THE EFFECTS OF BURNING ON HEATHER MOORS OF THE SOUTH PENNINES.

Dissertation for the Degree of Ph.D.

by

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1953.

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ACKNOWLEDGEMENTS.

I should like to express my gratitude to Professor A.R. Clapham for his unfailing interest, encouragement and stimulating discussion of numerous problems during his supervision of this work. I am also indebted to the other members of the Staff, both academic and technical, of the Botany Department of Sheffield University for their advice and ready co-operation at all times.

To the many game-keepers and shepherds who have given me the benefit of their experience and tolerated my presence on the moors at busy and anxious times, I am particularly grateful.

DECLARATION.

I hereby declare that this thesis consists of my own work except where it is specifically stated to the contrary. It is not, so far as I am aware, substantially the same as any thesis which has been submitted to this, or to any other University.

R. J. Elliott.

CONTENTS.

INTRODUCTION

General background and history of heather-moor burning.

There can be little doubt that heather moors, by virtue of their combustible vegetation and preference for better-drained sandy slopes, have experienced accidental burning throughout their history. The improvement in the fodder-value of the vegetation, observed as a consequence of burning, would certainly result in more recent times in the treatment being repeated. It seems probable therefore that a combination of accidental and deliberate burning will have modified the vegetation of the heather moors at least for several centuries. Certainly for a period of about 200 years, much of the existing moorland has been burned more or less systematically to maintain its stock-carrying capacity.

Farey (25), writing at the beginning of the last century, commented on the quantity of 'unenclosed' heather moor in Derbyshire and the custom of burning this to obtain pasturage. He considered burning a most inefficient agricultural practice because of the varying periods of unproductivity arising from different rates of heather recovery. If his observations are accepted, it must be inferred that systematic burning was not so universally practiced then, as later in the century. (Under rigid management the heather is not allowed to become so senile that long periods are necessary for recovery.) It seems probable that systematic burning was instituted as recognised agricultural practice in the mid 1700's when, as the result of industrialisation and the associated increase in population, the need arose for increased meat supplies. Previously, the role of sheep in agriculture had been that of wool producers associated with the maintenance of soil fertility on arable land (Thomas.J. 85). Cattle had been the main source of meat, often grazing moorland or semi-moorland areas for much of the year (Fenton 30). However in the 18th Century, sheep came to be considered as a source not only of wool, but of mutton as well. The demands of the increasing sheep population for additional pasturage, were met to some extent by the introduction of rotational cropping of arable land (Thomas.J. 85), but there seems little doubt that from this time the hardier native breeds were transferred in increasing numbers to rough moorland grazings to make room on the lowland pastures for the less hardy but more prolific and rapidly maturing breeds. This trend in events would clearly result in efforts to increase the fodder supply on the moors and the only economic method available would be by burning.

A comprehensive history on the subject of burning during the 19th century is provided by Lovat (49). Briefly this is as follows.

In the first half of the century moorlands were burned almost exclusively by shepherds, their leases usually specifying that 1/10th of the acreage had to be burned anually. Consequently it was the custom to choose the driest and windiest days in order to achieve a 'good burn' with the minimum of effort, the primary consideration being to fulfill lease obligations rather than to conform to what is now known as efficient moor-management.

The popularity of sport also increased during the early part of the century, culminating in the passing of the Game Act (1831). As the fashion on moors was to shoot over dogs, the newly installed keepers allowed the heather to become excessively old to enable a closer approach to the game and reasonable targets for the muzzle-loaded weapons employed. In 1853, grouse shooting received a considerable boost with the invention of the 'breech-loader' (Vesey-Fitzgerald 86), since it then became possible to 'drive' birds and arduous tramping over difficult country to find the game was no longer necessary. This revolution in slaughter-technique, associated with improved travel facilities (Railways principally - Rocket 1830) meant that relatively inactive but wealthy business-men could, in comparative comfort, indulge in a fashionable pastime.

Naturally shooting rents increased, and their value soon became proportional to the number of birds that could be killed. Consequently the keepers pushed up the grouse populations by all means at their disposal until in 1872-73 the inevitable occurred and the country experienced the worst epidemic of grouse disease that had ever been known. A Government Commission was appointed to investigate the outbreak and soon discovered that disease was absent or not so virulent on those moors where the grazing rights (and burning) had been maintained. The Commission eventually concluded that the general shortage of fodder on the unburned moors was the prime cause of the outbreak. This shortage resulted in the excessive concentration of birds in the limited areas where young heather was available with correspondingly increased chance of strongylid infestation. (N.B. general observations of Rothschild 67, on local over-population and incidence of disease in birds). The conclusions of the Commission were substantiated by the Grouse Disease Committee in 1911, which observed a high degree of correlation between strongylid infestation and lowered resistance due to malnutrition. Where sufficient heather had been burned, no shortage of fodder occurred and the grouse population was more evenly distributed over the moor. It was therefore decided that the interests of grouse and sheep were the same and that regular burning should be a feature of moor management. Some controversy on the exact interval that should elapse between successive burnings arose between graziers and sportsmen. However, the Committee suggested that an average cycle for the country as a whole would be one of 15 years, although it recognised that considerable variation in cycle-length might be necessary to meet local conditions.

