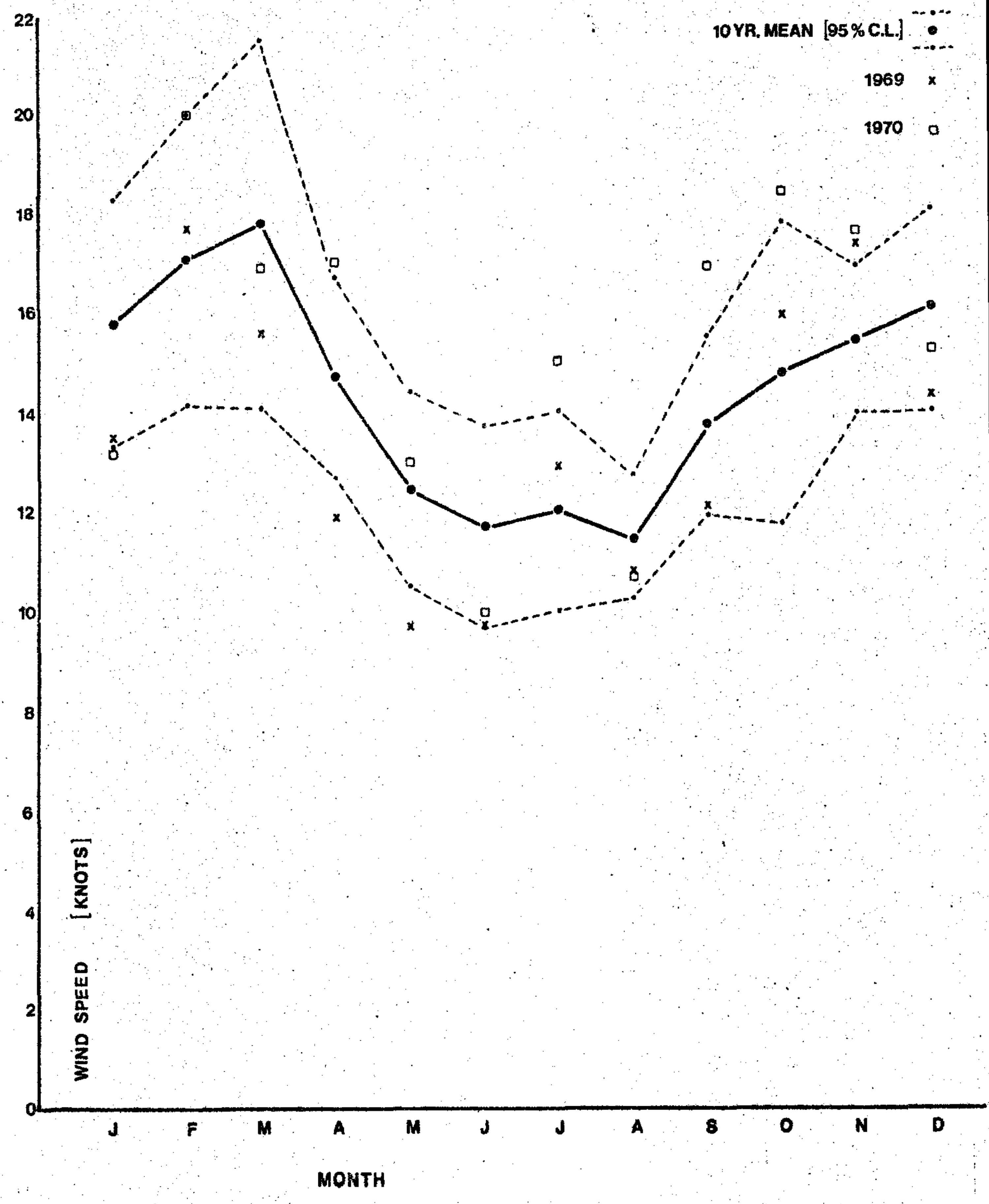


FIG 21 WIND SPEED [KNOTS]



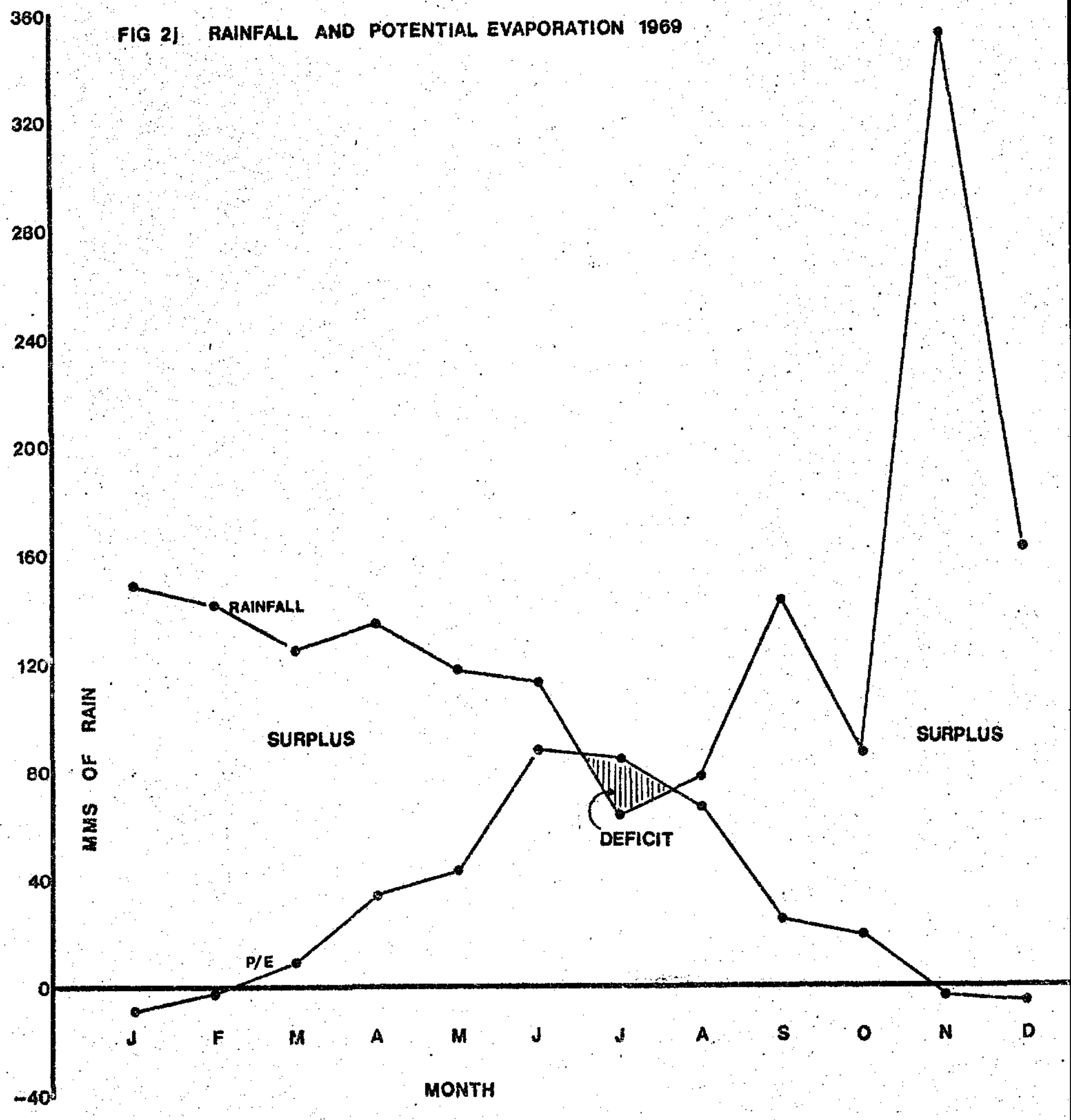


FIG 2J RAINFALL AND POTENTIAL EVAPORATION 1969
360
320
280
240
200
160
120
80
40
0
-40
MMS OF RAIN
RAINFALL
SURPLUS
DEFICIT
SURPLUS
P/E
J F M A M J J A S O N D
MONTH

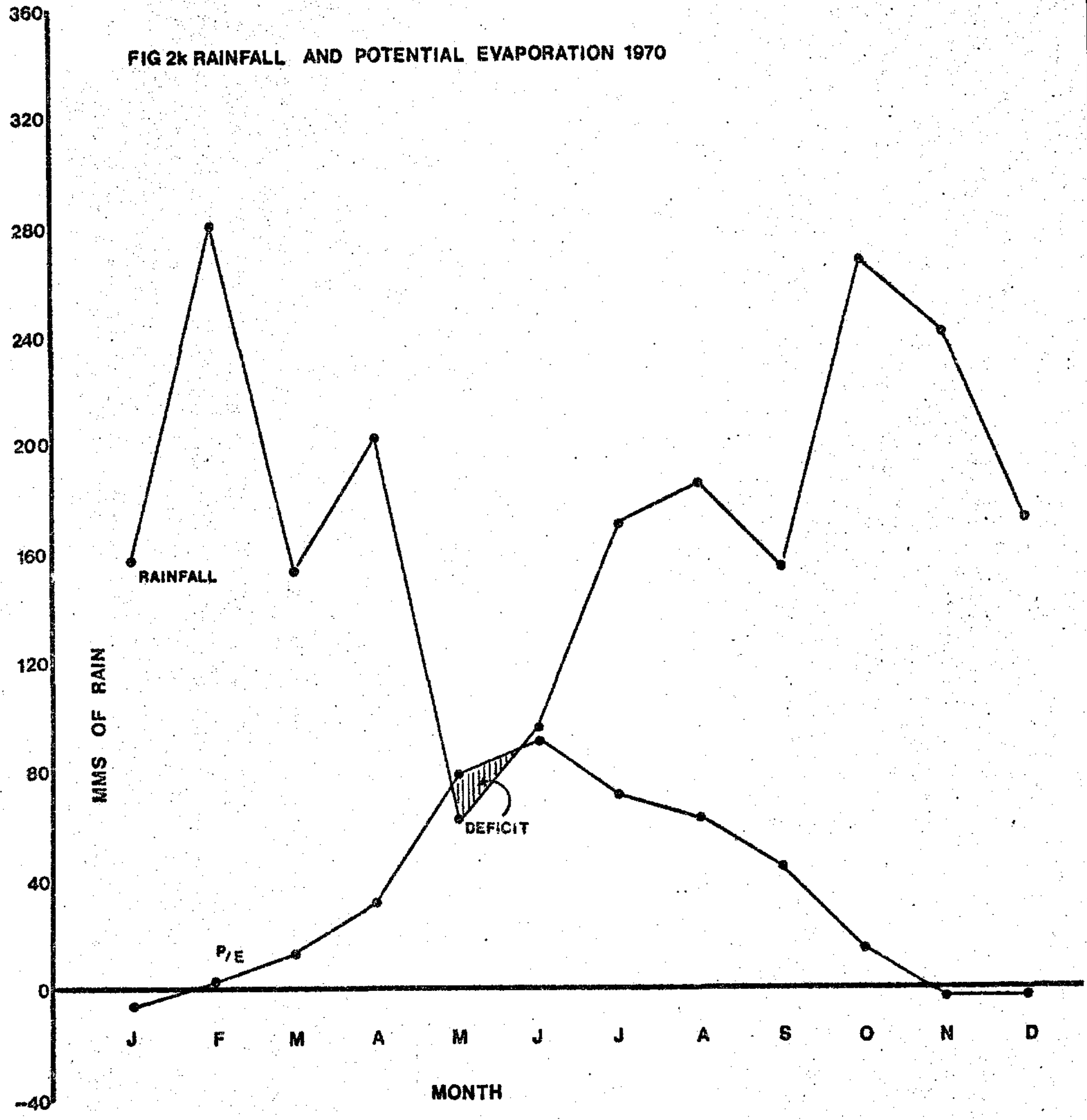


FIG 2k RAINFALL AND POTENTIAL EVAPORATION 1970
360
320
280
240
200
160
120
80
40
0
-40
MMS OF RAIN
RAINFALL
DEFICIT
P/E
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

FIG 21 MOORHOUSE TOTAL SOLAR RADIATION [MONTHLY TOTALS]

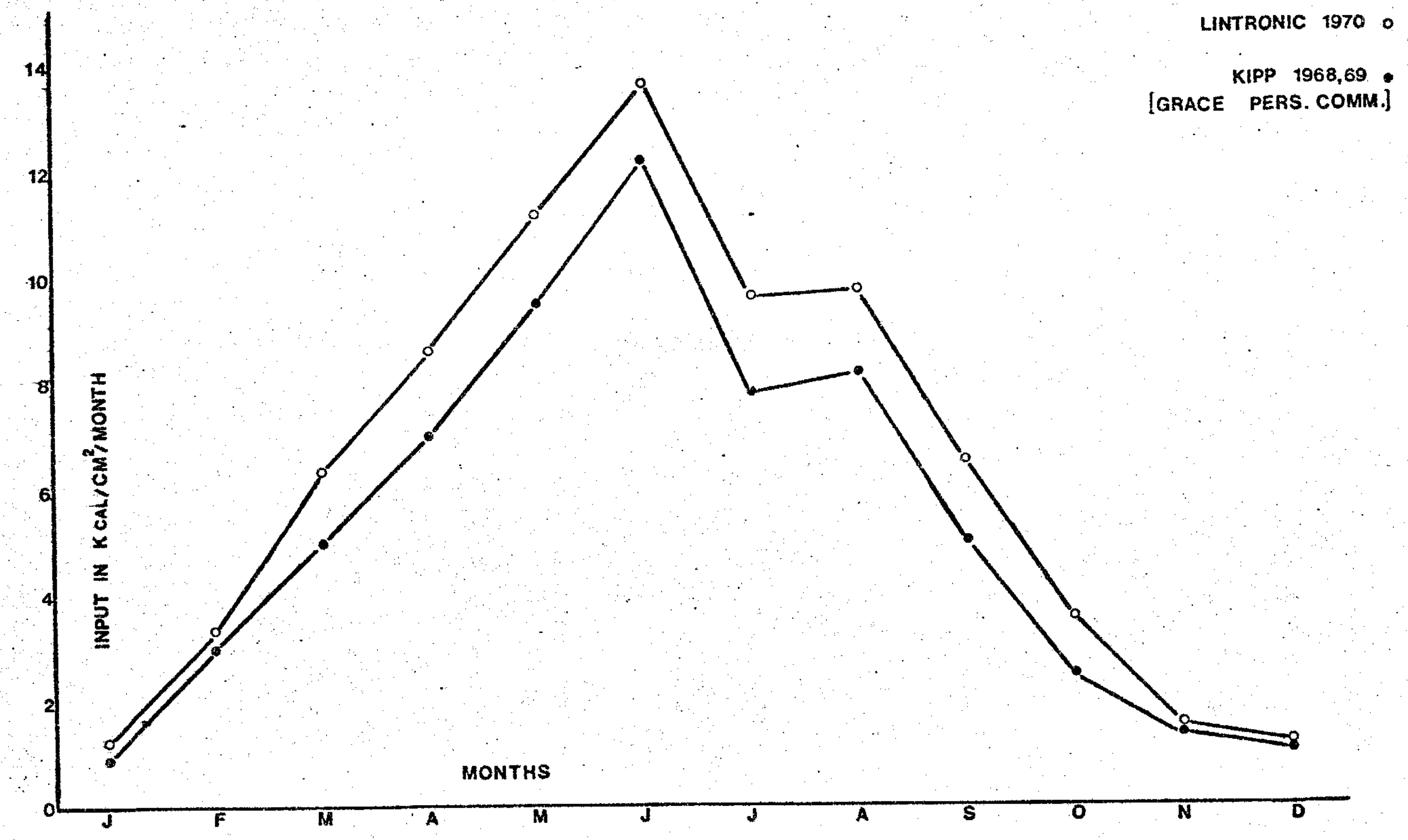


FIG 3a DAILY TEMPERATURE MEANS FOR CALLUNA PROFILE IN JUNE 1970

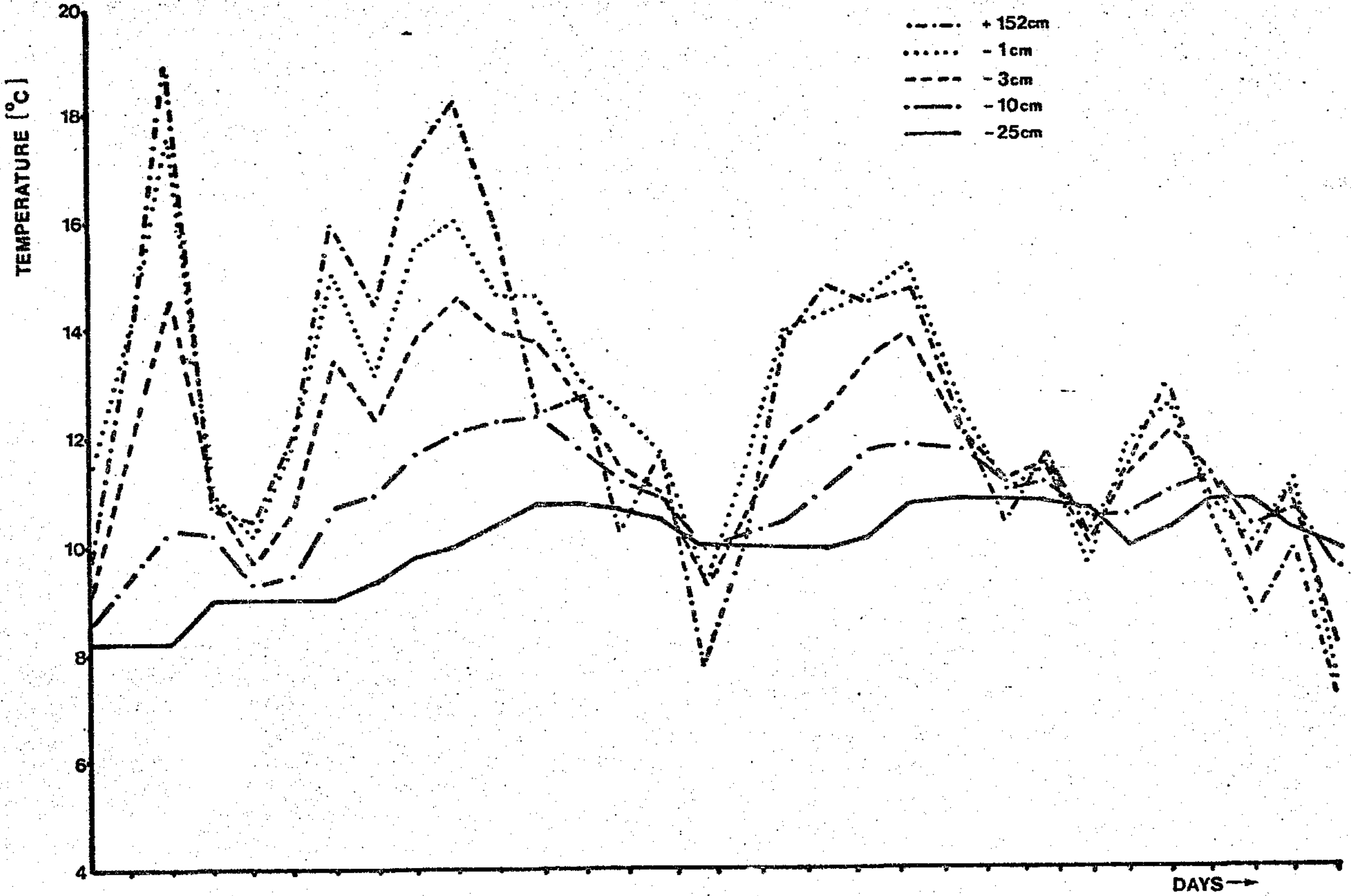


FIG 3b WEEKLY MEANS AND FOURIER ANALYSIS OF ANNUAL TEMPERATURE VARIATION IN 1969[-6·0cm IN CALLUNA PROFILE]

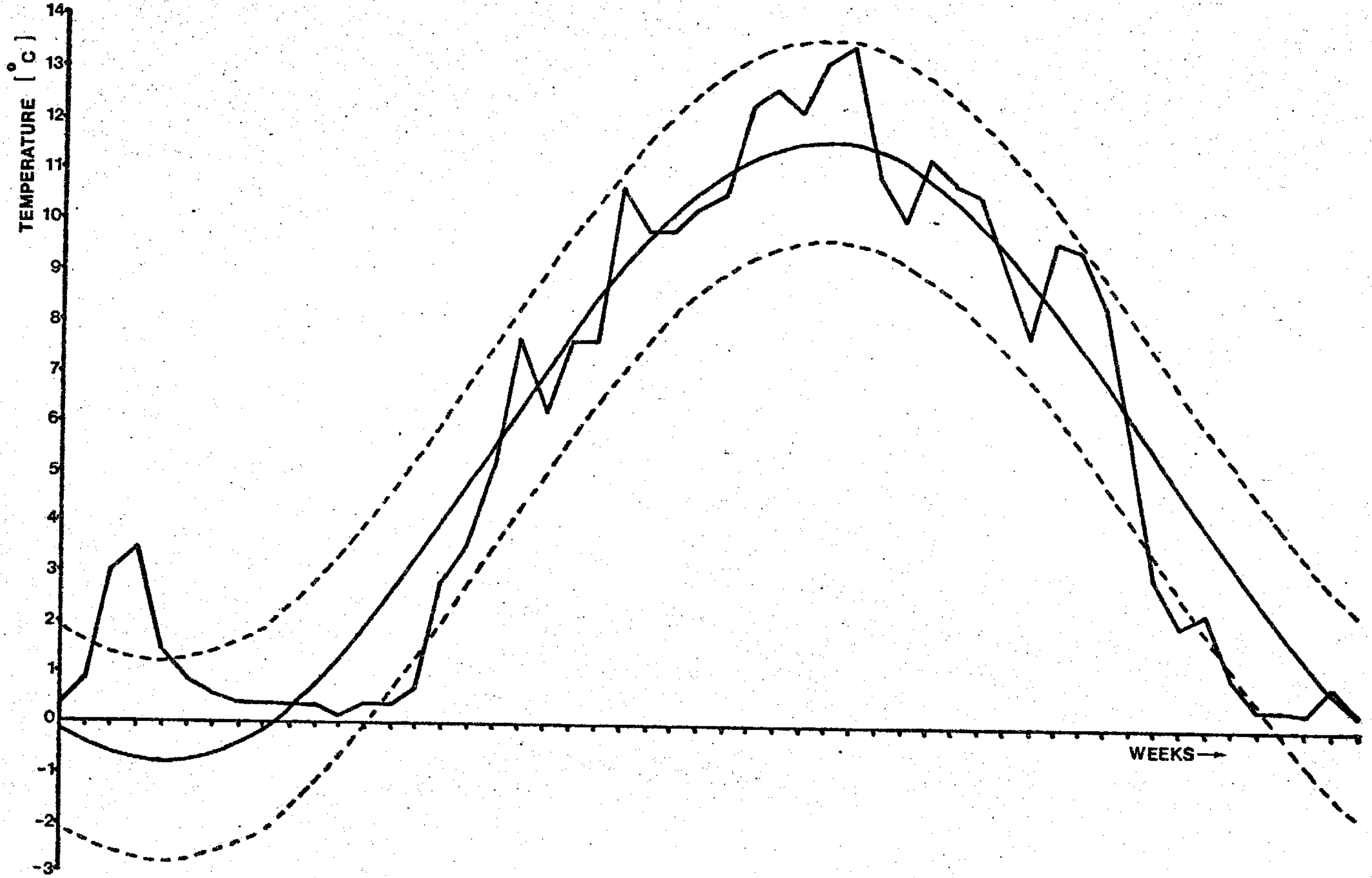


FIG 3c *CALLUNA* PROFILE — FOURIER ANALYSIS OF ANNUAL TEMPERATURE VARIATION IN 1969

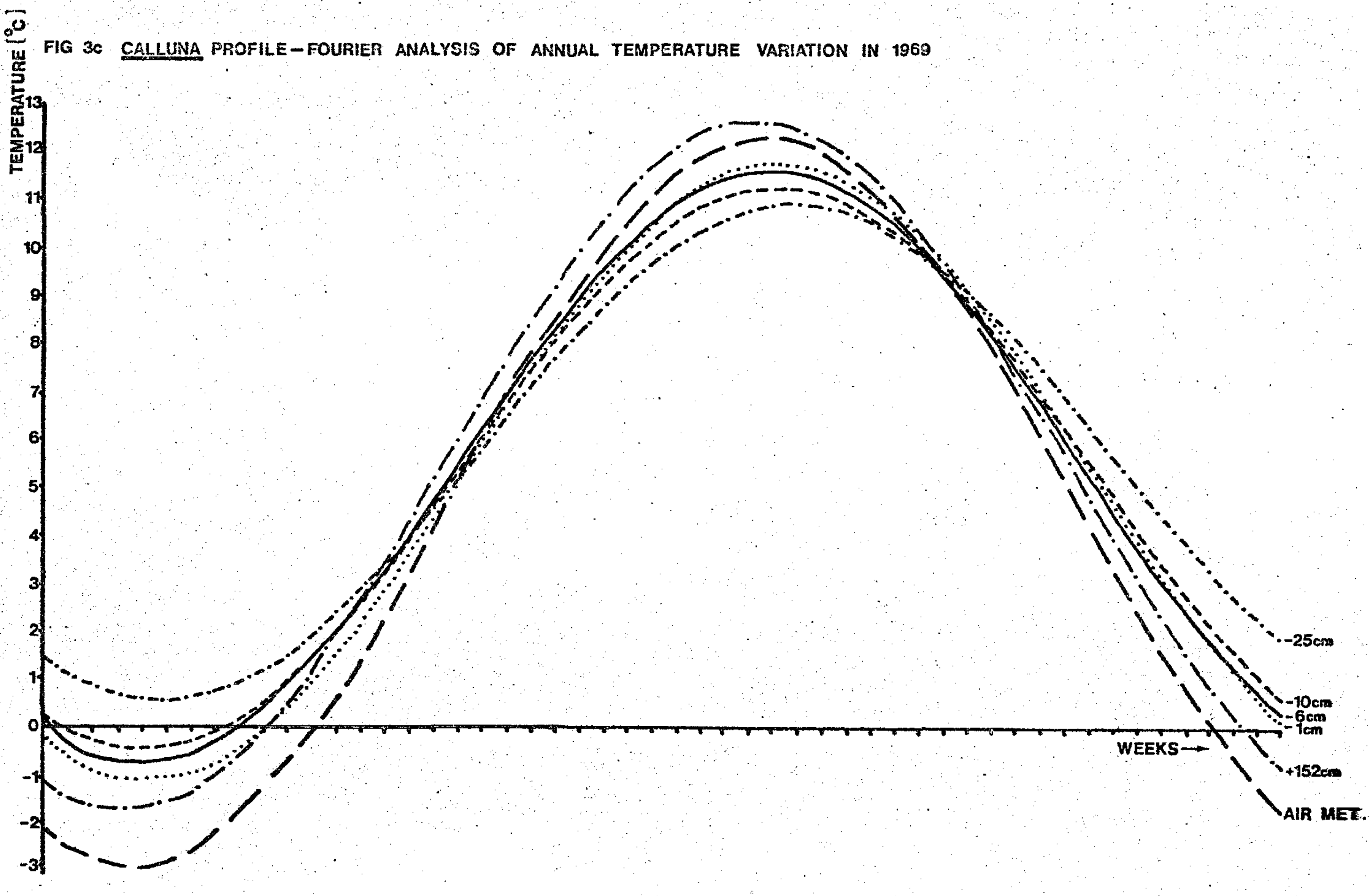


FIG 3d *JUNCUS* PROFILE—FOURIER ANALYSIS OF ANNUAL TEMPERATURE VARIATION IN 1969

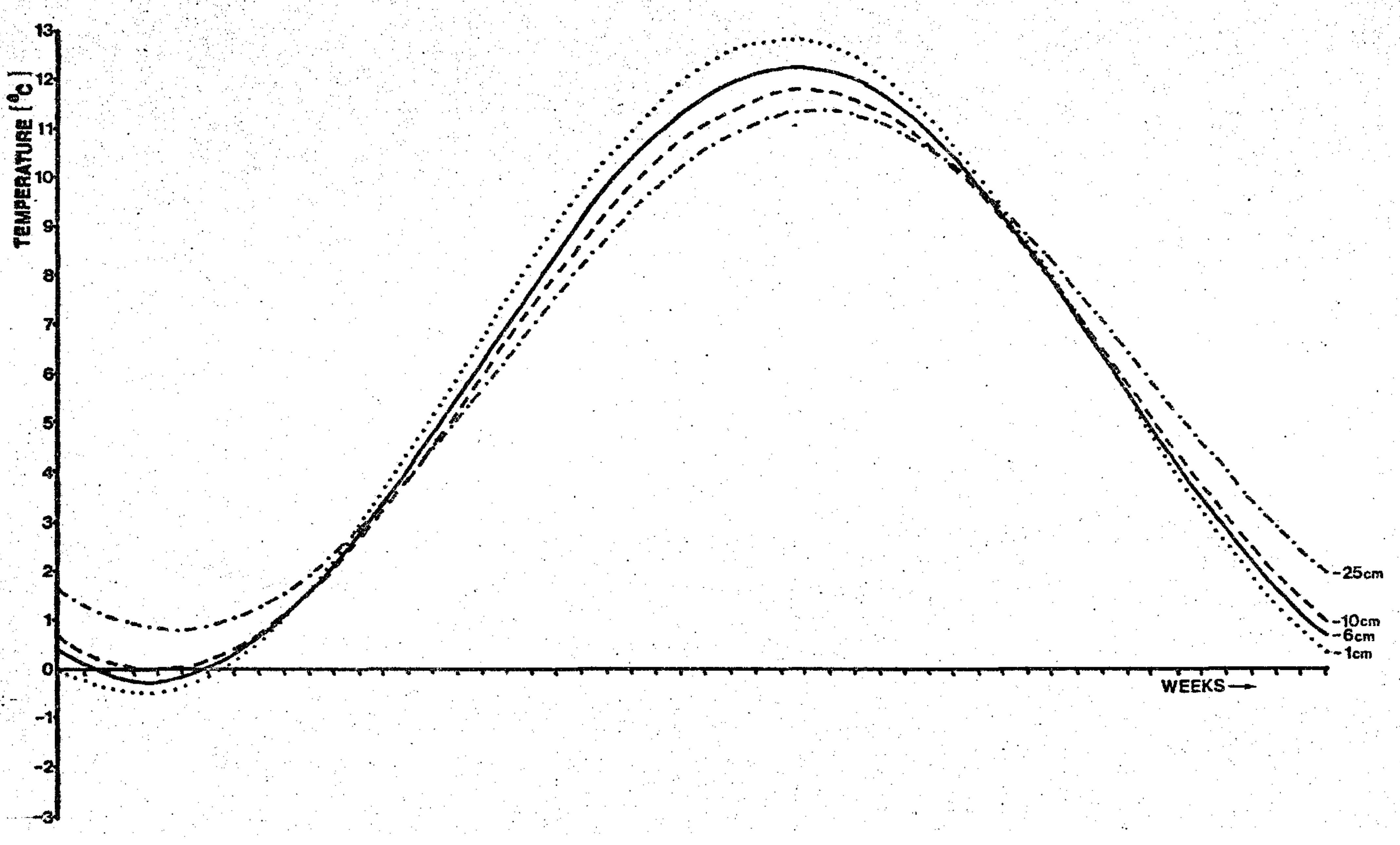


FIG 3e LOG_e AMPLITUDE OF TEMPERATURE VARIATION WITH DEPTH IN <u>CALLUNA</u> AND <u>JUNCUS</u> PROFILES

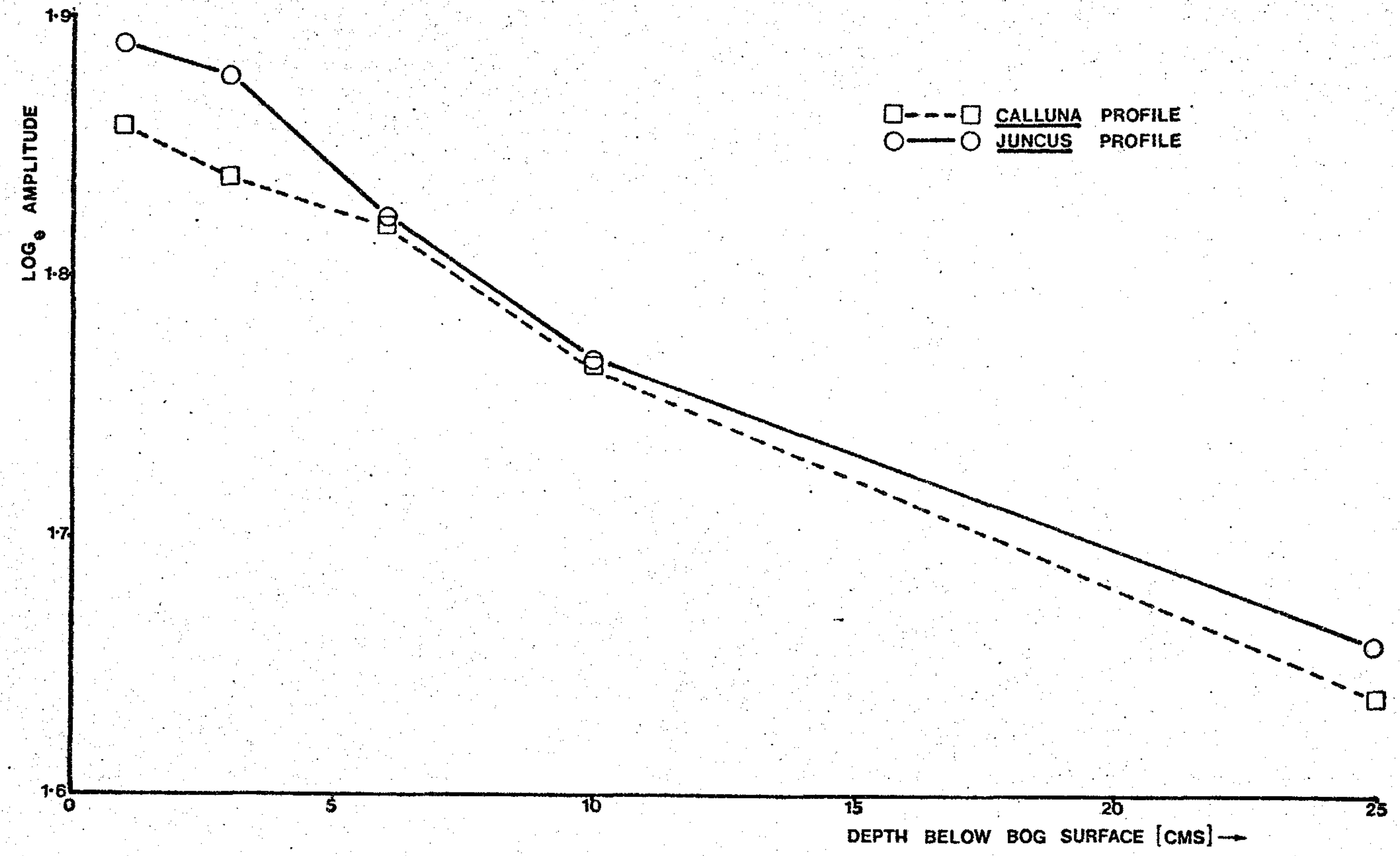


FIG 3f FOURIER ANALYSIS OF ANNUAL TEMPERATURE VARIATION IN DIFFERENT LITTERS IN 1969

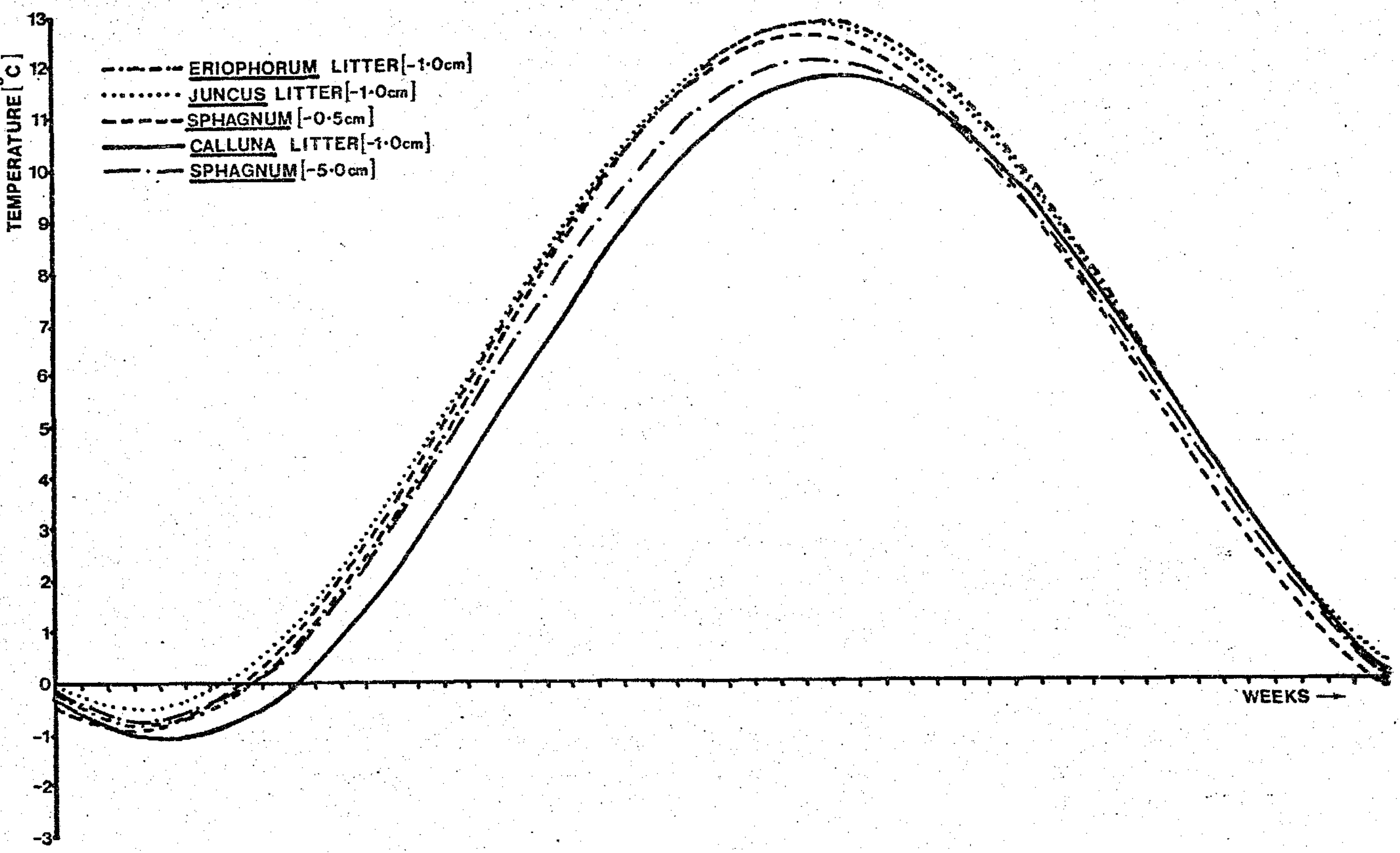


FIG 3g WEEKLY MEANS OF DAILY MAX. AND MIN. TEMPERATURES FOR 26 WEEKS FROM 31.3.69 – *JUNCUS* LITTER AND *SPHAGNUM* [NON-CALIBRATED DATA]

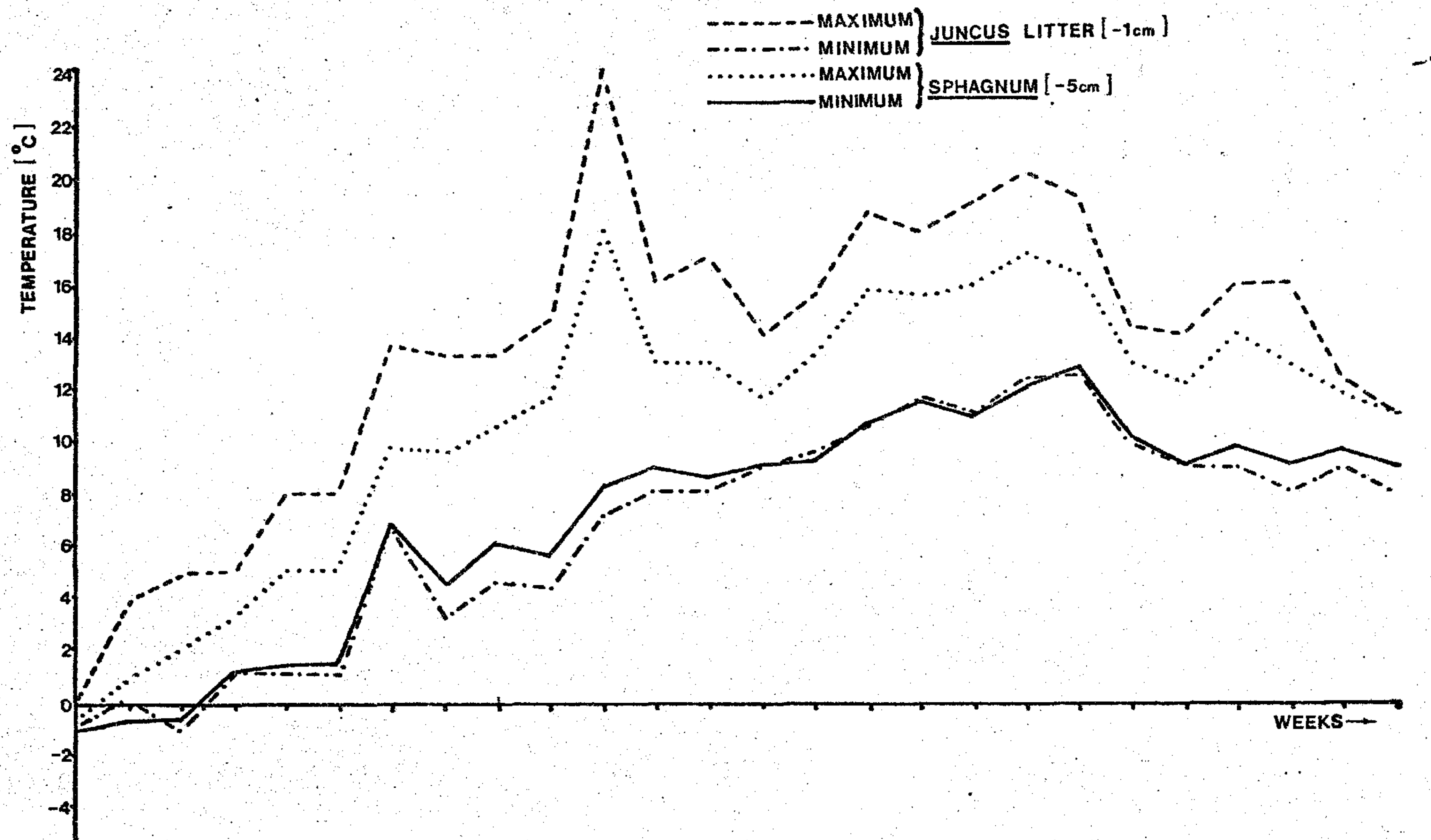


FIG 3h WEEKLY MEANS OF DAILY MAX. AND MIN. TEMPERATURES FOR 26 WEEKS FROM 31.3.69 – ERIOPHORUM AND CALLUNA LITTERS [NON-CALIBRATED DATA]