It can therefore be assumed that since 1870 the majority of moor owners have attempted to burn their moors more or less systematically. However, two wars and the subsequent increased costs and shortages of material and labour have probably involved some sacrifice of ideals even among the most enthusiastic supporters of the findings of the Grouse Disease Committee.

PART I.

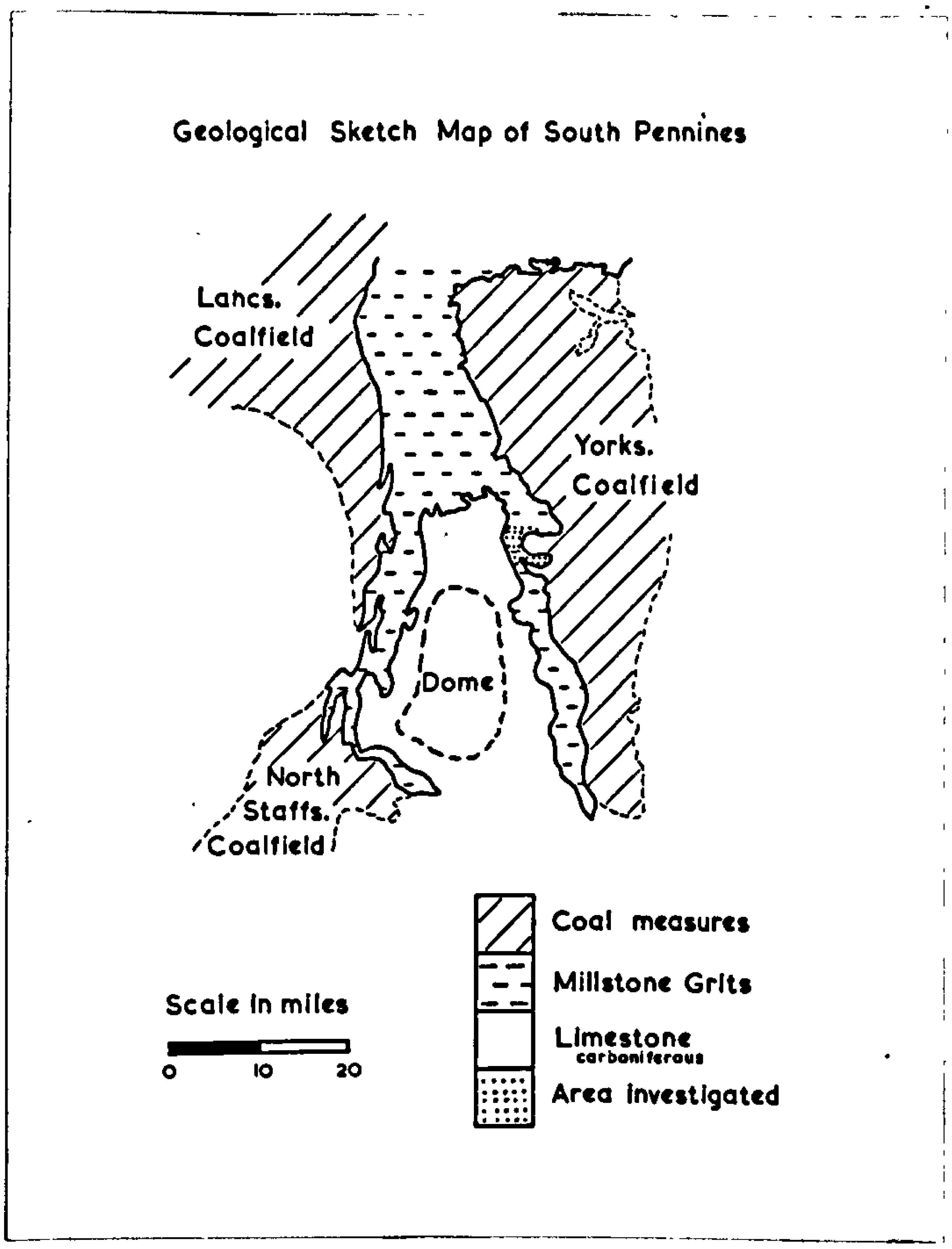
Statement of problem

The burning of heather moor is frequently discussed in articles on the subject of moor management. (Wallace 89, Lovat 49, Cameron 7 & 8). Emphasis is usually on the practical application of this mode of agricultural husbandry and the conclusions drawn appear to be founded primarily on the general experience of the observer over many years, rather than the result of an intensive and detailed investigation of the effects of burning per se. Although it is unlikely that the combined and accepted observations of the experienced agriculturalist, shepherd and keeper will be challenged, it is felt that these must necessarily be of a superficial nature and confined to short-term observations.

On the other hand, the effects of burning are occasionally mentioned in purely scientific investigations of heather communities but usually this is incidental to the main topic and receives only brief comment. The work of Fritsch (33) and his collaborators is an exception, but this is confined to observations on lowland heath and little justification exists for automatically applying the findings on this type of Callunetum to heather moors.

Clearly more precise information on the results of burning heather moor is desirable, particularly with regard to long-term effects. So far as is known, no investigation with

Fig. 1.