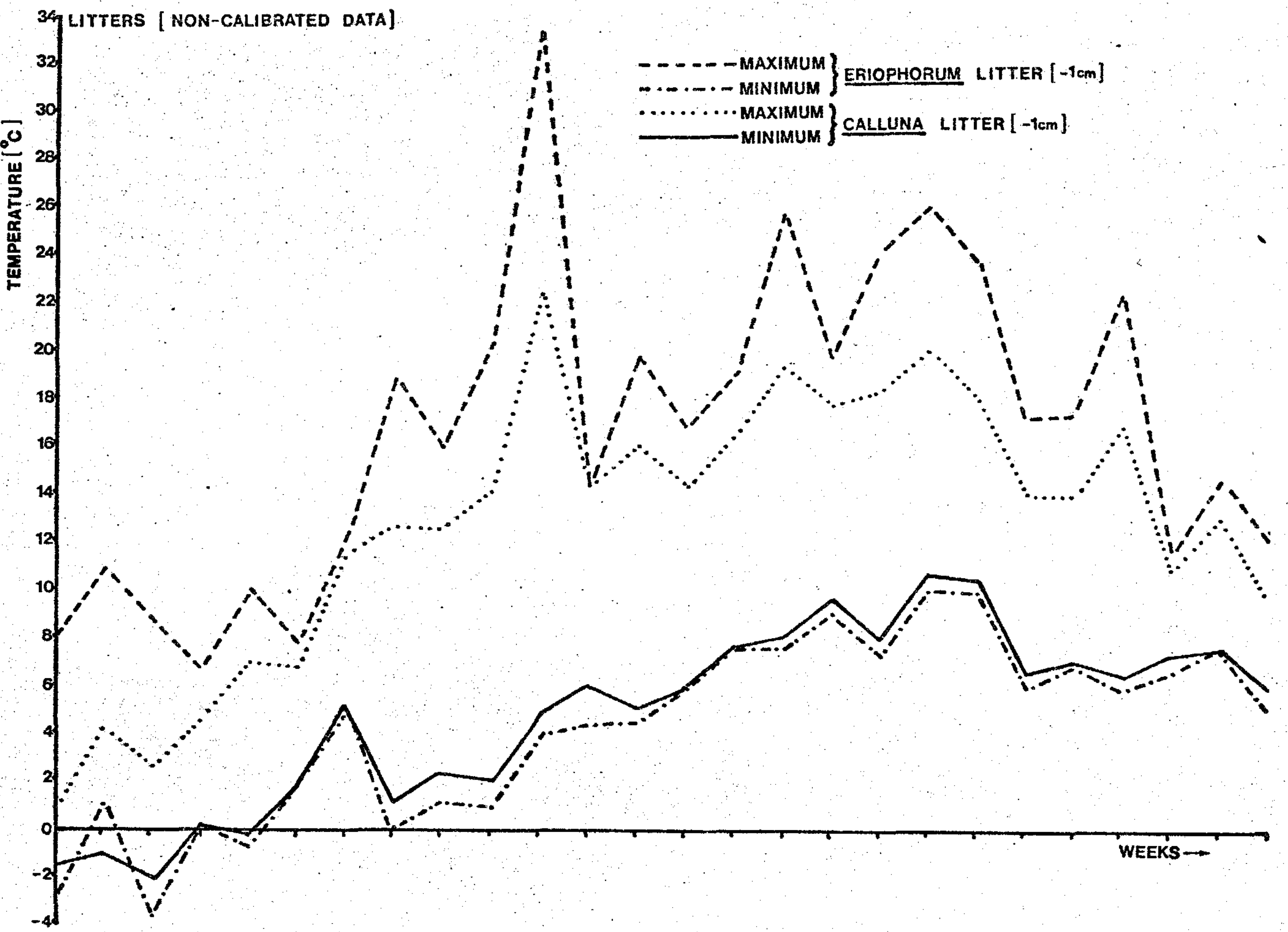


FIG 31 2° ISOTHERMS OF WEEKLY MEAN TEMPERATURE VARIATION IN A PEAT PROFILE FOR 1969 [NON-CALIBRATED DATA]

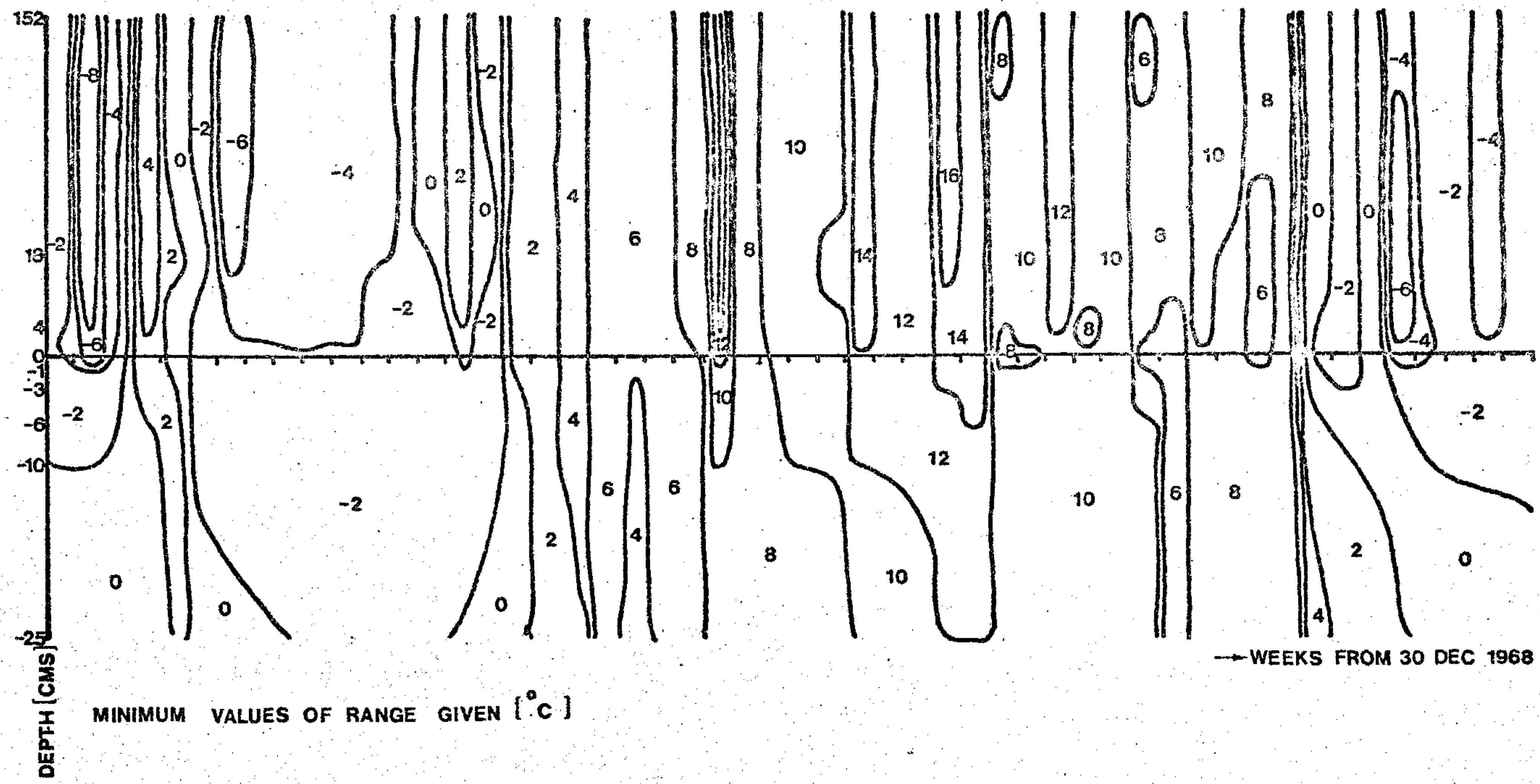
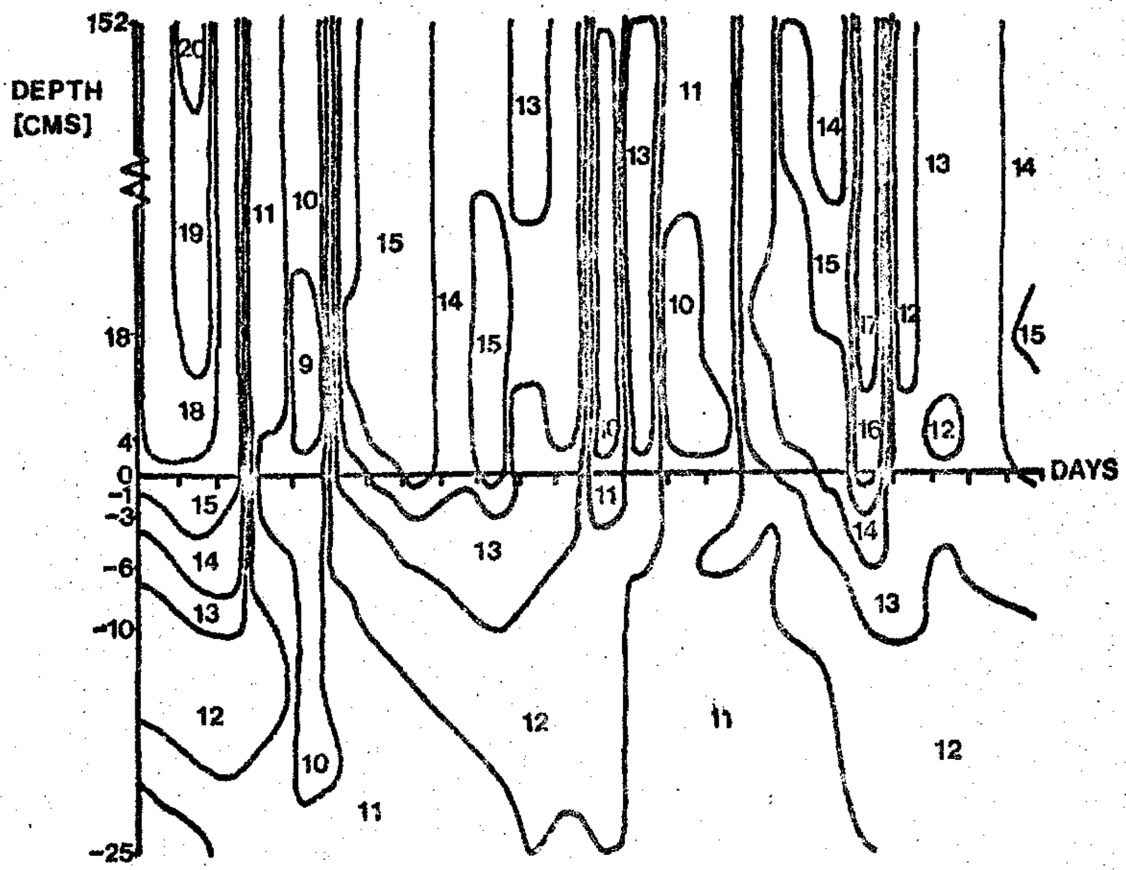


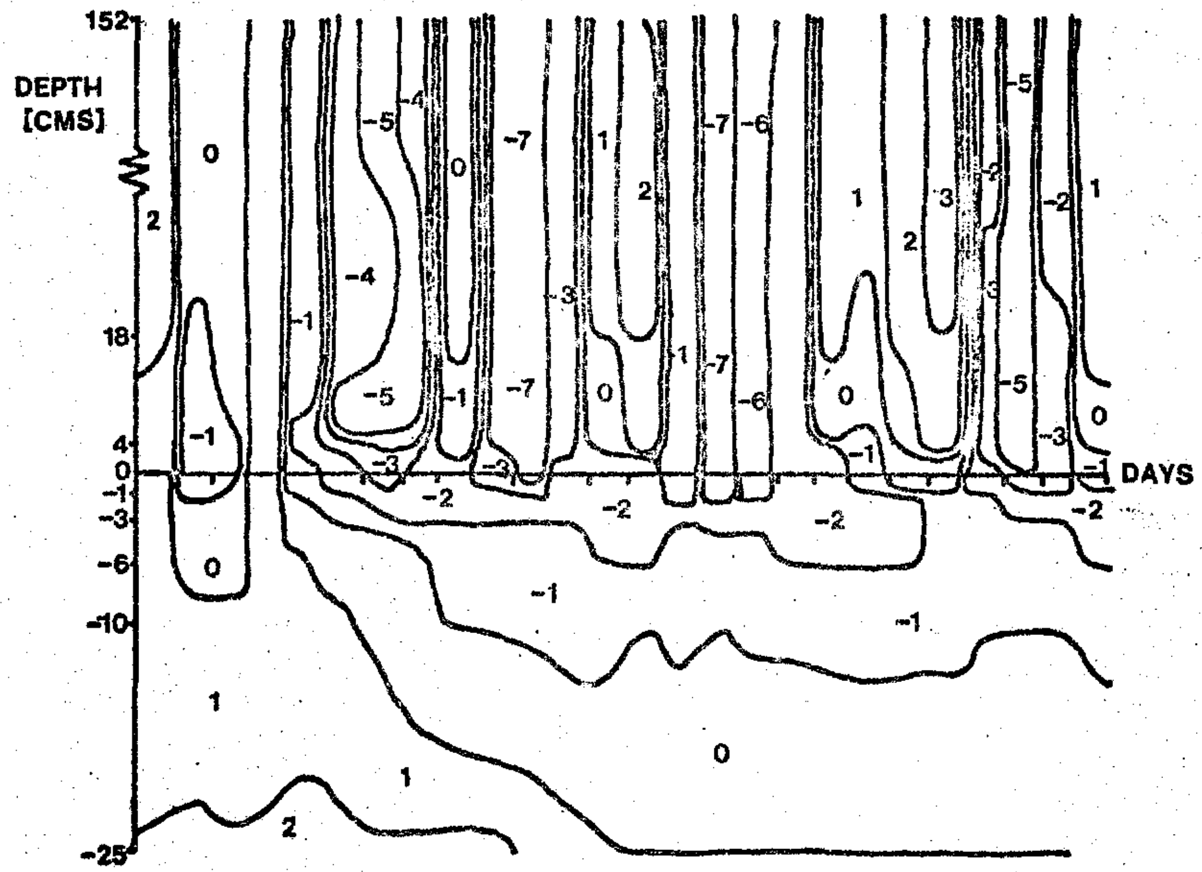
FIG 3) 1° ISOTHERMS OF DAILY MEAN TEMPERATURE VARIATION IN A PEAT PROFILE

[NON-CALIBRATED DATA]

SUMMER [14 JULY-6 AUG 1969]



WINTER [19 NOV-14 DEC 1969]



MINIMUM VALUES OF RANGE GIVEN [°C]

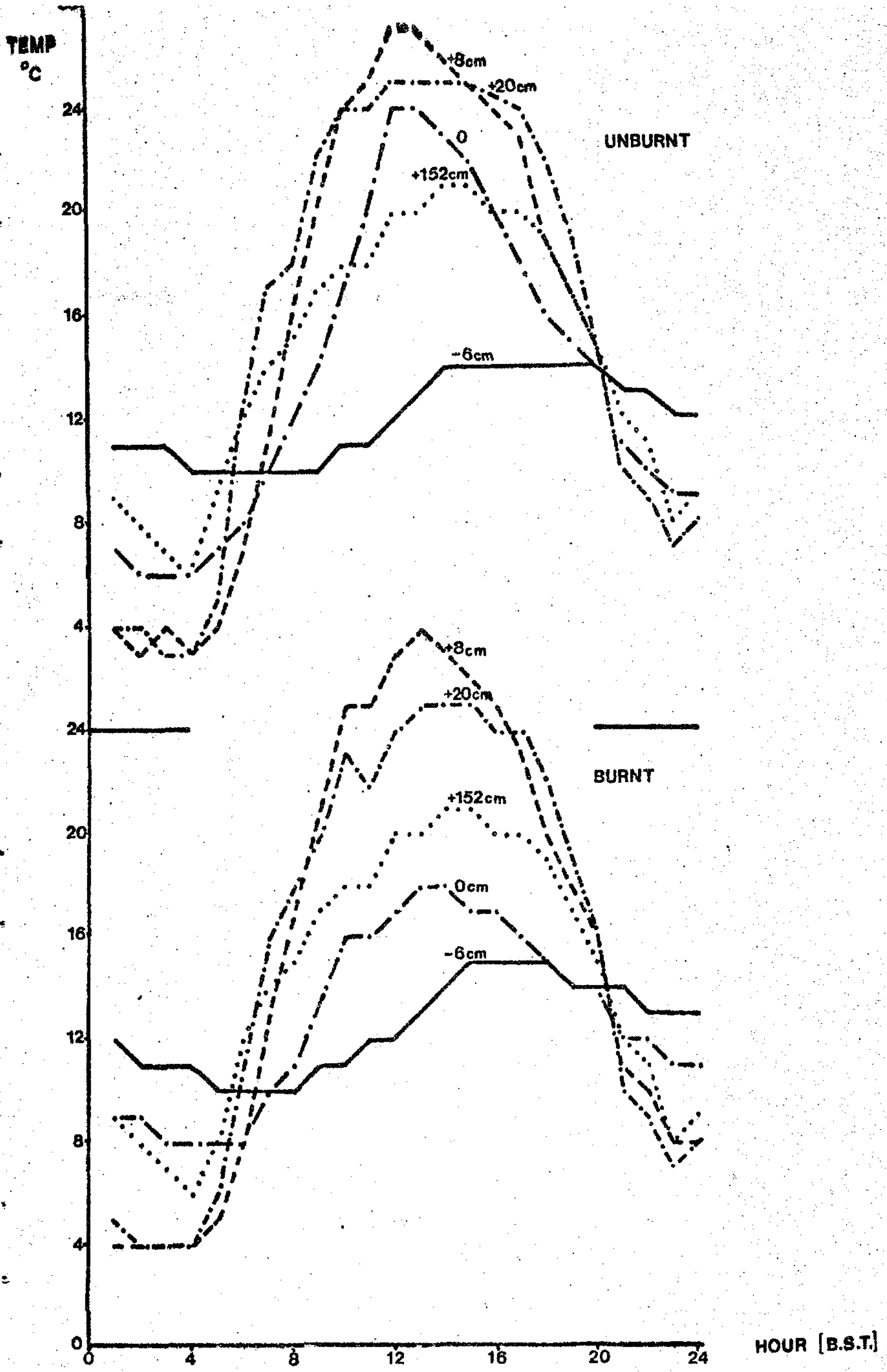
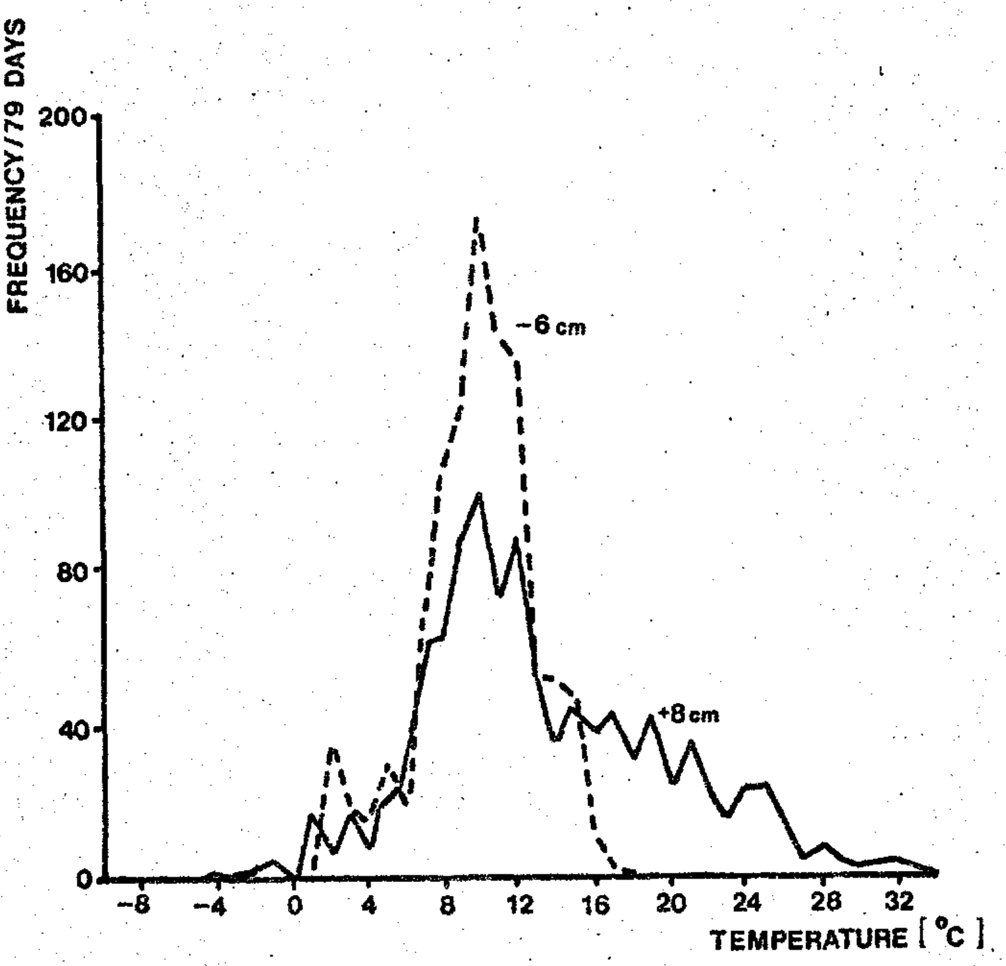


FIG. 3k TEMPERATURE PROFILES OF BURNT AND UNBURNT AREAS [19th JUNE 1970]
[T. MARKS PERS. COMM.]

FIG 31 FREQUENCY DISTRIBUTION OF TEMPERATURE READINGS FROM TWO PROBES IN BURNT AREA 07.00-19.00 HRS. PERIOD EACH DAY [T. MARKS PERS. COMM.]