Geological Sketch Map of South Pennines
Lancs. Coalfield
Yorks. Coalfield
Dome
North Staffs. Coalfield
Scale in miles
0
10
20
Coal measures
Millstone Grits
Limestone carboniferous
Area investigated

this primary aim in view has been undertaken and in the following account an attempt is made to do this.

The district investigated.

Geology

The Pennines consist of an upland plateau ranging from 1,000 - 2,000 ft. above sea-level, being in reality a broad monoclinal uplift with a tilt towards the east (Wray 96). Geologically the North and South Pennines can be recognised as massifs of Carboniferous Limestone, whilst the intervening formations consist largely of sandstones and shales of the Millstone Grit Series. In the Southern Pennines the Millstone Grits wedge out altogether, and at the same time the lateral extent of the formation decreases, becoming reduced to a narrow tongue on either flank of the limestone Derbyshire Dome. (Fig.1.)

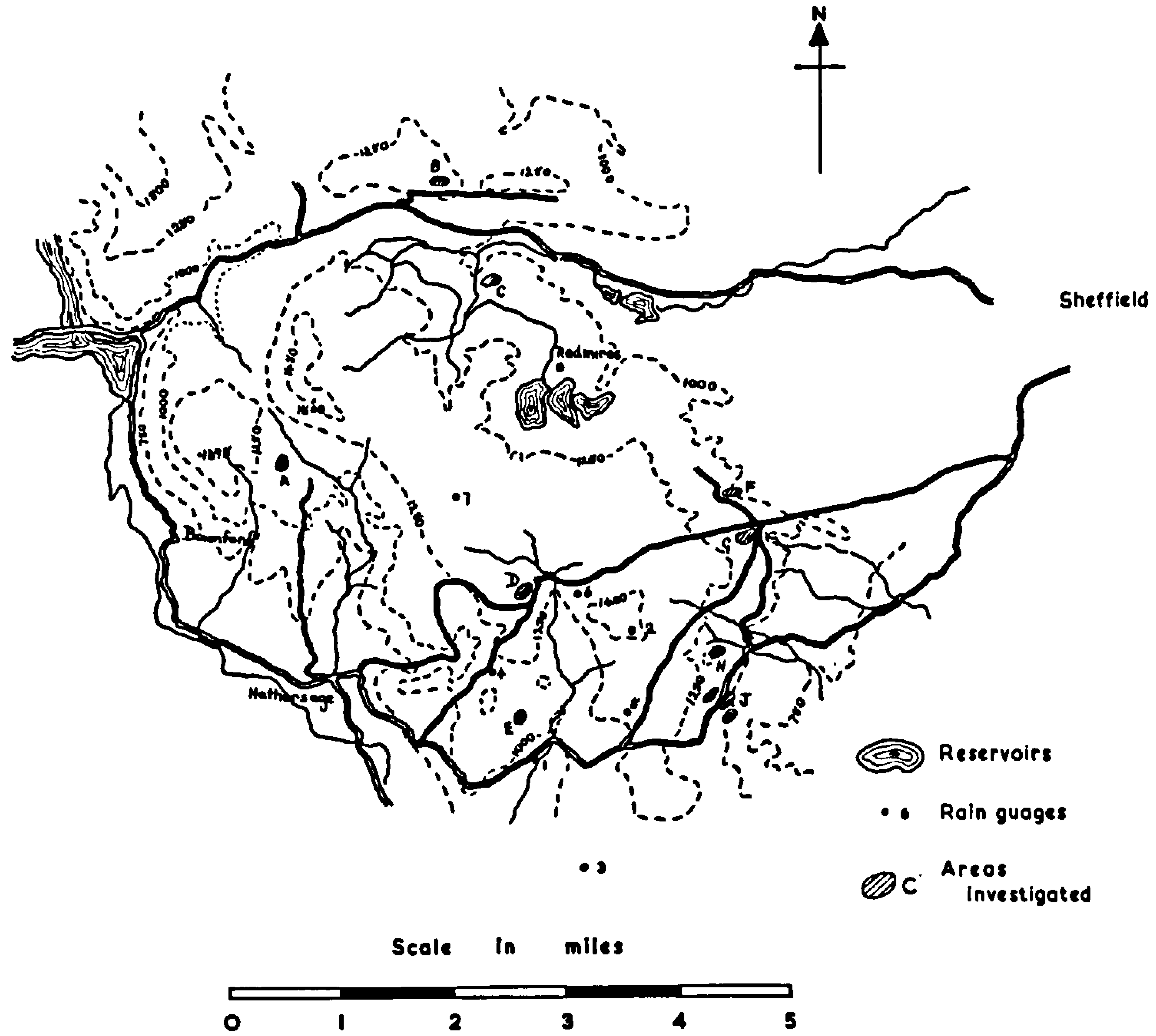
The rock of the Millstone Grit Series consists of alternating strata of hard sandstone with soft mudstone or shale, and since the strata are inclined, erosion results in a series of westerly-facing escarpments which in this district are exemplified by Froggatt, Burbage, Bamford and Stanage 'Edges'. The gentle, well-drained dip-slopes towards the east appear ideally suited to the development of Callunetum.

Geography

Owing to the poverty of mineral nutrients in the soils arising from the Millstone Grits, and the rocky, broken nature

Fig. 2.

Map of the main area investigated.



Showing the location of rain-gauges referred to in Appendix A. and most of the sites mentioned in the text.

A. Bamford
B. Lodge Moor
C. Hallam
D. Ringinglow
E. Toadsmouth
F. Porter Clough
G. Lady Canning
H. Houndkirk Hill
J. Blacka Plantation

Rain-gauges are numbered as in Appendix A.

Mean monthly rainfall at Redmires. 1,150 ft.

(Based on observations during 35 years)

January	3.80
February	3.38
March	3.18
April	2.70
May	2.74
June	2.55
July	3.24
August	3.80
September	2.77
October	4.00
November	3.60
December	4.76
Total	40.5

of the terrain, conditions are unfavourable for agricultural development and apart from the valleys, the district is relatively thinly populated. Callunetum is distributed more or less continuously over the district investigated (Fig.2.), being interrupted only at the 'edges', cultivated valleys and stream courses where vegetation of a different character occurs. Almost the whole of the district lies between the altitudes of 700 and 1,500 ft.

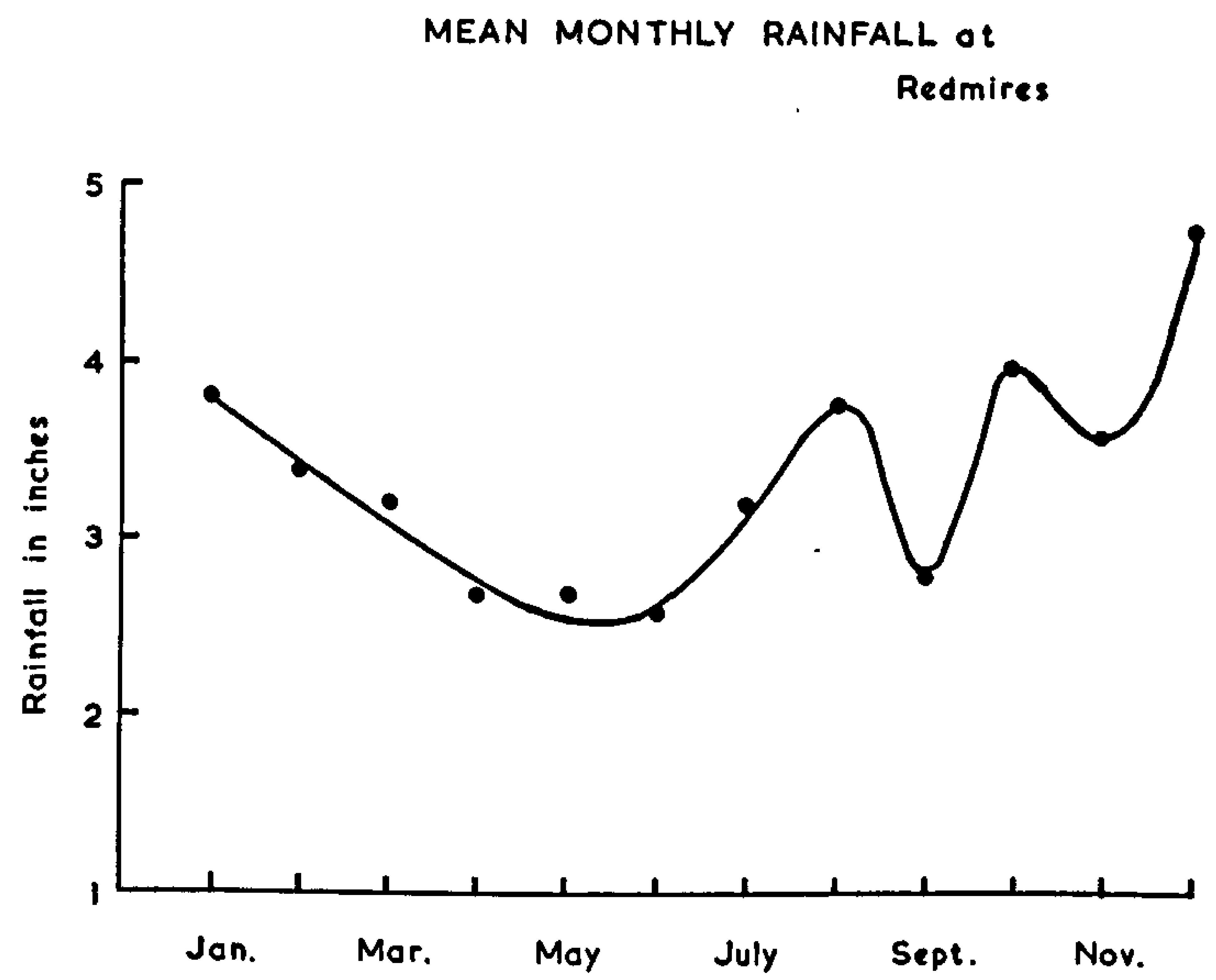
The moorlands under consideration are situated in the northern part of the tongue of Millstone Grits nearest Sheffield (Fig.1.). None are located further than 10 miles from the city and in view of the disposition of the Grits, are found mainly to the west and north-west, although some moorland (not investigated in detail) lies to the south-west of Sheffield, towards the extreme tip of the eastern tongue of the Grits.