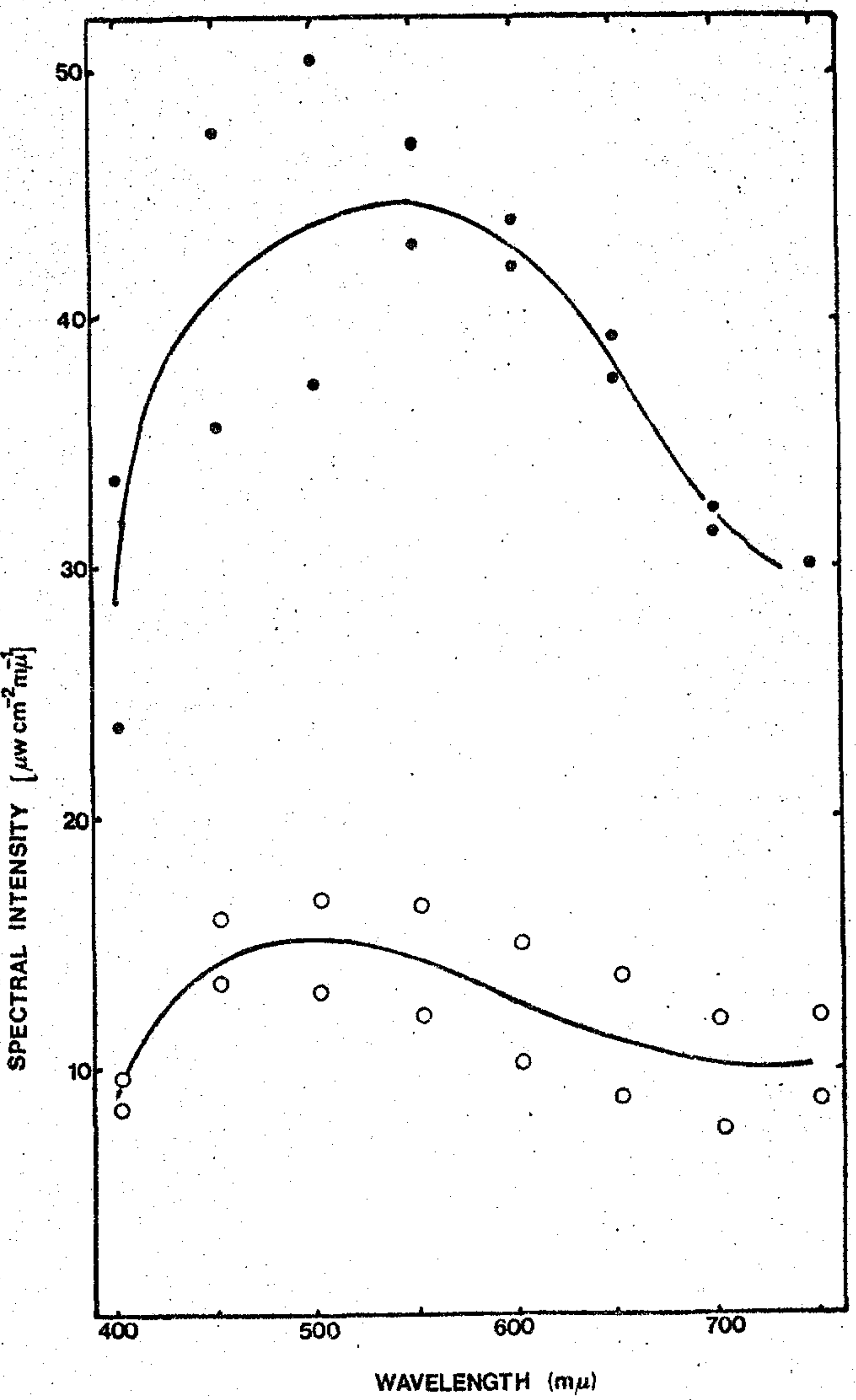


FIG 3m SPECTRAL ENERGY DISTRIBUTION ABOVE [●] AND BELOW [○] CANOPY (GRACE 1970)

FIG 4b GEOLOGICAL SECTION ACROSS MOOR HOUSE NNR [JOHNSON & DUNHAM 1963]

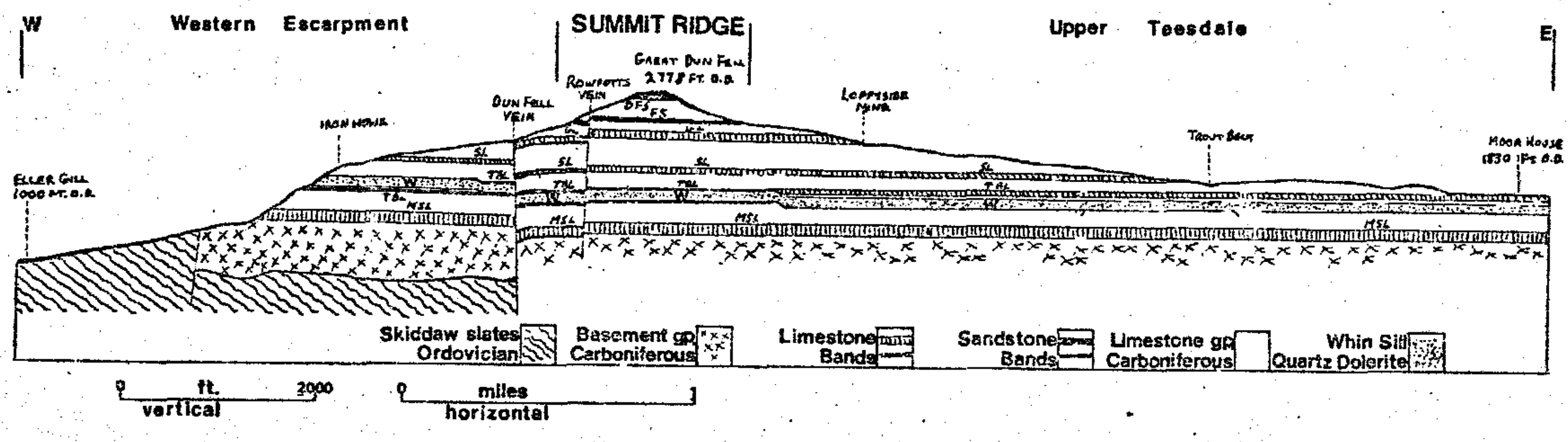


FIG 5b VARIATION IN SOIL GROUP AND VARIOUS PROPERTIES WITH DEPTH OF SUPERFICIAL DRIFT OVER LIMESTONE [HORNUNG 1968]

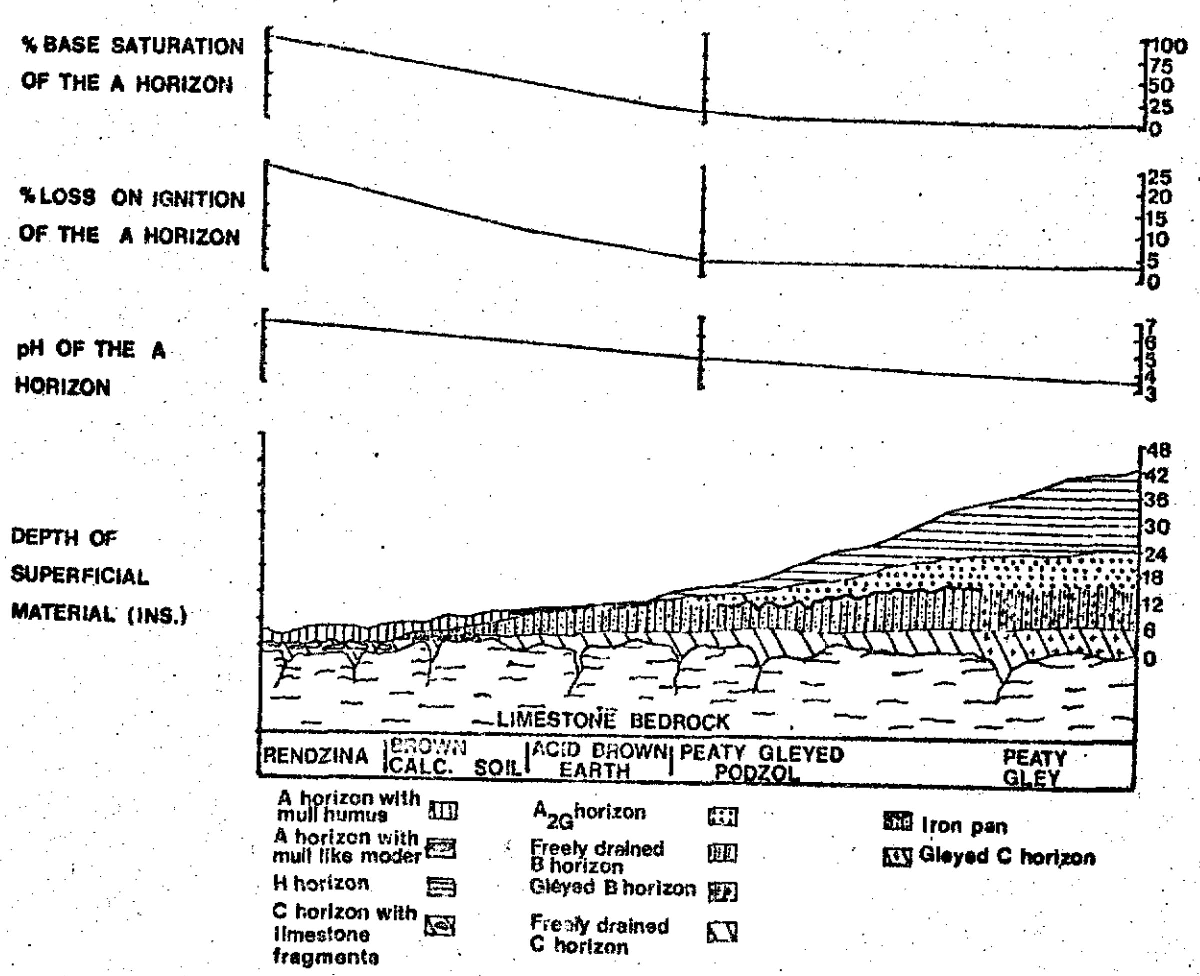


FIG 5c SLOPE SEQUENCE OF SOILS (HORNUNG 1968)

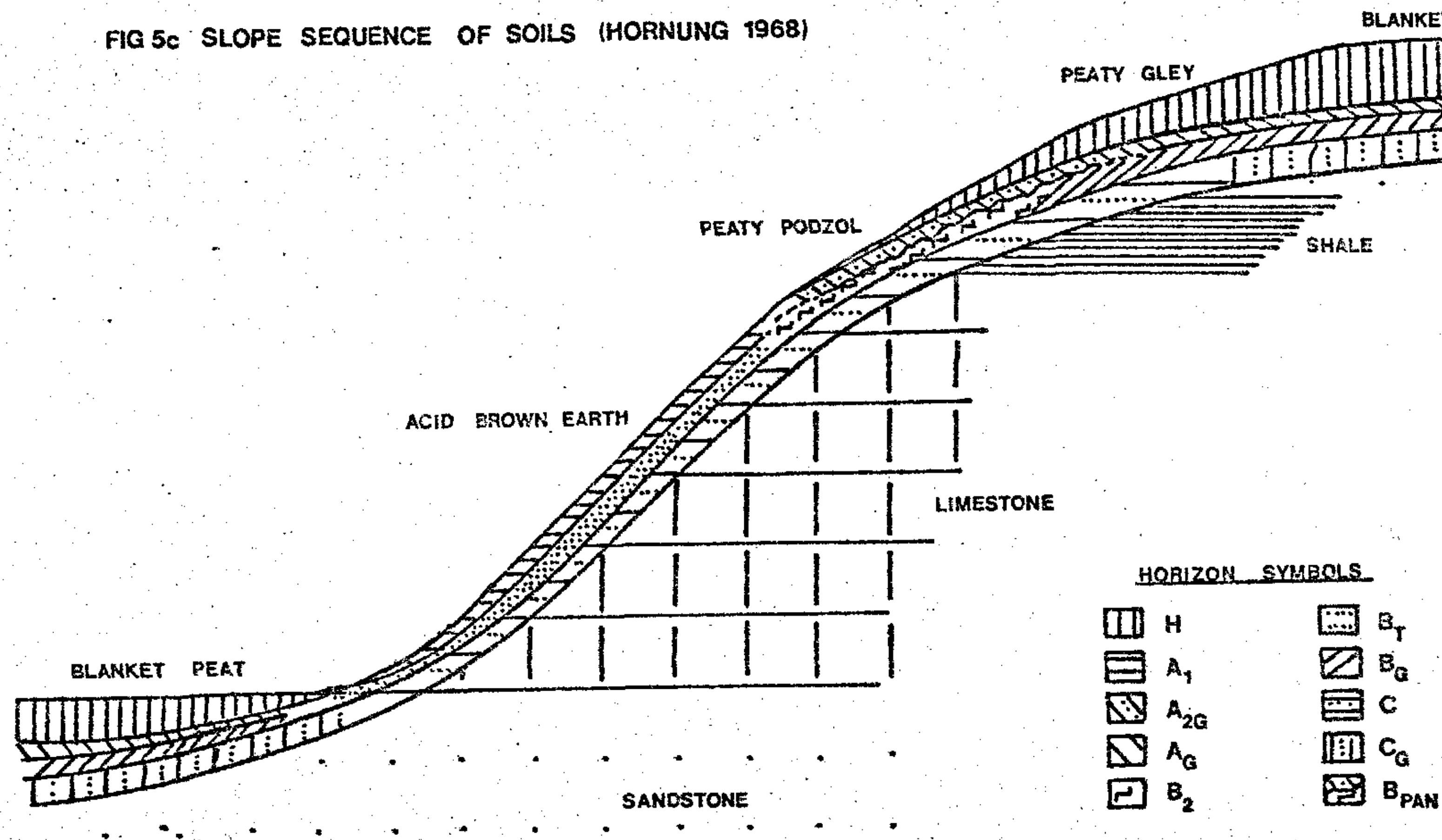
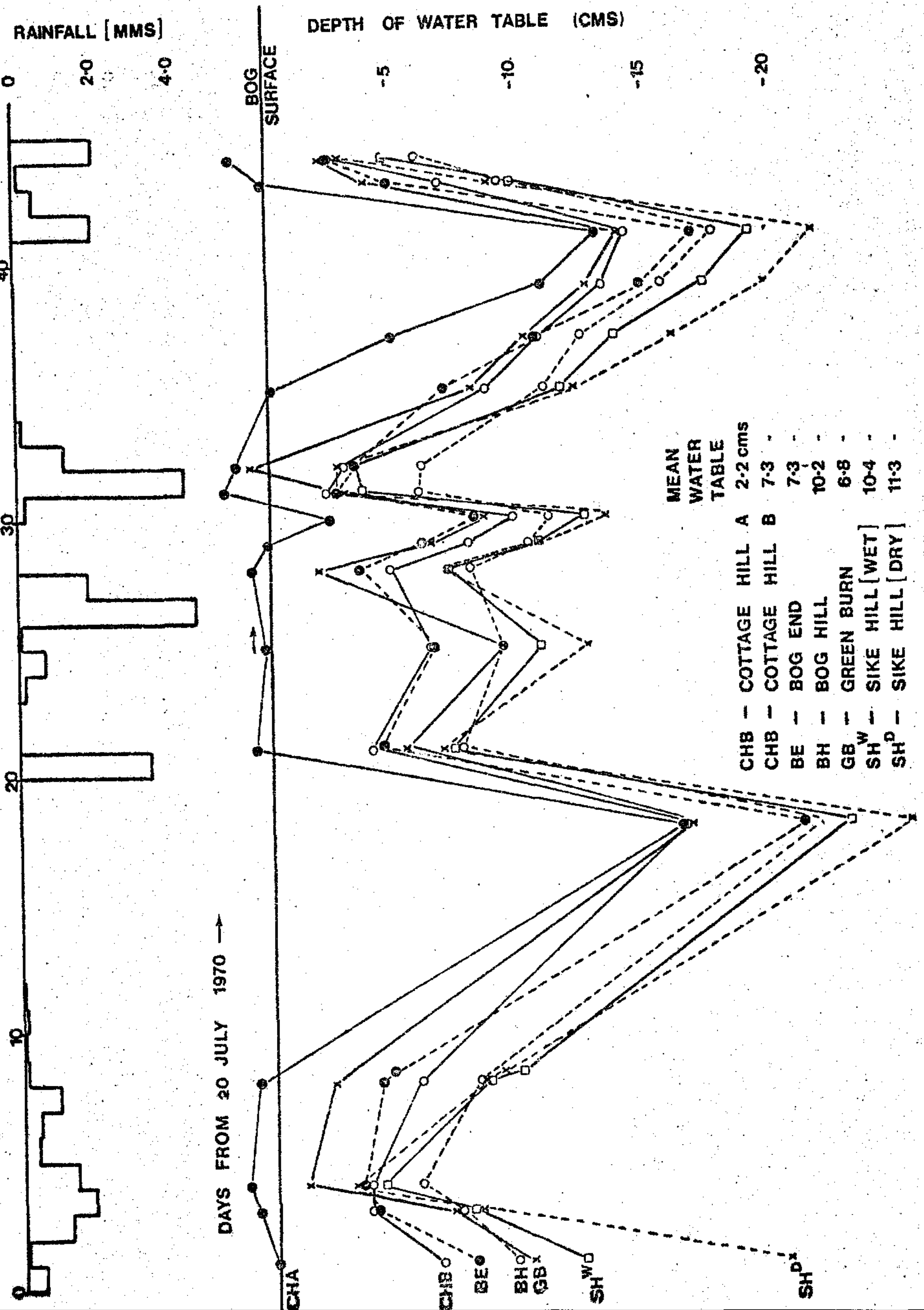


FIG 5d VARIATION OF WATER TABLE AT SEVEN SITES JULY – SEPT 1970

[FORREST PERS. COMM.]



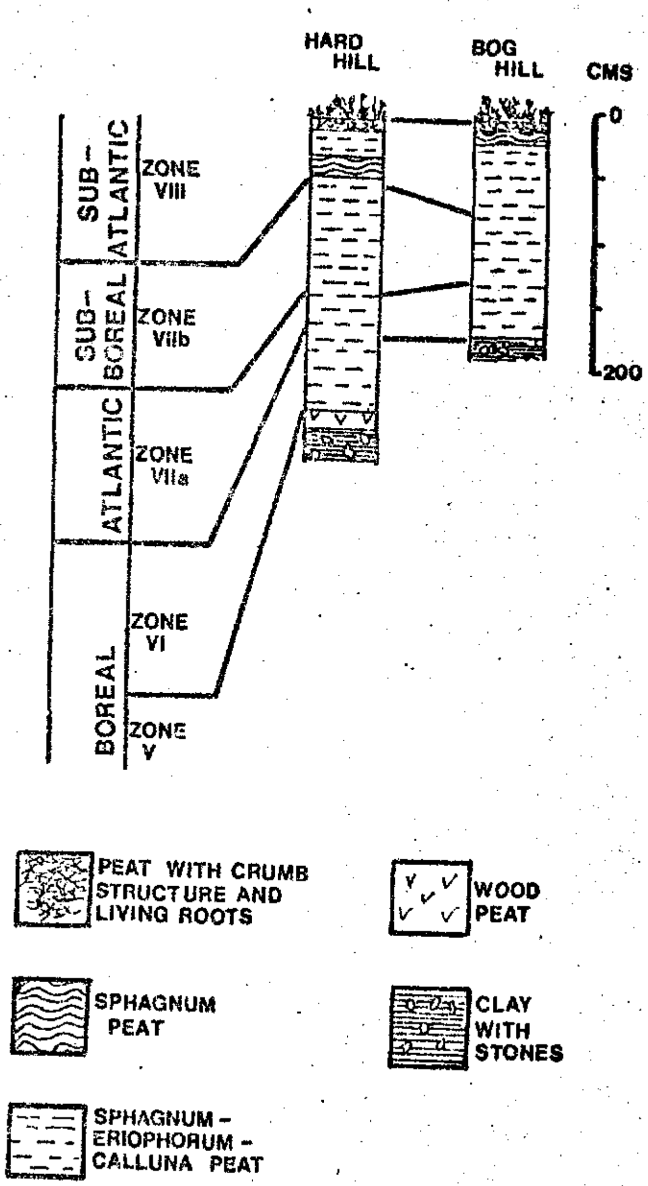


FIG 5e COMPARATIVE SECTIONS OF BLANKET PEAT ON THE MOOR-HOUSE RESERVE
[AFTER JOHNSON AND DUNHAM 1963]

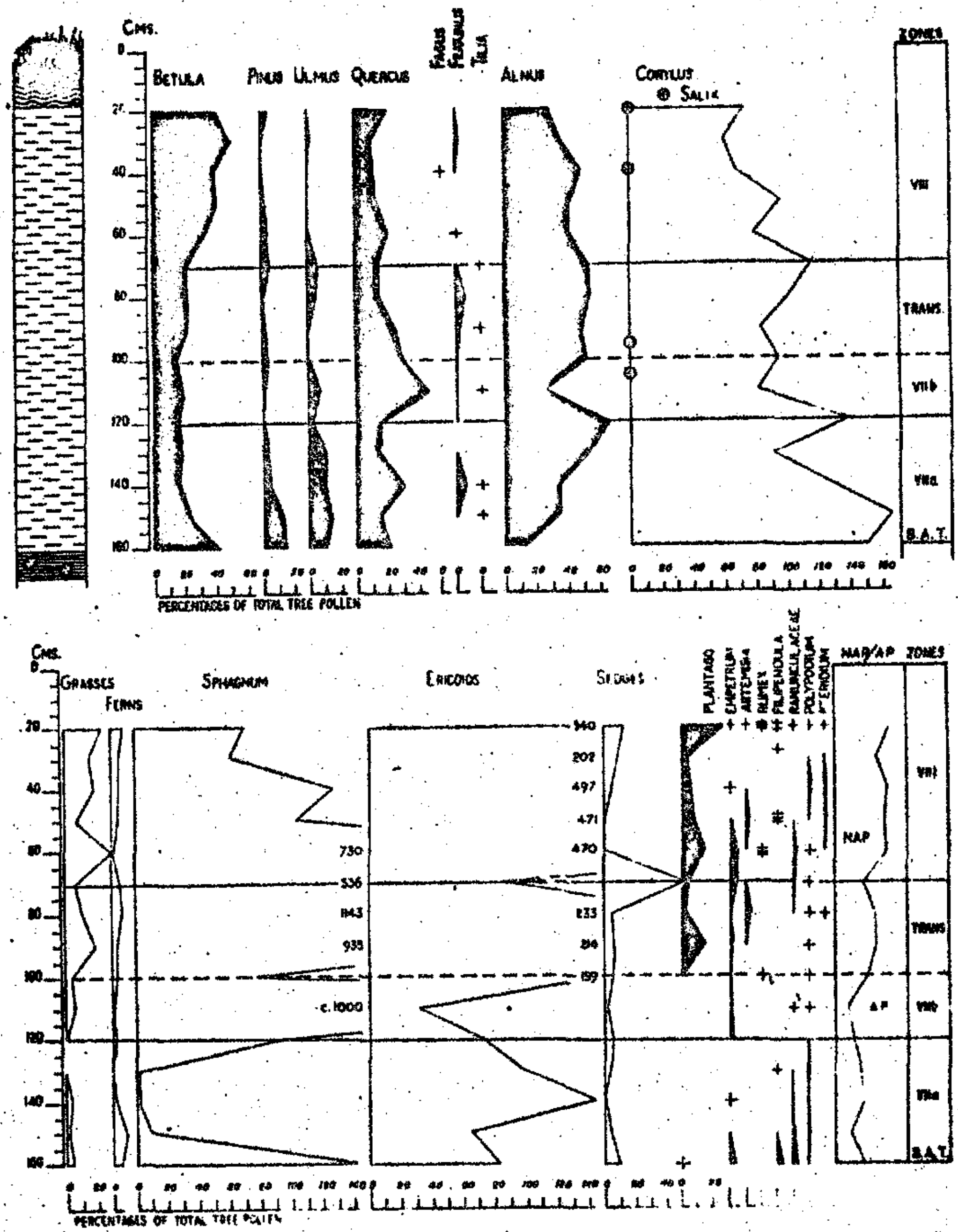


FIG 5f POLLEN DIAGRAM FOR BOG HILL [AFTER JOHNSON AND DUNHAM 1963]