<u>Climate.</u>

No data appears available for temperature ranges on these moors. For the information on rainfall, I am indebted to the Sheffield Corporation Water Works Department.

The Redmires data (opposite) can be considered typical for the area as a whole, since the station is situated in approximately the centre of the area investigated and is at about average altitude (1,150 ft.). The long-average annual rainfall figure, based on observations during 35 years, is

Fig. 3.



Based on observations over 35 years (by Sheffield Corporation Water-works Dept.).

40.5". The mean monthly values (based on a similar period of observation) are shown and also graphed in fig. 3. The latter shows quite clearly that there is a general decline in the monthly amount of rainfall from Jan.-June followed by a corresponding increase during the second half of the year. However, unlike the first half of the year, the second is characterised by violent fluctuations in monthly precipitation which results in September and November being almost as dry as May and July, and August and October as wet as January.

This annual trend in rainfall is important in considering the effects of burning, since the decline after February and March means that soil erosion and the loss of base due to surface run off and leaching is likely to be less after spring burning than after autumn burning when the wettest months of the year are to follow.

The annual rainfall for the years 1941 - 51 and the monthly values for 1951 are shown in Appendix 1 for a number of stations within the main area (Fig.2.) and give an indication of the variation from the Redmires data presented above.

Heavy mists are common during the winter, although in spring and summer the atmosphere can be surprisingly clear and insolation considerable. No data is available for wind velocities, direction etc., although from general observations, the velocity at Ringinglow for much of the year is about 3-4 on Beaufort scale (8 - 18 m.p.h.).

Economics.

Despite the predominance of moorland, the district is not to be considered as an entirely uneconomic tract of country. The moors are of considerable importance as catchment areas for the heavily populated industrial centres, particularly Derby and Sheffield, on the adjacent foothills and lowlands. In aggregate the moors produce a vast amount of fodder especially in the spring and early summer so that their utilisation in stock-raising releases the more fertile and tractable lowlands for other purposes. The close proximity of enclosures means that removal of stock at lambing-time and in the severest weather can be accomplished without the considerable expense which this involves in many moorland areas. Formerly the moors were of considerable value due to the high sporting rents which they commanded, largely as the result of their accessibility to sportsmen from the nearby towns, whose time 'in the field' was restricted by business commitments. However, their importance in this respect seems to have declined in recent years so that shooting rights are no longer so much more remunerative to the owner than grazing rents.

The status and composition of the local heather moors.

The Callunetum.

By definition the term Callunetum implies a community dominated by Calluna and including certain characteristic associated species. Authors, too numerous to mention individually, have described the Calluneta typical of different parts of the British Isles under particular environmental conditions, and this aspect cannot be considered further in this thesis.

Tansley (78 p. 723) and Beijerinck (2 p. 109) describe the complex of major factors which govern the distribution of Calluneta as:

1. No excessive fluctuation in humidity, a condition associated with an oceanic or sub-oceanic climate.
2. Soils mainly of low base-status or small supplying-power of assimilable salts.
3. Moderately free drainage of substrate.
4. High soil acidity (pH 3.5 - 6.7). This may be essential for the existence of the symbiotic fungus Phoma radicis Callunae. Tansley (78). Rayner (65).

Beijerinck adds two further conditions governing the distribution of Calluna as distinct from Callunetum,

5. Adequate light (freedom from shading).
6. A protective snow cover during winter months in far north and higher mountains.

Tansley (p. 723) and Beijerinck (p. 105) describe the horizontal distribution of Calluneta. Beijerinck employs a map with a series of zones radiating from the centre of distribution (Netherlands, Denmark, S.Scandinavia, E. British Isles) in which

a. is the region of optimal conditions, where Calluneta with only slight admixture of other species occur;

b. a region in which the admixture of species becomes greater; and

c. a limit beyond which heather is normally represented only as a component of other communities.

The South Pennines are found to be situated just on the limits of the zone of optimal conditions (a).

Information on the vertical distribution of Calluneta is dealt with by Tansley (p. 747-758) and Beijerinck (p. 112). Although the altitudinal limits vary with locality, the position is probably best summarised by Tansley (p. 753)- "In the British Isles, Calluna begins to lose dominance under any conditions of topography or soil above 2,000 ft.".

<u>Heath and heather moor.</u>

The variety of Calluneta has already been mentioned. It is however possible to recognise two major 'types' in this country although it is not easy to draw a hard and fast demarcation between them. These are the heather or grouse moors and the lowland heaths. The latter are situated nearer to sea-level and are largely restricted to the East Coast and Southern England. The former are more northerly and westerly in distribution and occur at altitudes of 750 - 1,500 or 2,000 ft. above sea-level. In general it may be said that the accumulation of peat is more marked on the heather moor. No doubt this is related to the more humid and less favourable conditions for bacterial and fungoidal decomposition.

Floristically considerable differences exist between heath and heather moor, particularly among the non-vascular plants. Watson (90) compares heather moor with wet heath and records noticable differences in species lists. (Comparison with dry heath would undoubtedly show even greater differences).

However, Pearsall (61) points out that, although convenient to distinguish these two Calluneta on the basis of certain characteristic species, their flora and fauna tend to merge into one another.

Heather moor.

Although the term heather moor is often used as if it implied a unity, it is essential to recognise the subtle distinctions existing within this general term. It has already been suggested that the term is best confined to those Calluneta located between 750 and 2,000 ft. (cf. high level Calluneta at 3,000 ft., Metcalfe 53). Adamson (1) has described the moors of the Southern Pennines as upland heaths and although this classification may not be acceptable, his differentiation of moors into those originating on peat derived from the decomposition of previous Calluneta and those originating on 'foreign' peat, (e.g. Eriophorum) seems worth utilising. Moor managers have long made this distinction the basis of their terms 'thin' and 'thick' moor.

Whilst Tansley (p. 747) does not recognise the term upland heath, he does believe that above the tree limit on exposed well-drained slopes with acid soils, Callunetum even if left unburned and ungrazed would not be succeeded by any other vegetation, i.e. it represents a climatic climax (p. 765).

It would therefore seem possible to recognise four potentially different Calluneta within the genus heather moor, based on origin and spatial separation, as follows,

1.	Calluneta	above	the	tree	limit	On 'thick' moor
2.	"	below	"	"	"	
3.	"	above	"	"	"	On 'thin' moor
4.	"	below	"	"	"	

Although all four heather moors may appear vegetationally similar, there is clearly a fundamental difference between them and the removal of existing biotic influences could be expected to lead to divergent types of vegetation.

The moors investigated would clearly fall into category 4 above i.e. originating primarily on peat of their own making above acidic mineral soils on well-drained slopes and located on potential forest sites. (p.103). Even so, it is dangerous to think of the local heather moor as a vegetational unit. Apart from allied associations and their transitional stages which merge into the heather moor, the latter must incorporate a number of 'suppressed' societies moulded into apparent uniformity by sustained human interference. In this manner, minor topographical or soil differences which would have formed sub-habitats have, as the result of repeated burning, been prevented from exhibiting characteristic vegetation. Consequently a superficially homogenous community may represent a complex of modified and typical vegetation under existing environmental conditions.

Floristically, the Southern Pennine moors are remarkable for their poverty of species, although as Pearsall (61) has pointed out, if a sufficiently large area is investigated, it is usually possible to discover representatives of all the typical moorland species. Both Pearsall (61) and Tansley (78) suggest that this poverty of species is related to a long history of burning.

Tansley (78 pp. 754-56) gives a composite list of species found on the heather moors of the South Pennines by Lewis, Moss and Watson, with the reservation that some are not typical moorland plants. By contrast the list of species encountered on or near the areas investigated, is much briefer and composed as follows.

x Only those species mabked with an asterisk are of common occurence, the remainder are encountered only occasionally.

*Agrostis tenuis
Carex nigra
*Deschampsia flexuosa
*Empetrum nigrum
Epilobium angustifolium
Erica tetralix
*Eriophorum angustifolium
* " vaginatum
Festuca ovina
Galium hercynicum
*Juncus squarrosus
" effusus
*Molinia coerulea
*Nardus stricta
Potentilla erecta
*Pteridium aquilinum
Rumex acetosella
Trichophorum caespitosum
*Vaccinium myrtillus
* " vitis-idaea

The only mosses noted have been

*Campylopus flexuosus
Dicranum scoparium
Hypnum cupressiforme
*Webera nutans

Of the macro-fungi the following have been seen

*Clytocybe cyathiformis
Mycena spp.
*Paneolus campanulatus
*Stropharia semi-globata
*Tubaria furfuracea

Of the non-vascular plants W. nutans is much the commonest species. With regard to the fungi, S. semi-globata and P. campanulatus are characteristic dung species, whilst C. cyathiformis and T. furfuracea although more typical of woodland are here found in senile heather stands and recently burned areas respectively. The Mycena species were also confined to the burned areas. Flammula carbonaria although commonly occurring on experimentally burned soils in the greenhouse has not been encountered in the field.

All vascular plants have been named above and throughout the thesis according to the nomenclature used in, 'Flora of the British Isles' Cambridge 1952. (13).

Moor management.

In addition to differences due to variations in natural environmental conditions, it will be shown that the composition of heather varies as the result of differences in burning treatment. It would therefore seem advisable at this stage to mention briefly some details of this treatment.

The need to maintain heather moor in a vigorous condition, by burning the old stands before they become senescent and useless from the standpoint of fodder-production, is now generally accepted by moor managers. In order to ensure maximum productivity it is necessary to have a routine method of treatment by means of which heather on every part of the moor is burned after it has reached a certain age. The moors are then said to be under cyclic management. As most moors are now managed for the benefit of sheep as well as grouse, attempts are made to burn in cycles of 10 - 15 years. However, in practice, the difficulties of maintaining a given cycle are considerable and are adequately dealt with by Lovat (49). In this district, few of the keepers seem to burn sufficient heather to maintain a rigid cycle, with the result that stands of 20 years or more since burning are not uncommon. (Admittedly restrictions on burning during the recent war may have been in part responsible for this, although it seems that economic difficulties are the main cause). The advice of the Grouse Disease Committee, to burn in strips of limited area in order to segregate stock and facilitate seedling recovery, is probably the major cause of this failure to maintain a rigid burning regime. Where the shepherd's practice of burning in blocks (e.g. Bamford) has been employed, there seems to be no difficulty in maintaining a given treatment. There are therefore appreciable differences in the 'efficiency' with which moors are burned now and have been burned in the past.