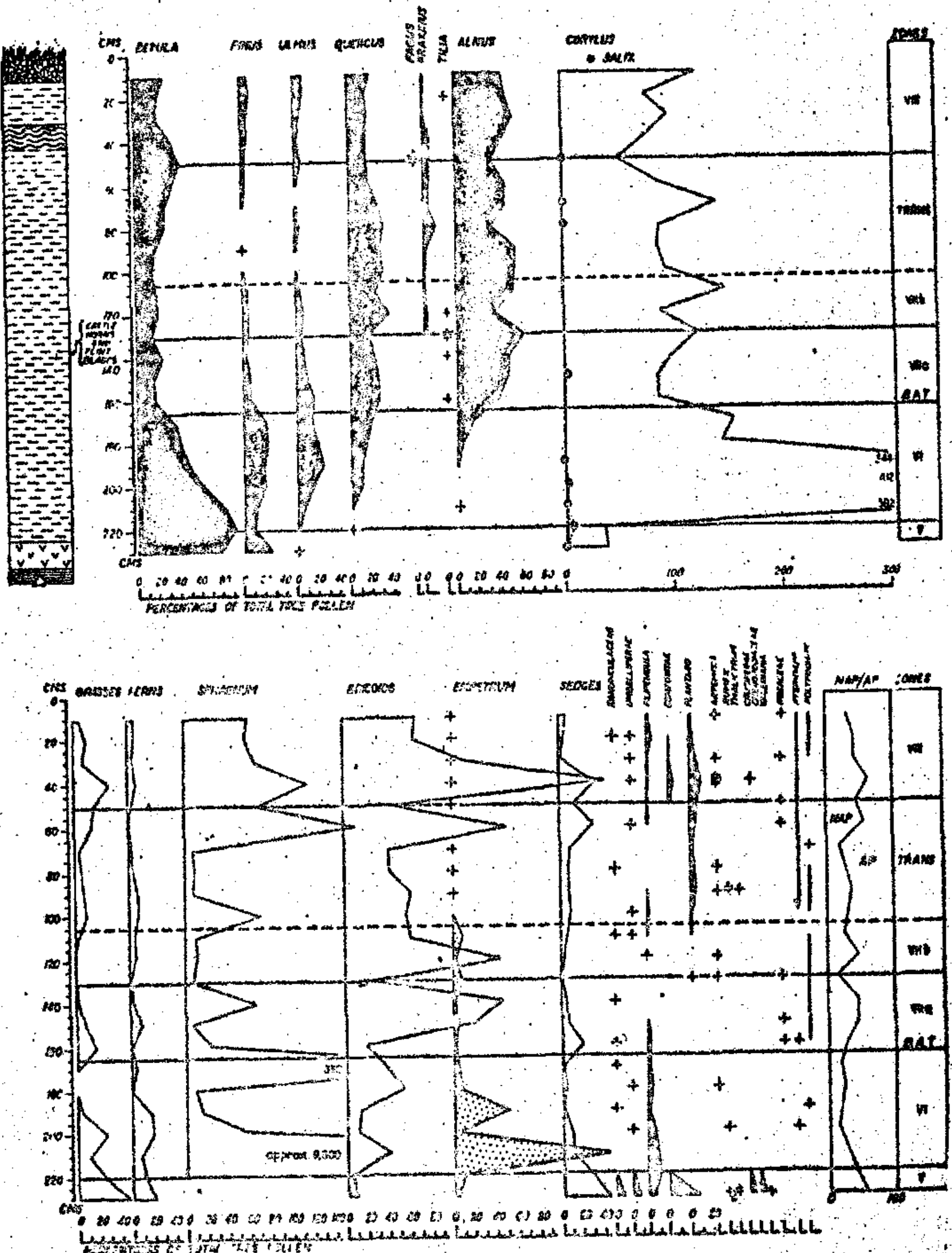


FIG 5g POLLEN DIAGRAM FOR HARD HILL [AFTER JOHNSON AND DUNHAM 1963]

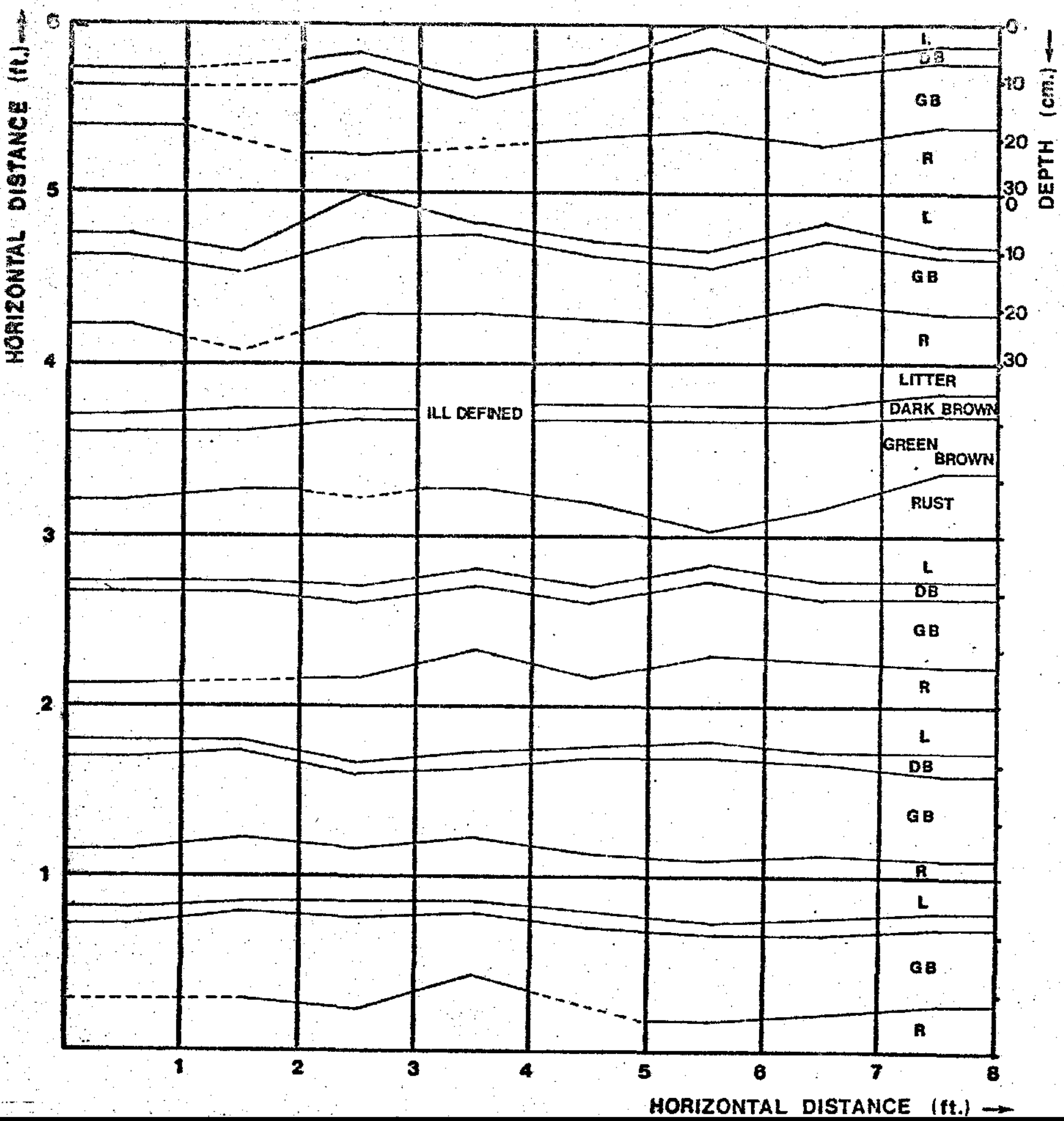
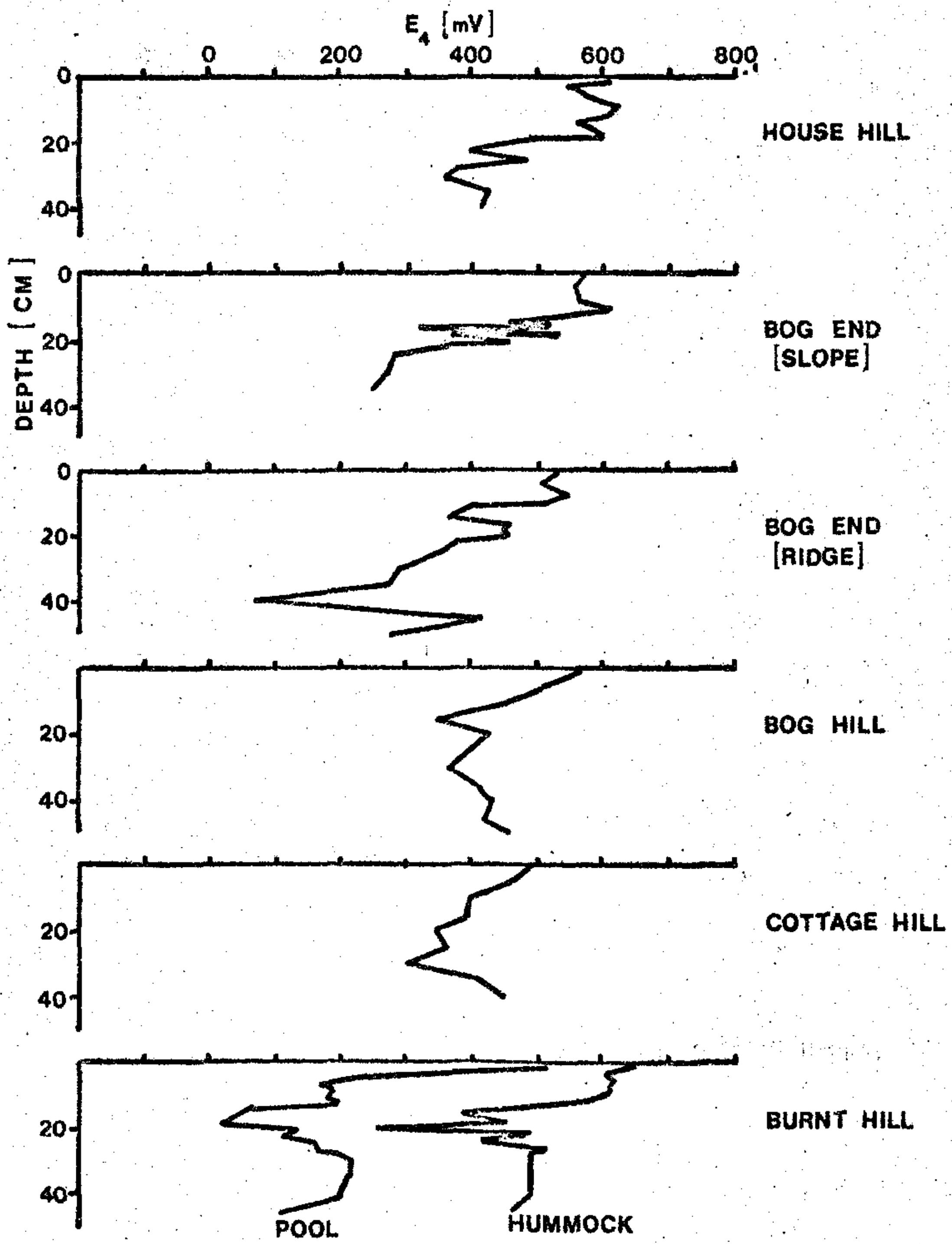


FIG 5h HORIZONTAL VARIATION OF COLOUR ZONE DEPTH
[MARTIN PERS. COMM.]

FIG 51 PEAT PROFILE REDOX DATA [FROM URQUHART 1969]



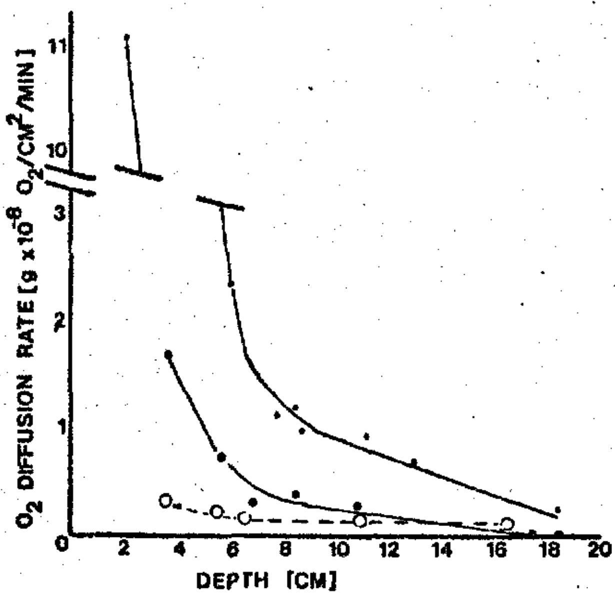


FIG 5j SUTHERLAND. O_2 DIFFUSION RATES IN THE CENTRE OF A FLUSH (·), AT THE EDGE OF A FLUSH (•) AND ON THE BOG SURFACE (o). [ARMSTRONG & BOATMAN 1967]

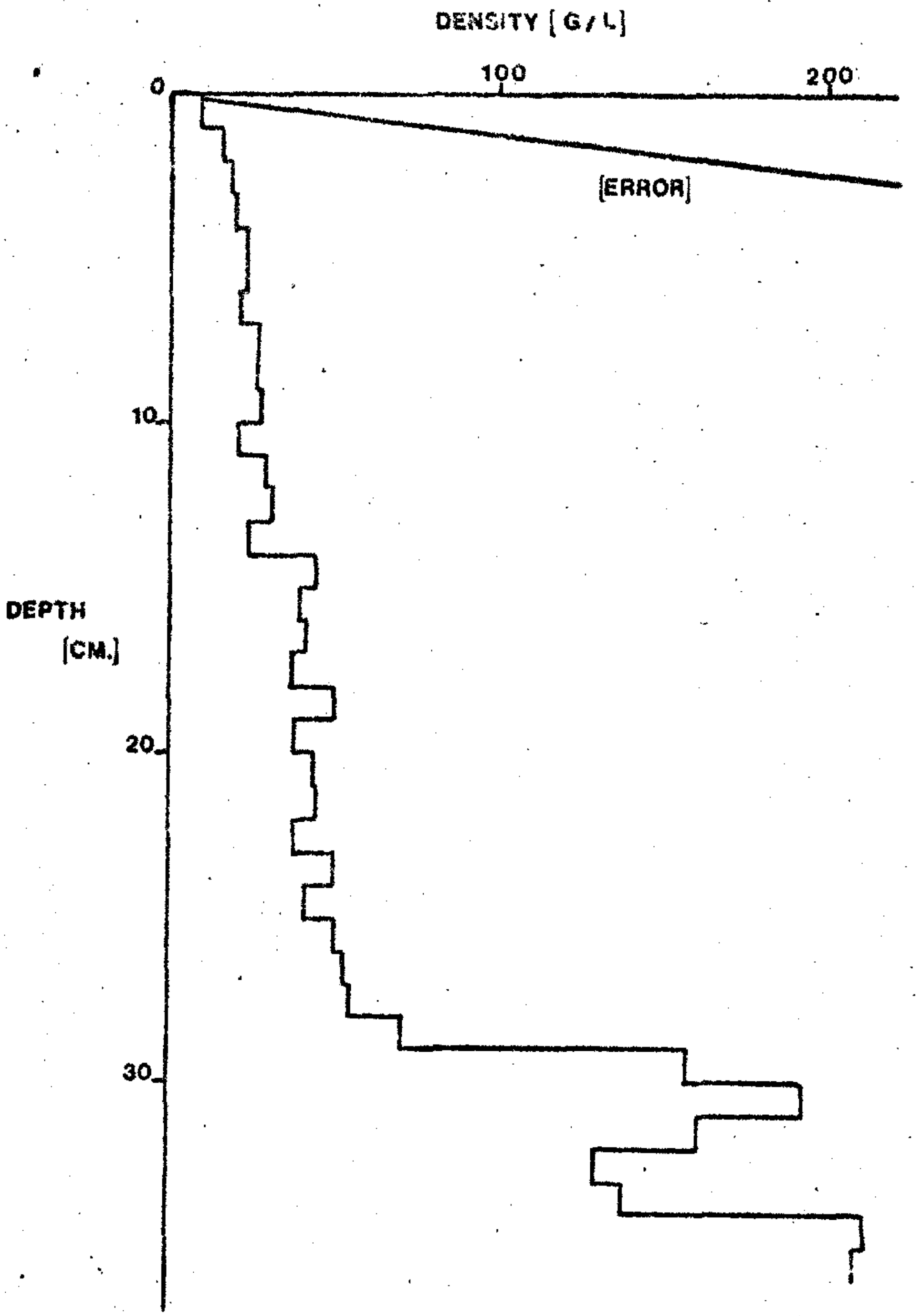


FIG 5k VARIATION IN BULK DENSITY OF PEAT WITH DEPTH
[CLYMO PERS. COMM.]

Fig. 7b. Normal information analysis of vegetation of IBP sites (R. S. Clymo, pers. comm.)

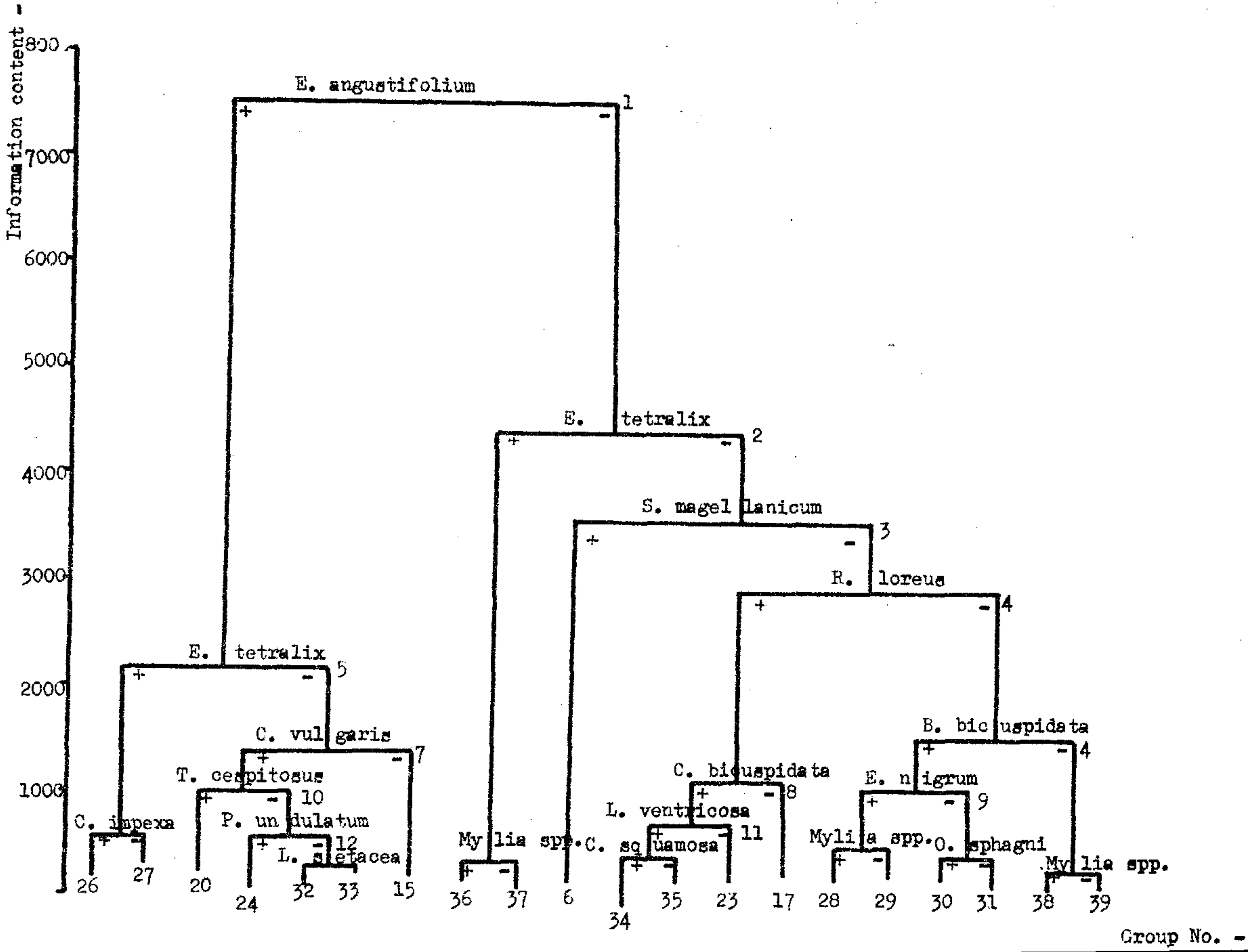


Fig. 7 c SITE DISTRIBUTION OF INFORMATION ANALYSIS QUADRAT GROUPS (R. S. CLYMO PERS. COMM.)