Superimposed on intentional burning is a considerable amount of accidental burning. This is not unexpected since about half the population of England resides within approximately an hours journey of the South Pennines. Certainly most keepers agree that the incidence of accidental burning has increased since 1900, in proportion to the popularity of motoring, hiking, cycling and other forms of out-of-door activity.

General approach to problem.

Since most of the moorland in the district is privately owned and employed as rough grazing and, or, grouse moor, it has not been possible to undertake extensive experimental work. This has necessitated the utilisation of ready-made situations in the field as they presented themselves. Sometimes in spite of ardent search, desired comparisons have not been available.

As the result of these restrictions, the approach to the problem has been broadly exploratory rather than intensively specialised.

Finally in order to determine the long-term effects of burning it was considered essential to first understand the short-term effects. As a consequence the thesis is presented under two main headings;

a. The short-term effects, and

b. the long-term effects of burning.

Under each heading changes in the vegetation and soil are investigated.

PART II.

Development of the investigation and techniques employed.

Vegetation analysis.

In the first instance, several of the local moors were inspected in order to obtain a general impression of the Calluneta typical of the district. Only a few of those examined were suitable for further investigation and details of these are given in Appendix 2.

Although the apparent uniformity of the vegetation and poverty of species was obvious, it appeared that differences existed in the associated species, not only between moor and moor, but often between different parts of the same moor. It was hoped that by suitable recording methods, some measure of these differences might be obtained.

Investigations were commenced with frequency analysis of the vegetation using for the purpose a 50 cms. x 50 cms. quadrat. It soon became evident that as some of the associates were poorly represented and occurred in erratic, isolated tufts or patches, there was a considerable difference in their frequency when for example the first and second 25 quadrats from a given area were compared. When the attempt was made to compare stands of different age (since burning), even with 50 or 100 quadrat results per stand, it was clear that little confidence could be placed in the differences observed in the less frequent species.

It seemed that little justification existed for the development of this technique on a larger scale in view of the small percentage of 'presences' to be expected for some of the associated species. In addition it was not possible to record large numbers of quadrats for some of the heather stands because of their restricted area. Moreover it is doubtful whether unqualified data on percentage frequency is of much value in this type of investigation. If the composition of an old heather stand is considered, it is clear that it might be possible for Deschampsia flexuosa (because of its sparse growth) to be represented by a frequency of almost 100%, and Eriophorum vaginatum by less than 10%. The cover in the two species might be almost identical. In another heather stand, or perhaps the same stand several years after burning, the frequency of these species might not have altered but the cover of Deschampsia under these conditions could be several times that of Eriophorum. It appeared therefore, that if the role of the individual species in different heather stands was to be determined, this should be done by area methods. (Fenton 27).

The 50 cms. x 50 cms. quadrat was therefore gridded into 100 squares with copper meshing. By this means it was possible to estimate very accurately in each quadrat the area covered by heather and the more prominent components of the vegetation. In the case of the less significant components, particularly sparsely distributed Deschampsia and V. myrtillus in dense heather, the mathematical expression of cover ultimately rested on subjective estimates, thereby preventing statistical scrutiny. Another disadvantage of the method was its time consuming nature. To record accurately the cover of each species in a quadrat meant that the examination of 25 quadrats required an excessive amount of time. Since it was felt that even this number of quadrats did not always constitute a fair sample for a stand, the method was discontinued.

Ultimately a compromise was achieved between the desire to depict the cover and at the same time incorporate information on the frequency of each species in a given area. This involved the construction of histograms for each area in which frequency is indicated on the vertical axis and the cover of each species on the horizontal. The estimates of cover are subjective but are based on three clearly defined values. Value (a) was awarded when a species was 'dominant' or 'co-dominant' in the quadrat being examined, i.e. where the cover constituted 50% or more of the area of the quadrat. Value (c) was awarded in cases where the contribution of the species to the appearance of the quadrat was 'insignificant', which for practical purposes was deemed about 10% or less cover. In all other cases i.e. where the species was not sufficiently conspicuous in its cover to be co-dominant and yet its contribution to the appearance of the quadrat was 'significant', the value (b) was awarded (i.e. cover of approximately 10 - 50%). In the histograms value (a) is indicated by the widest bands, value (b) by the narrower and (c) by the narrowest.

In practice this system of recording can be operated fairly rapidly and despite its arbitrary nature, the histogram of a stand does depict, with reasonable accuracy, the conditions that really exist in the field. Consequently, 50 quadrats were recorded in each of the more interesting areas in 1951 and again in 1952. Since the 1952 histograms do not in all instances 'tie-up' with those of the previous year, this must be largely attributed to small-sample error.