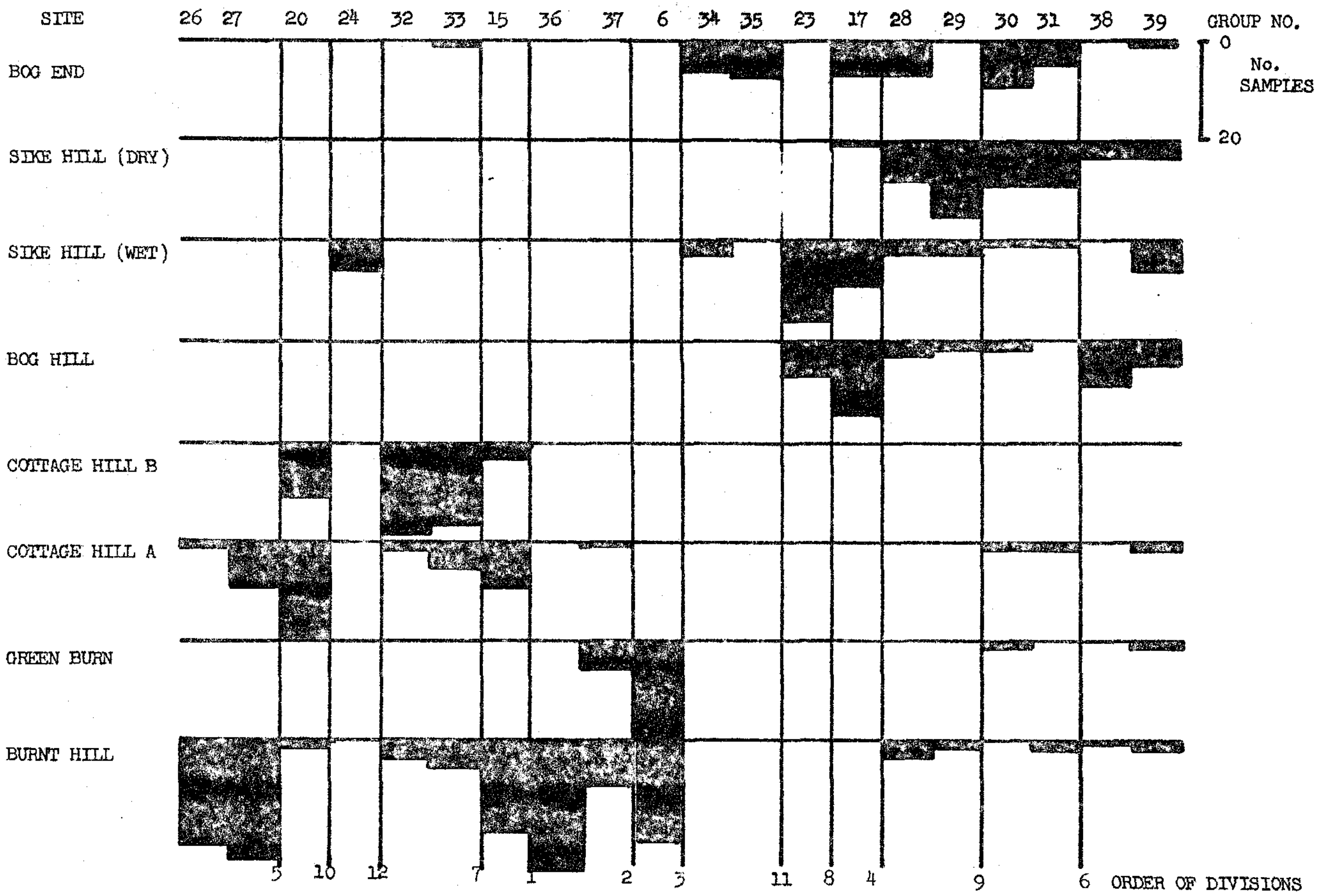


Fig. 7d. NORMAL INFORMATION ANALYSIS OF VEGETATION OF IBP SITES (OMITTING S. MAGELLANICUM) (R. S. CLYMO, PERS. COMM.)

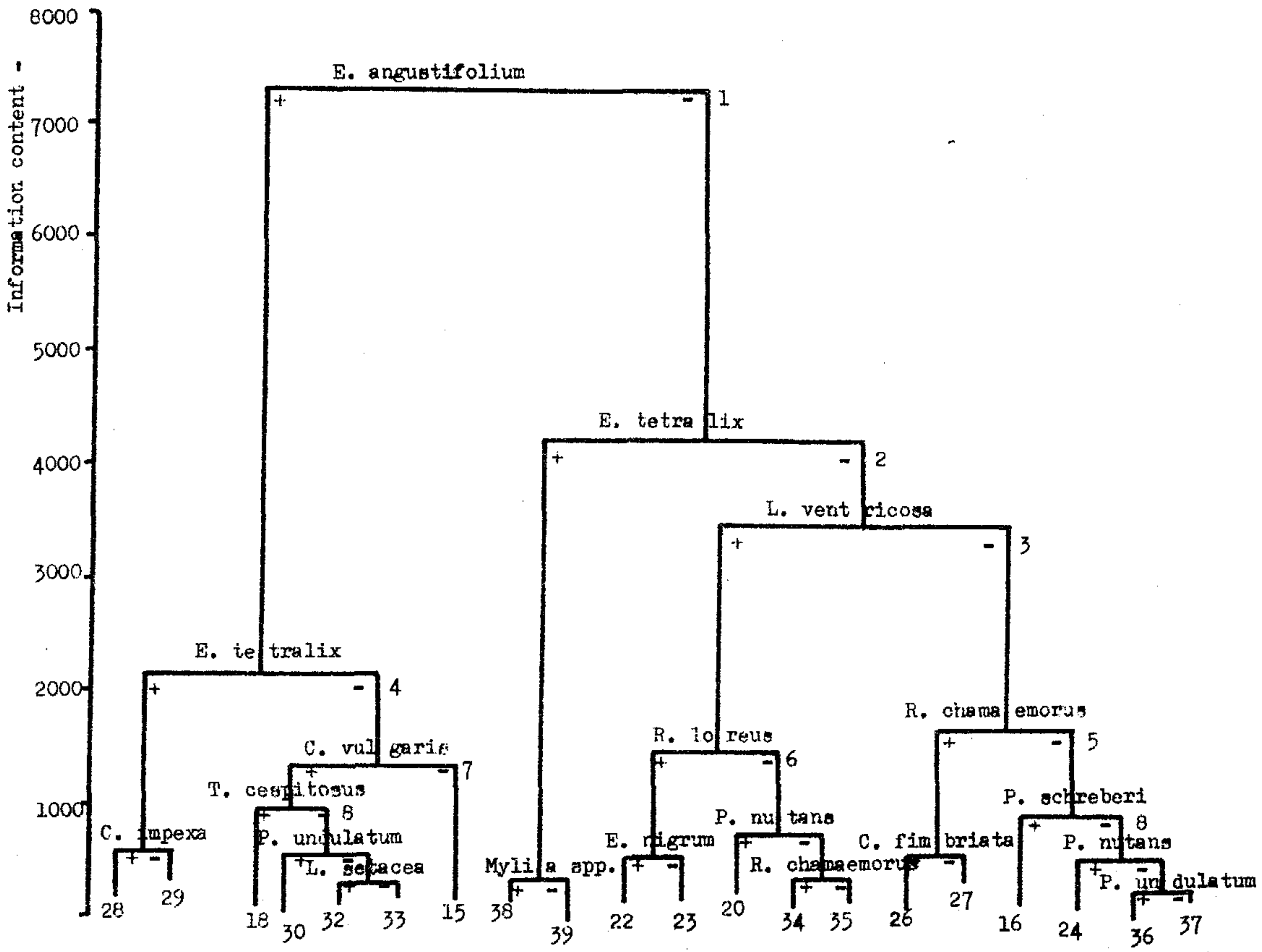


Fig. 7e SITE DISTRIBUTION OF INFORMATION ANALYSIS QUADRAT GROUPS (OMITTING *SPHAGNUM MAGELLANICUM*) (R. S. CLYMO PERS. COMM.)

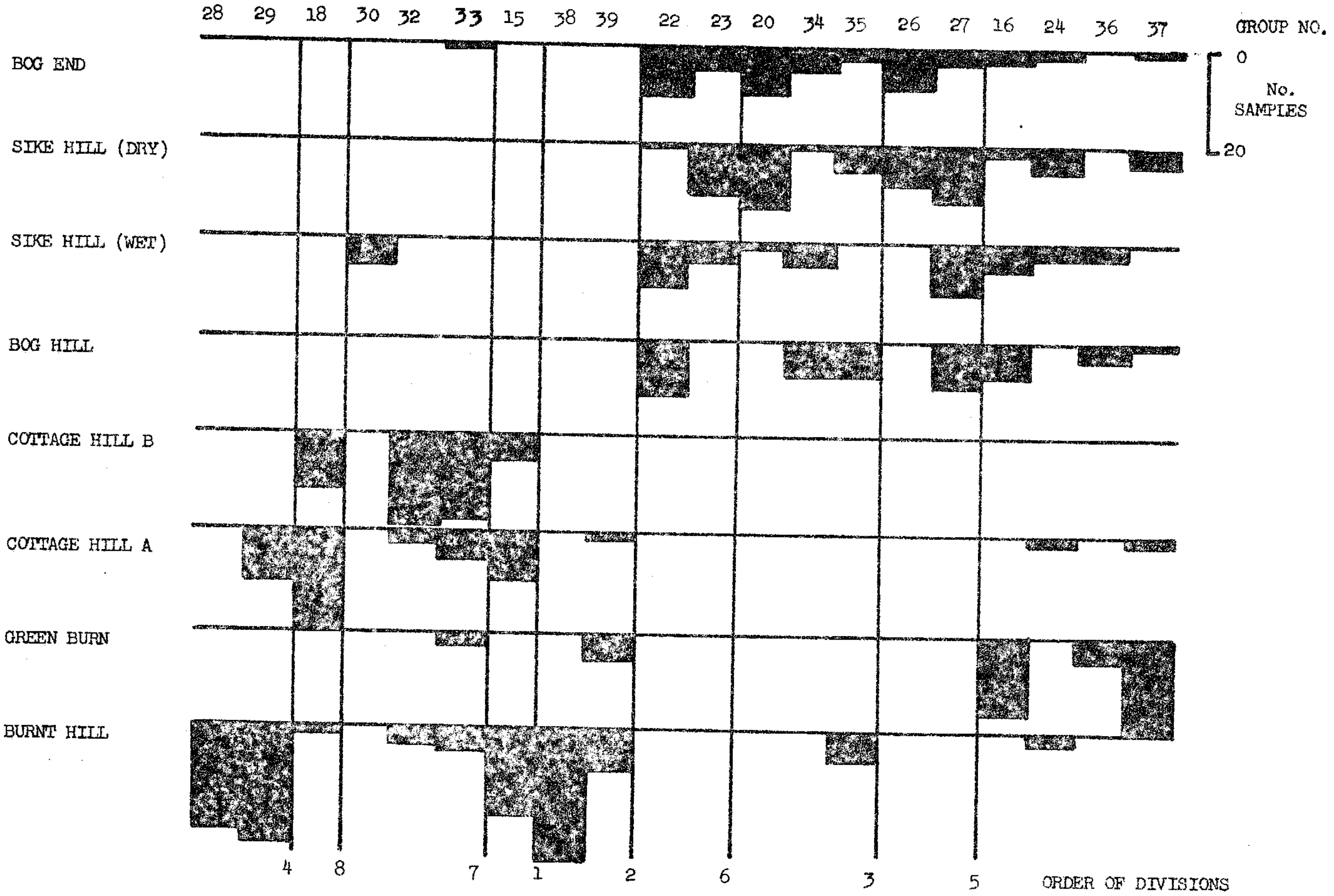


Fig. 7f INVERSE ANALYSIS OF VEGETATION OF BURNT HILL (AFTER CLYMO AND REDDAWAY, 1971, 1972)

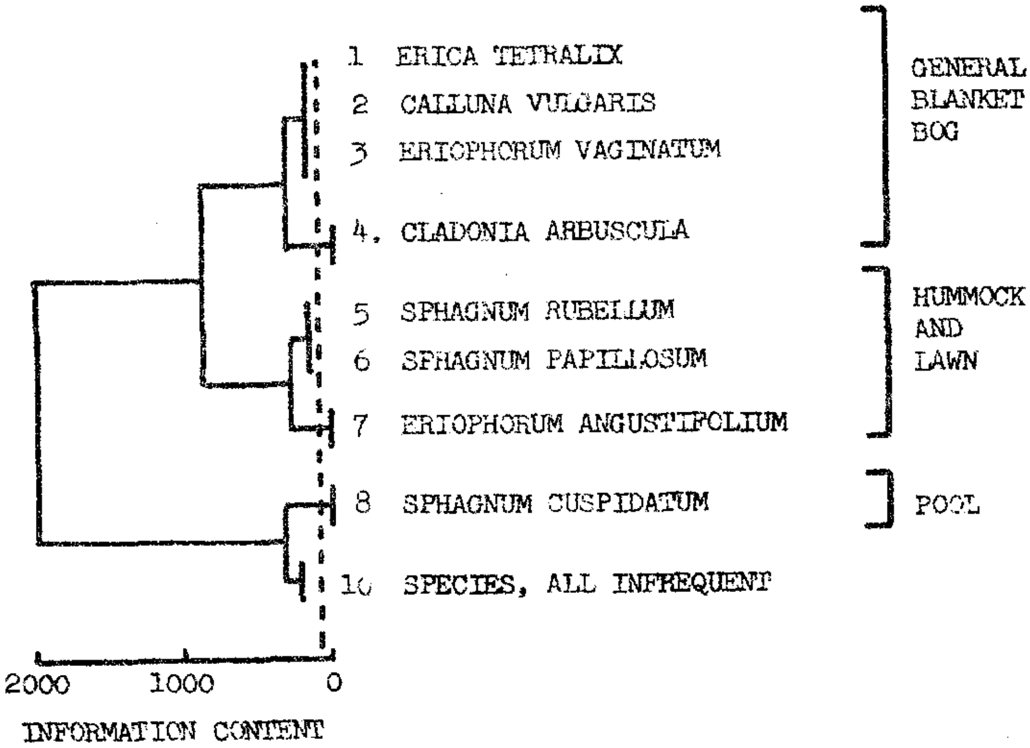


Fig. 8a BIOMASS DISTRIBUTION OF CALLUNA MODEL STAND
(AFTER GRACE 1970)

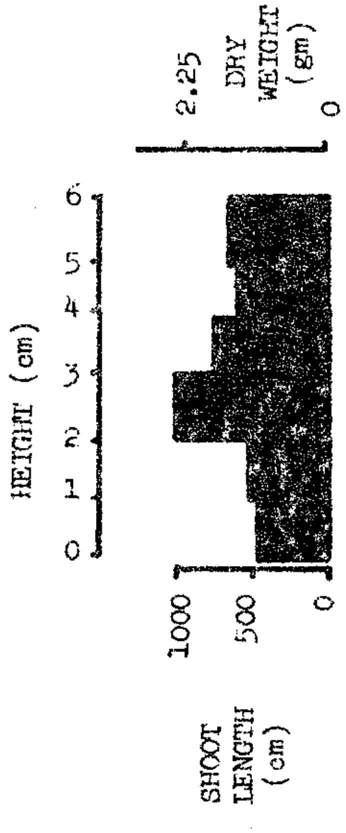
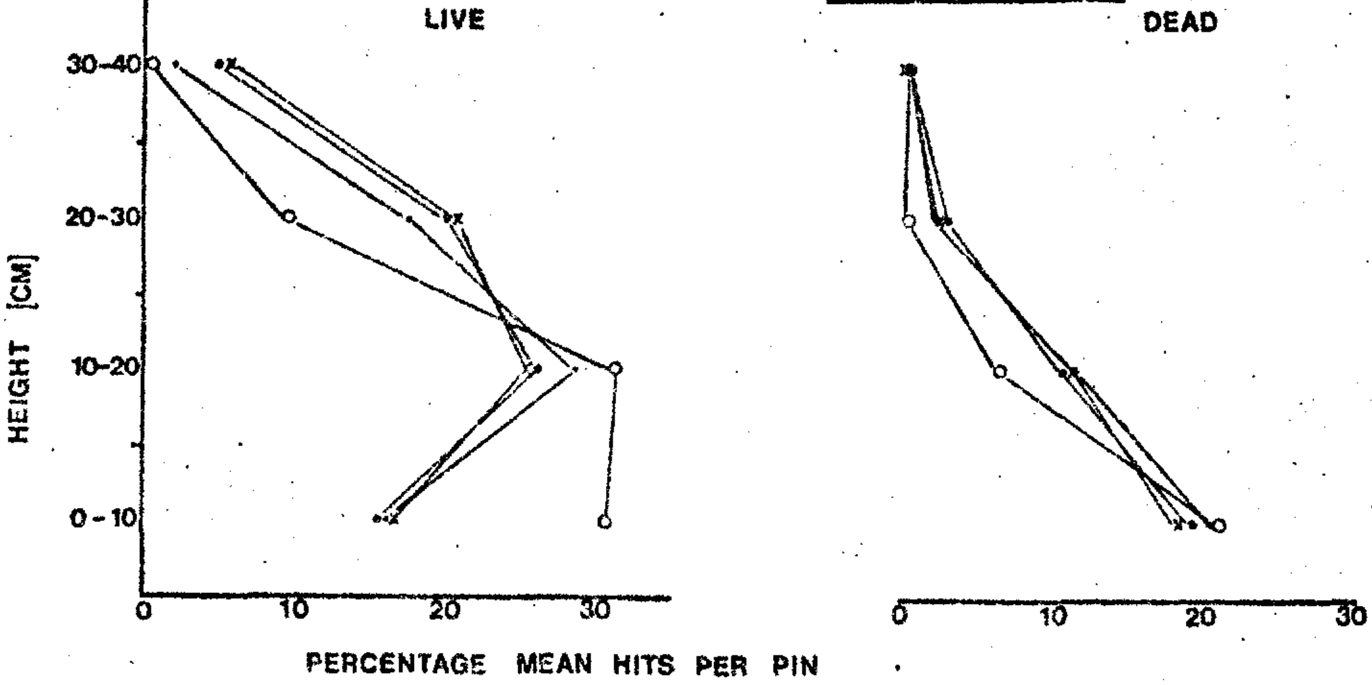
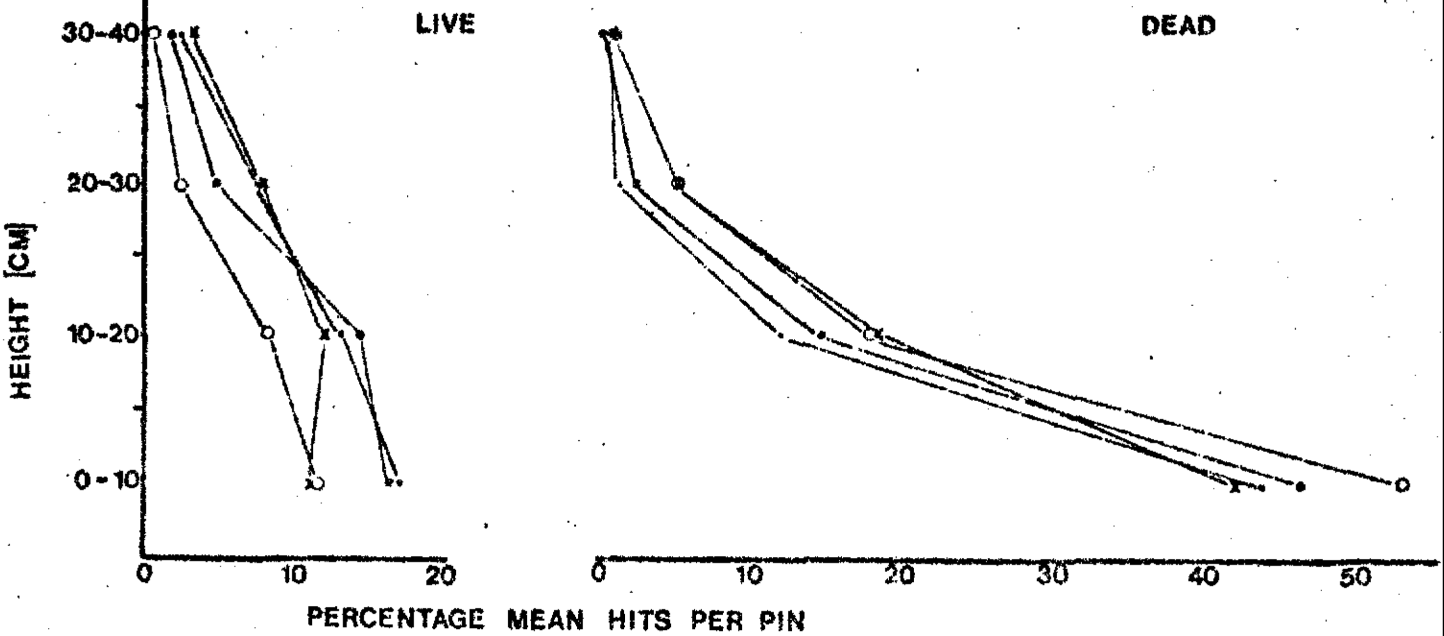


FIG 8b CALLUNA VULGARIS



o GREEN BURN; x BOG HILL; • SIKE HILL DRY; • SIKE HILL WET

FIG 8c ERIOPHORUM VAGINATUM



FIGS 8b+c VERTICAL DISTRIBUTION OF SPECIES ABOVE BOG SURFACE [AFTER FORREST PERS. COMM.]

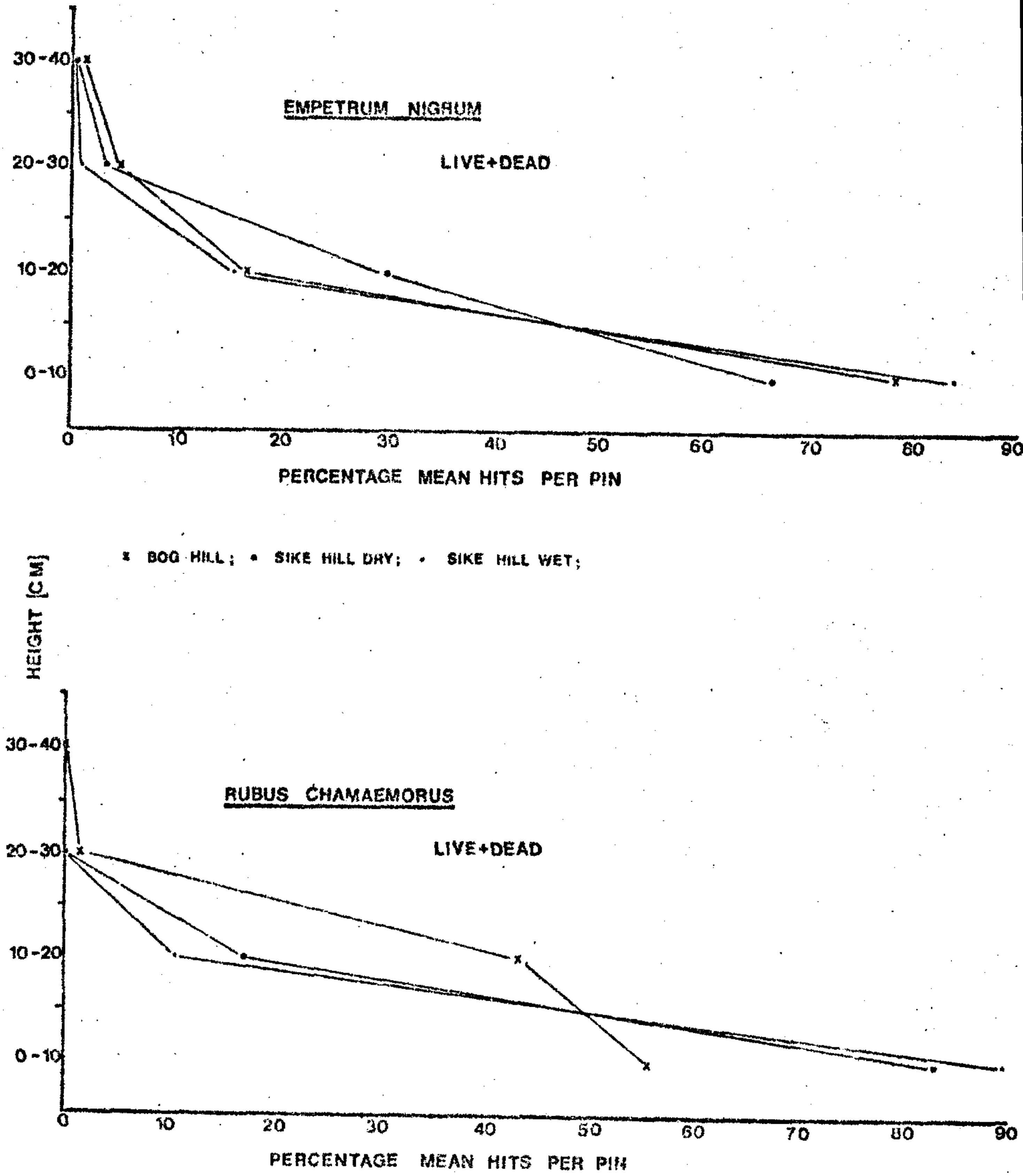


FIG 8d VERTICAL DISTRIBUTION OF SPECIES ABOVE

BOG SURFACE

[AFTER FORREST PERS. COMM.]

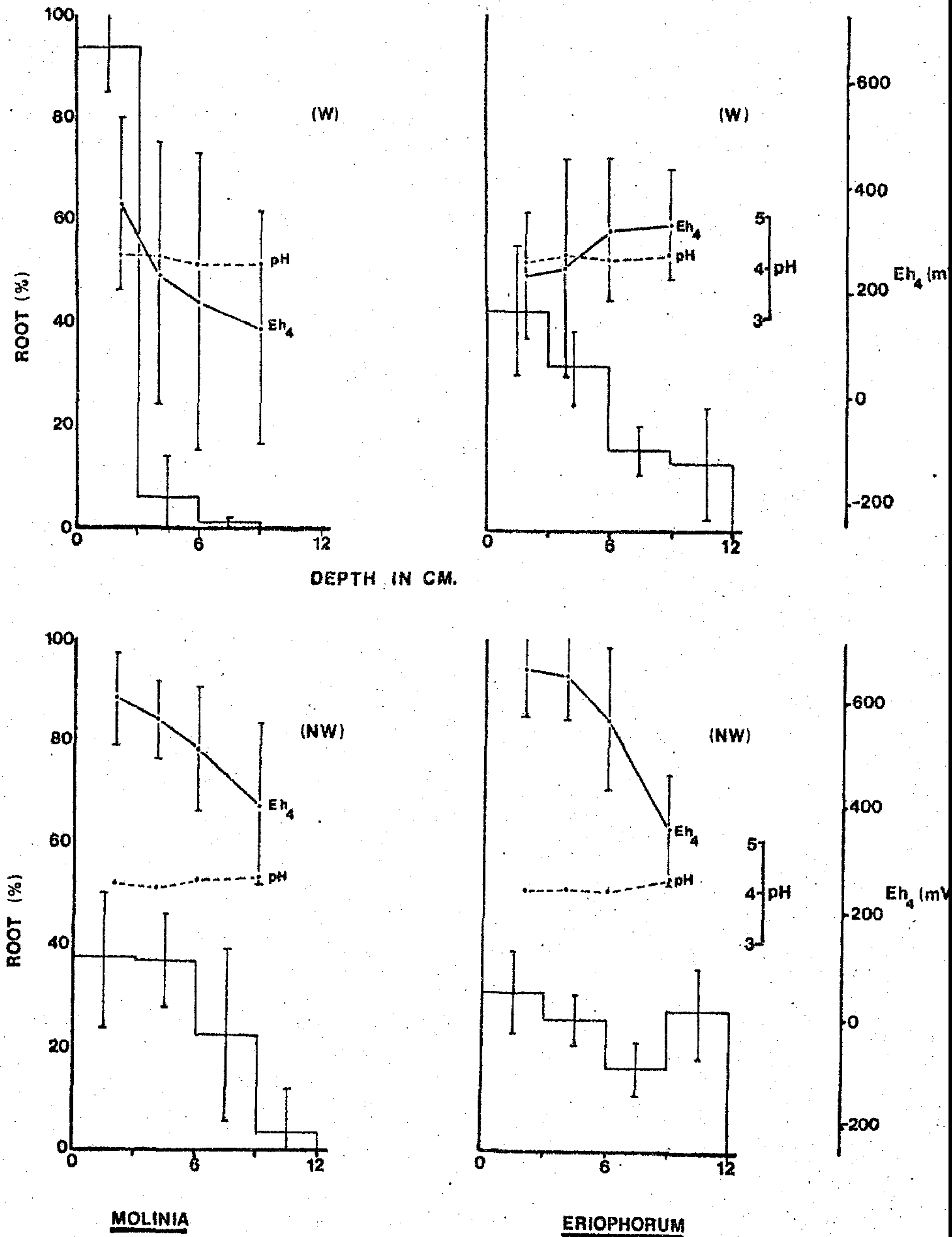


FIG 8e ROOT, Eh_4 AND pH DISTRIBUTION WITH DEPTH FOR

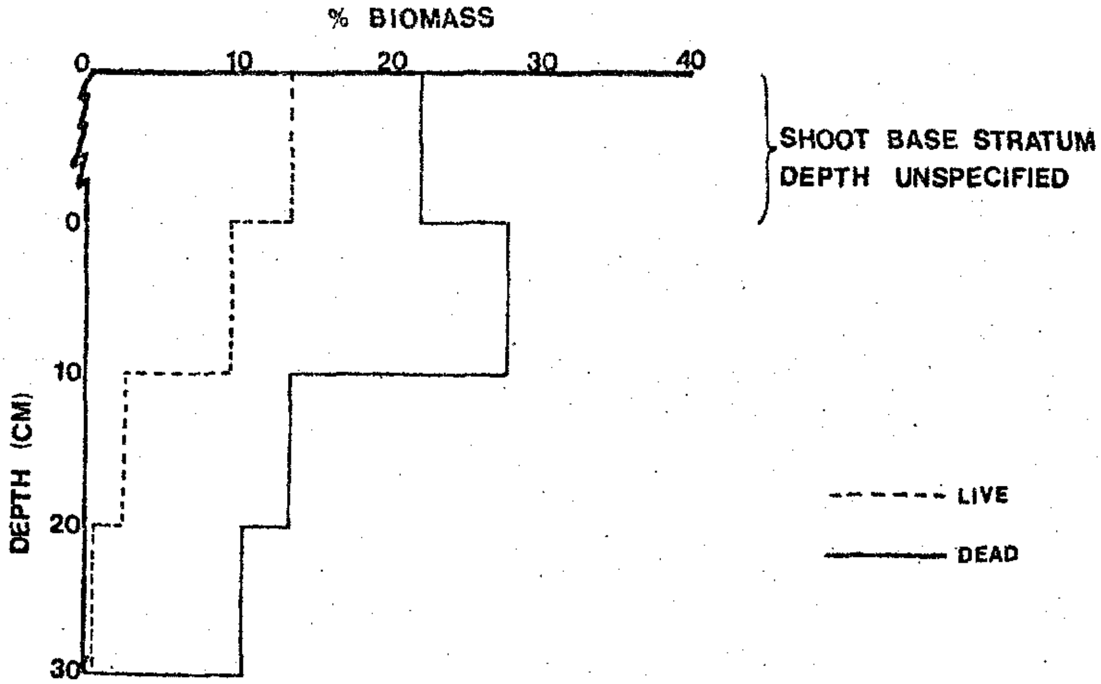


FIG 8f % BY WEIGHT OF LIVE AND DEAD ERIOPHORUM VAGINATUM ROOTS (DATA FROM FORREST 1971)

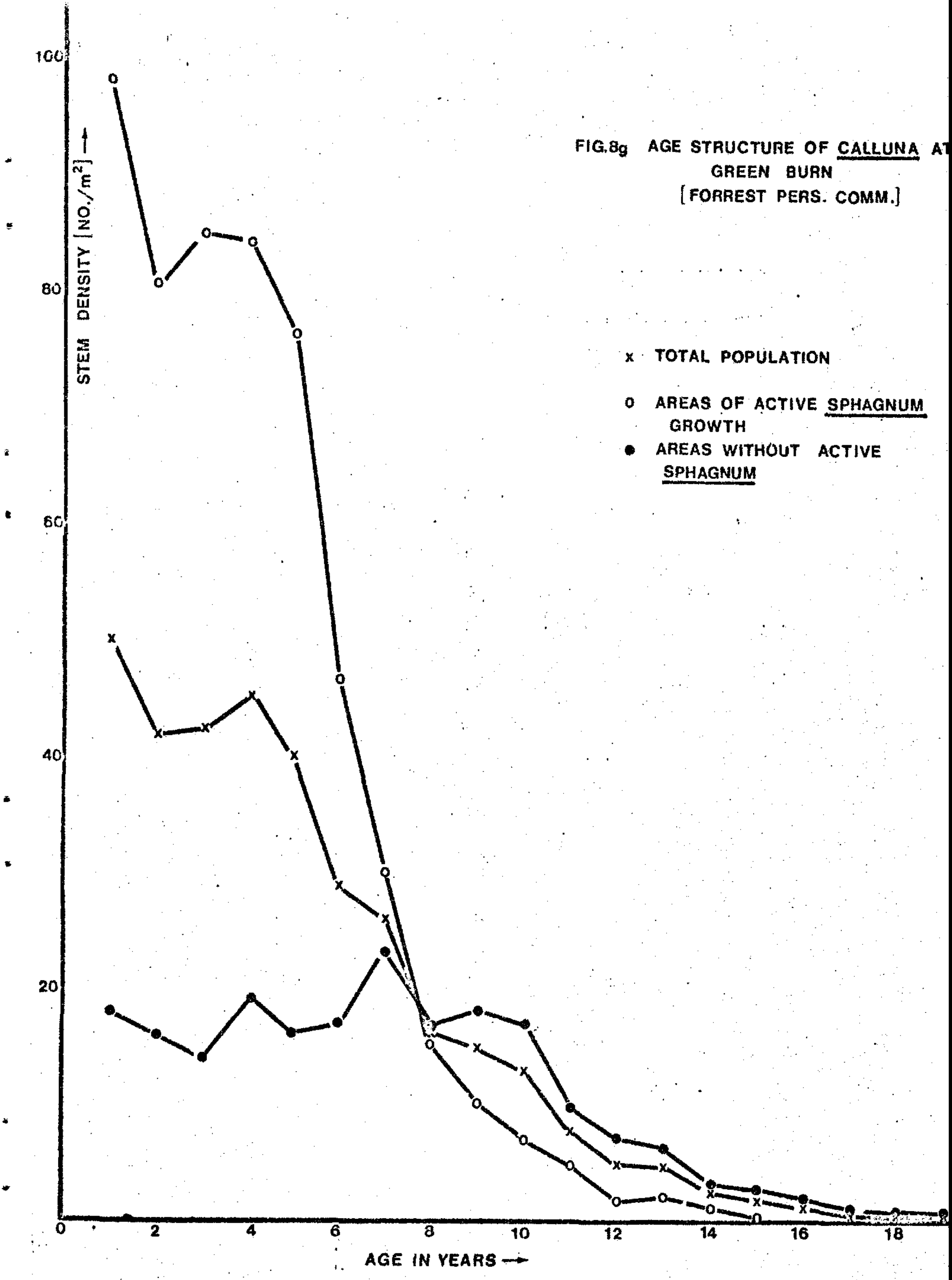
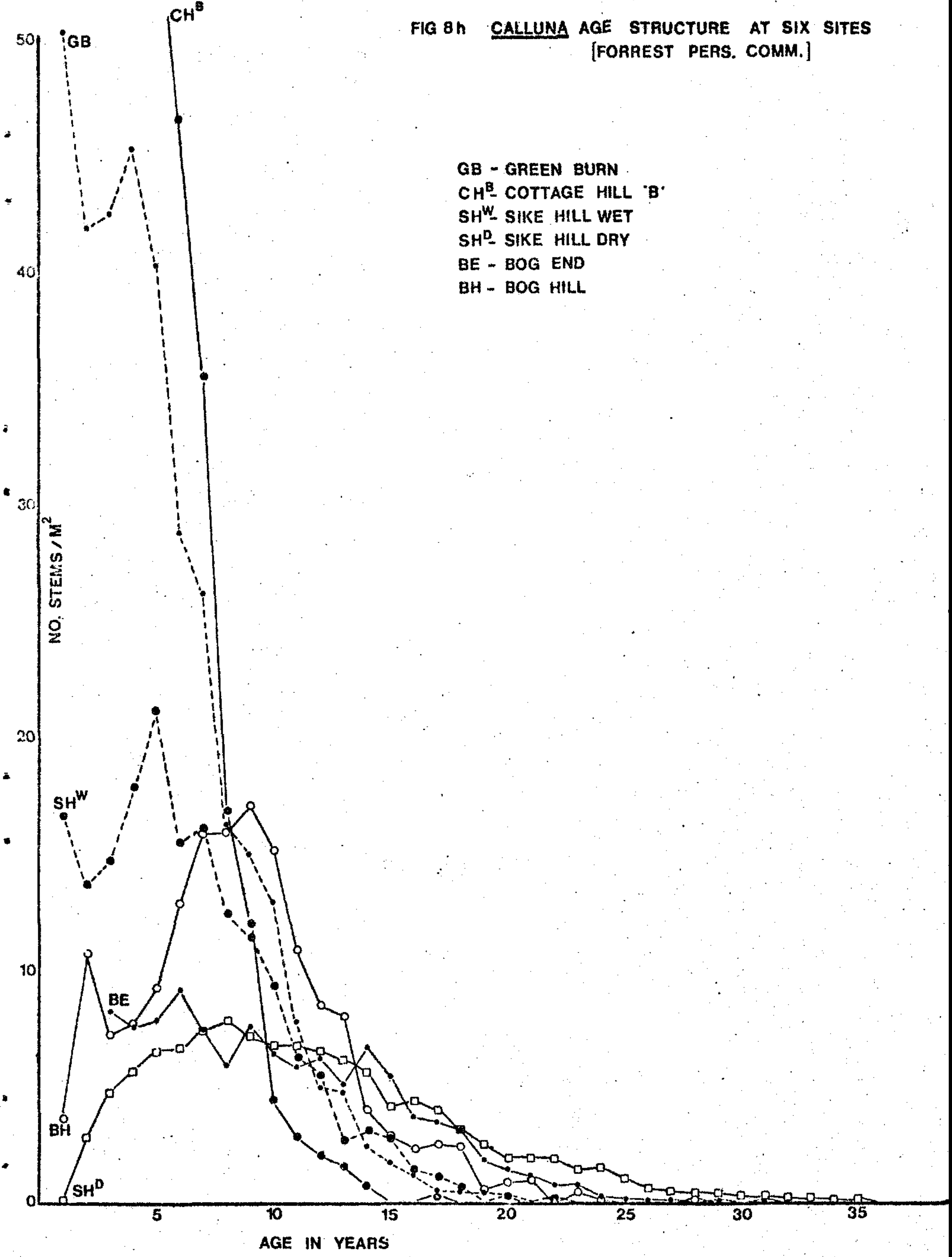


FIG.8g AGE STRUCTURE OF CALLUNA AT GREEN BURN [FORREST PERS. COMM.]

FIG 8h CALLUNA AGE STRUCTURE AT SIX SITES [FORREST PERS. COMM.]



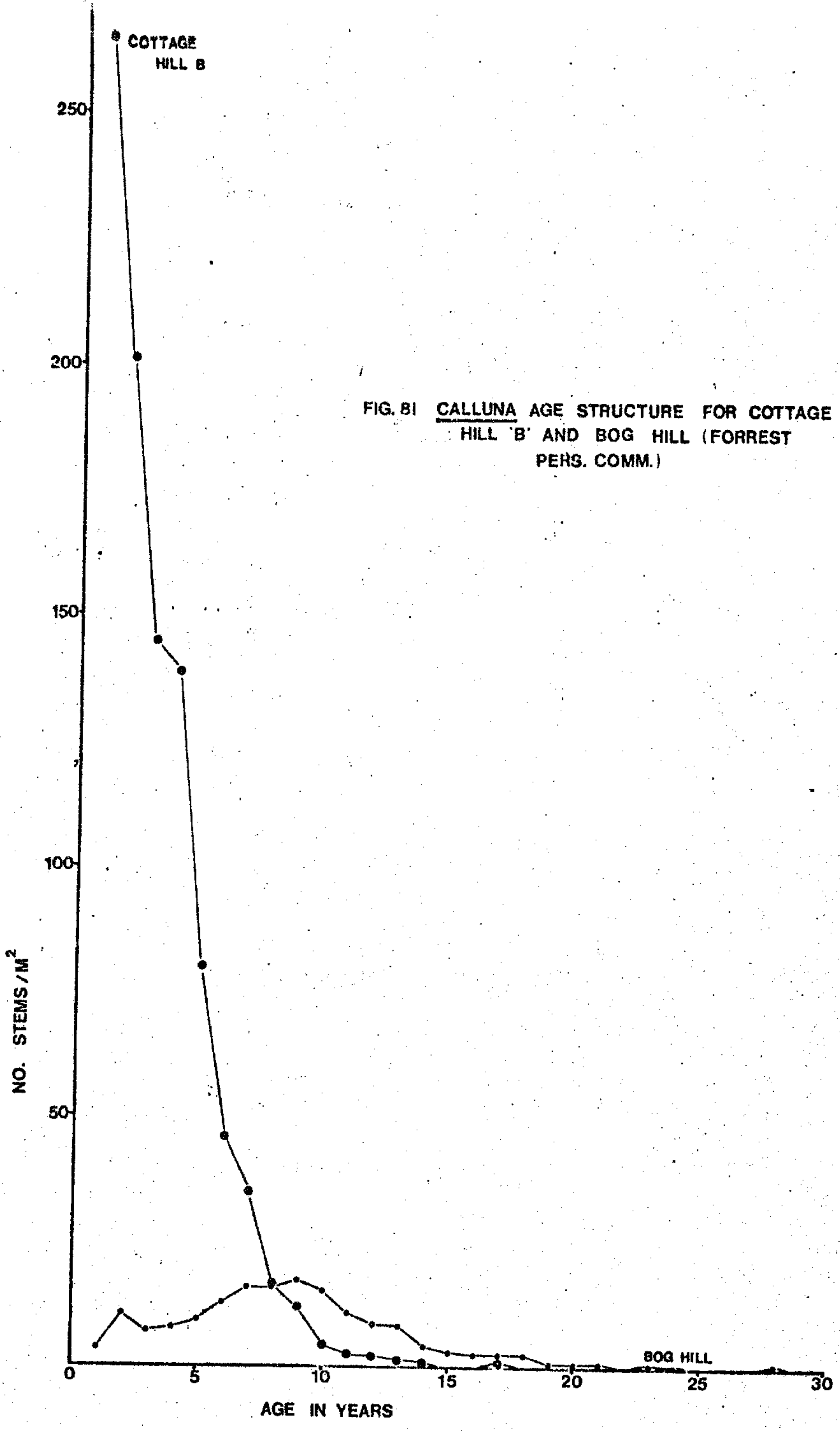


FIG. 81 CALLUNA AGE STRUCTURE FOR COTTAGE HILL 'B' AND BOG HILL (FORREST PERS. COMM.)

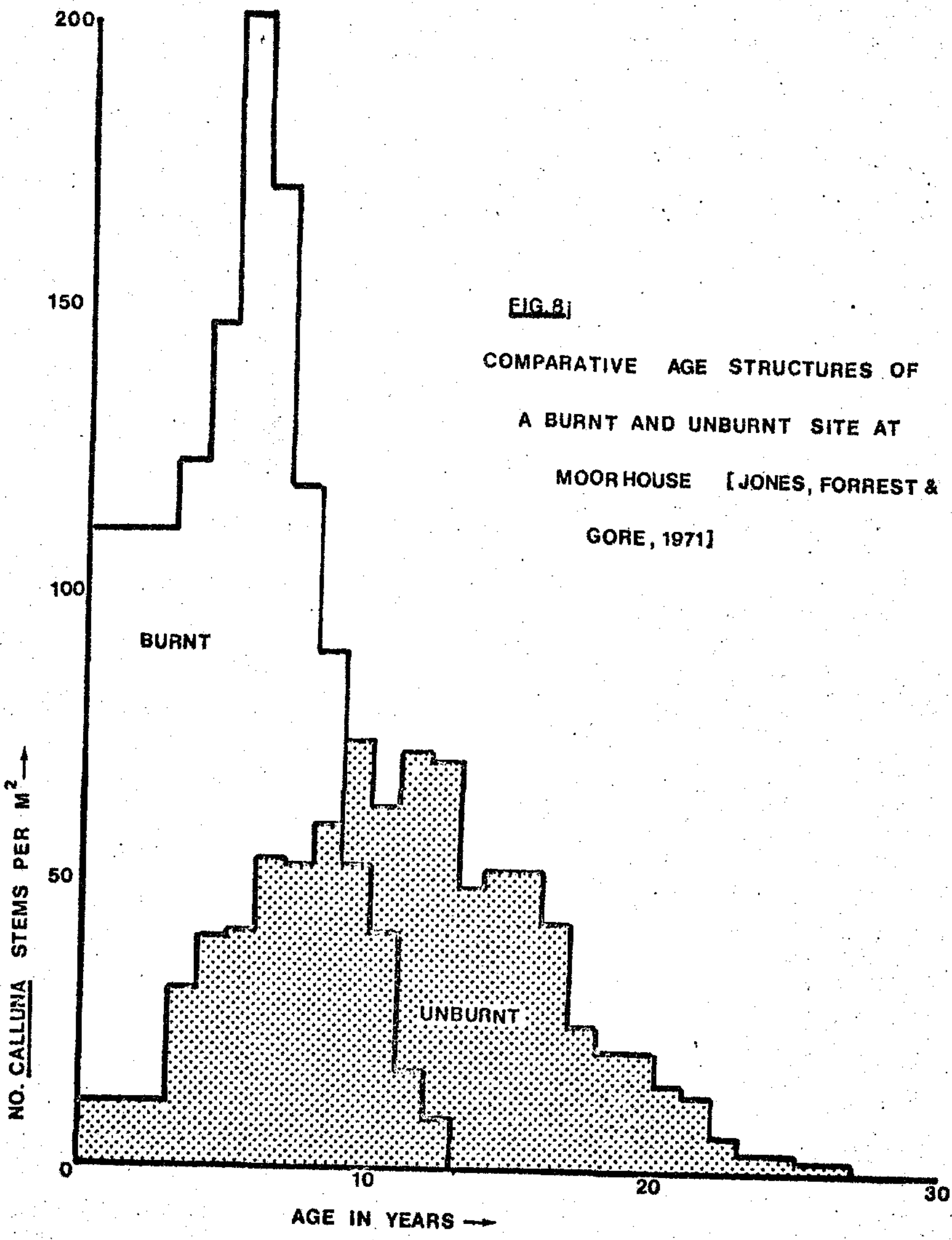


FIG.8

COMPARATIVE AGE STRUCTURES OF A BURNT AND UNBURNT SITE AT MOOR HOUSE [JONES, FORREST & GORE, 1971]

FIG 8k *E. VAGINATUM* TUSSOCK SIZE DISTRIBUTION FOR SIKE HILL (DRY) (FORREST PERS. COMM.)

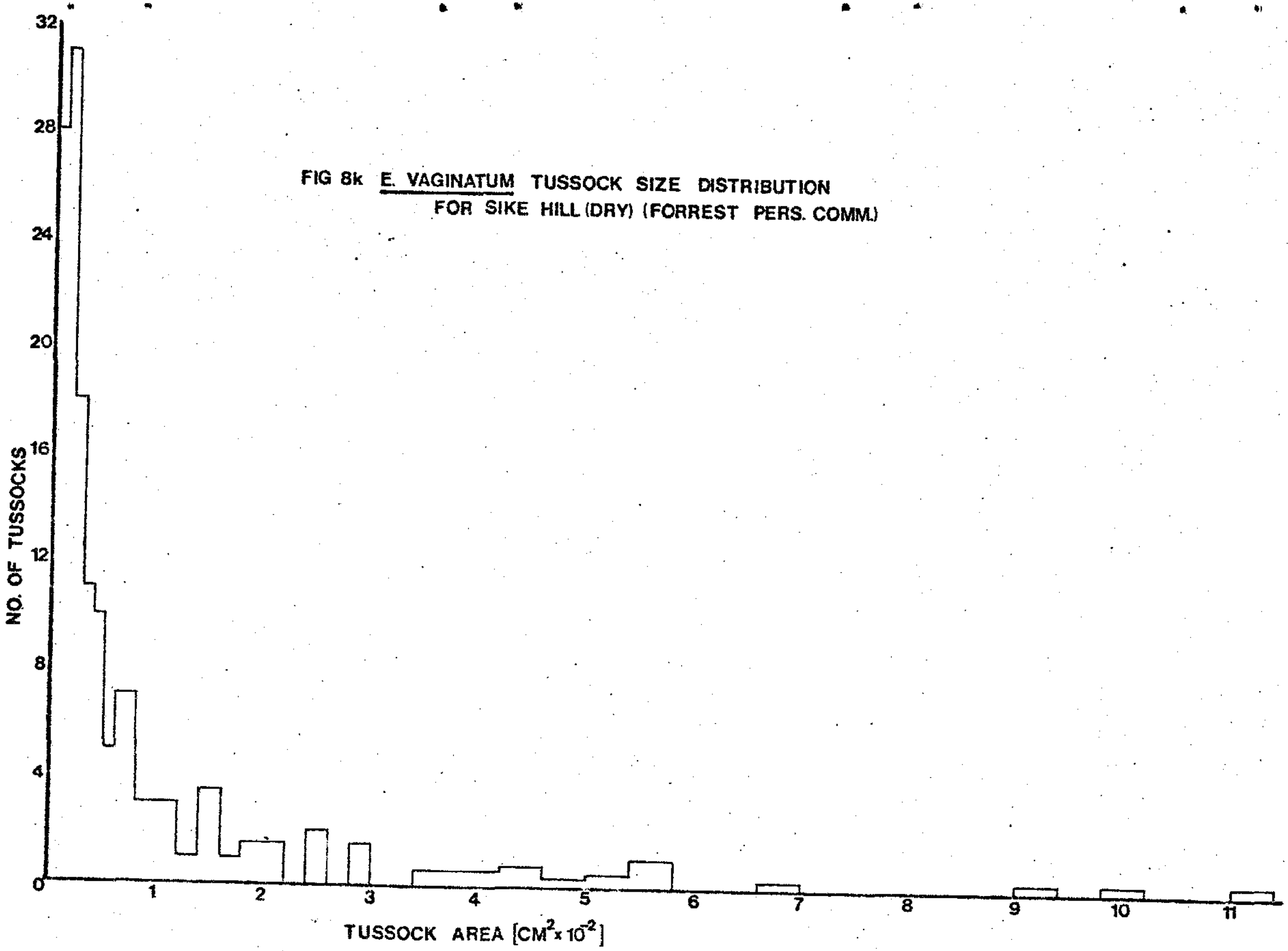


Fig. 81 LOG TUSSOCK SIZE DISTRIBUTION OF *ERIOPHORUM VAGINATUM* FOR SIKE HILL (DRY) (FORREST PERS. COMM.)

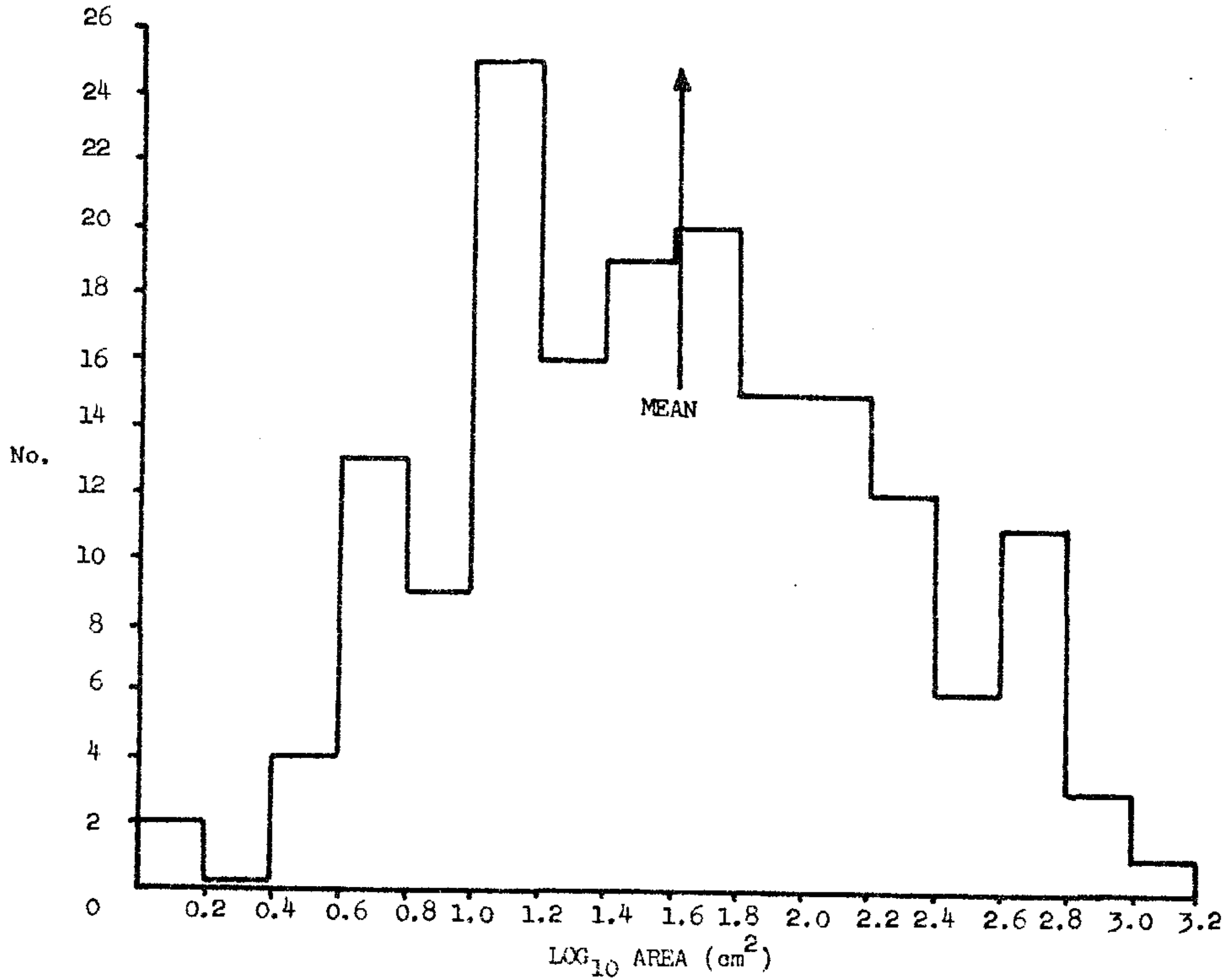


FIG 9a EFFECTS OF BURNING ON CALLUNA PERFORMANCE [AFTER STUDLEY 1967]

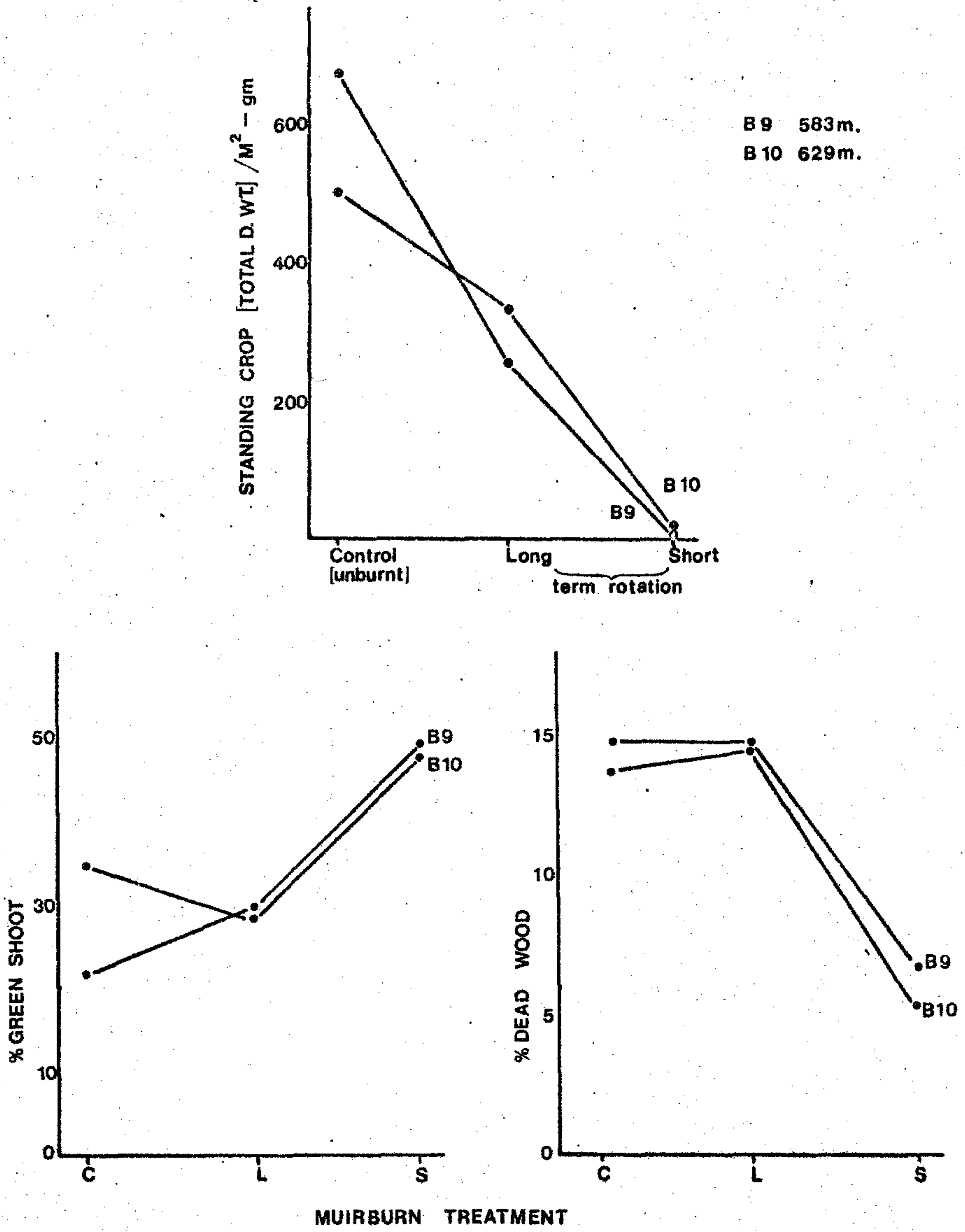


FIG.9b STANDING CROP AGAINST AGE OF STAND AT DORSET, BANCHORY, AND MOORHOUSE

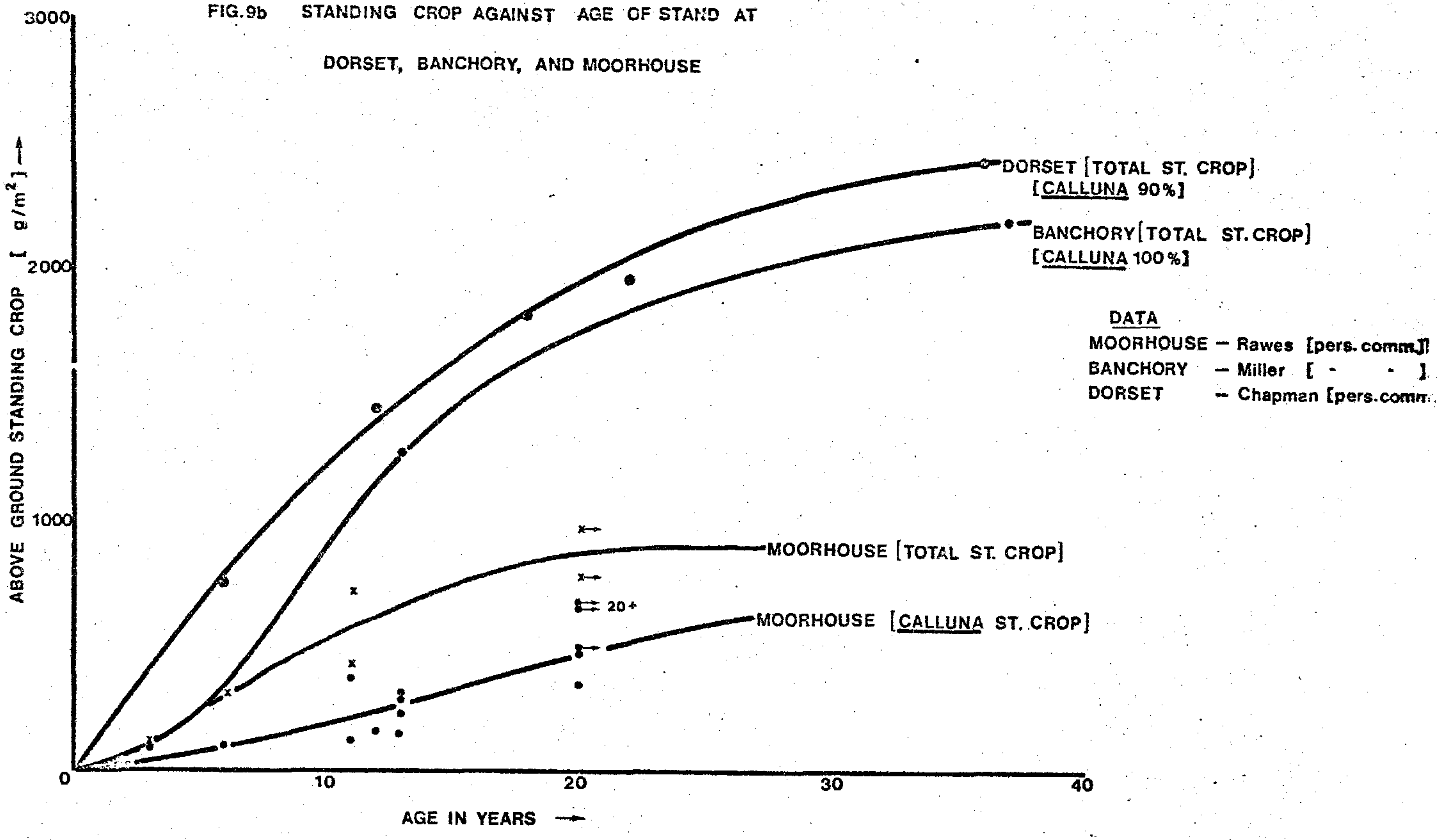


Fig. 10a COMPARISON OF THE MICRO-ORGANISMS AND THEIR ACTIVITY IN FOUR SITES (LATTER, CRAGG AND HEAL, 1967)

1. The number of bacteria estimated by direct count (May 1962)

2. The number of bacteria estimated by dilution count (October 1963)

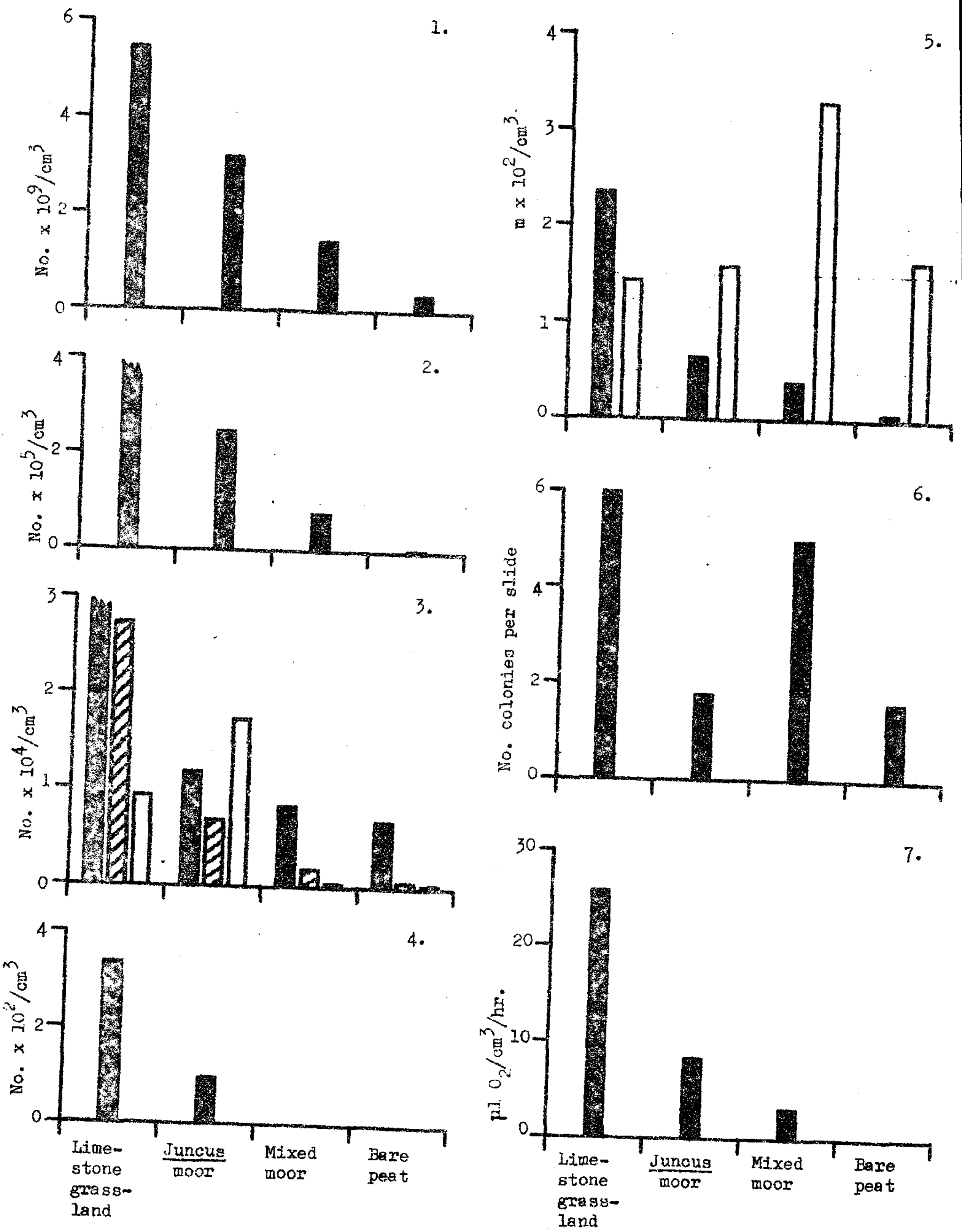
3. The number of bacteria estimated by dilution count on selective media (October 1963)
Denitrifying = ▓ , gelatin liquifying = ▧ , pectin liquifying = □ .

4. The number of nitrifying (NH_4) bacteria estimated by dilution count (October 1963)

5. The quantity of fungal mycelium estimated by dilution count (May 1962). Stained = ▓ , unstained = □ .

6. The average number of fungal colonies/slide on 10 slide traps (June-July 1963)

7. Oxygen uptake (July 1962)



1.
No. x 10^9/cm^3
6
4
2
0
2.
No. x 10^5/cm^3
4
2
0
3.
No. x 10^4/cm^3
3
2
1
0
4.
No. x 10^2/cm^3
4
2
0
Lime-
stone
grass-
land
Juncus
moor
Mixed
moor
Bare
peat
5.
m x 10^2/cm^3
4
3
2
1
0
6.
No. colonies per slide
6
4
2
0
7.
µl O2/cm^3/hr.
30
20
10
0
Lime-
stone
grass-
land
Juncus
moor
Mixed
moor
Bare
peat