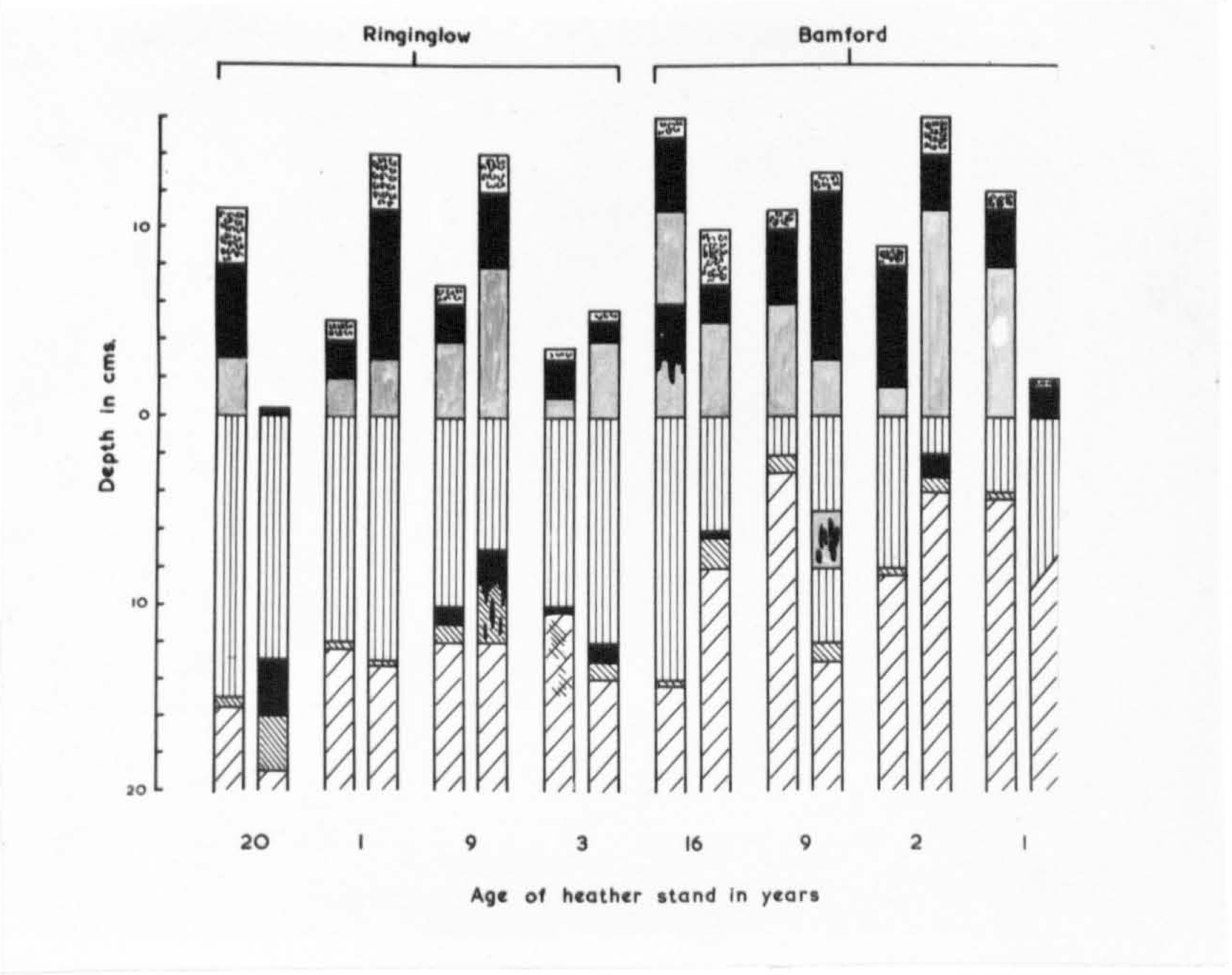
Soil characteristics.

Whilst burning must inevitably destroy most of the vegetation, it has been shown that a certain amount of peat destruction also occurs (Haines 37). This in conjunction with increased exposure and leaching, and the liberation of a relatively high concentration of soluble mineral material on to the soil surface, must considerably alter the equilibrium of conditions in the soil profile. It therefore seemed logical to suppose that moors which had been burned systematically for a long time would show divergent soil characters from those where burning had been less frequent.

It was therefore necessary to obtain areas for comparison, in which factors influencing the soil were, with the exception of treatment, as nearly identical as possible. Unfortunately

Fig. 4.

Soil profiles from heather stands of different ages.



Selected to illustrate the diversity to be expected in relatively small areas. (Symbols used are the same as in fig. 5).

there have not been many suitable areas. However a number of pits were constructed in each area to a depth of about 18-24" by which time the bright yellow, ochreous or orange-tinged sub-soil had been reached. Digging was not continued further since, in cases where this had been done, the sub-soil showed little obvious change with increasing depth. Although only a limited number of pits were constructed in order to avoid undue damage to the vegetation, it was soon apparent that the diversity in the profiles was remarkable. (Fig. 4.) It was not possible to construct a characteristic profile-diagram for any given area since the het-erogeneity of the individual profiles was too great (not infrequently the depths of almost every horizon varied appreciably on each of the three faces of a pit). The difficulty of determining accurately the limits of the different horizons (see profile description page 26), deterred any serious attempt to accumulate data of such debatable value. Perhaps the inspection of a really large number of profiles would reveal inter-area relationships but the labour involved and the damage caused to the vegetation in digging, does not seem justified. The disadvantage of dealing mathematically with data dependent on arbitrary measurements would still of course remain.

Clearly such heterogeneity is not only the result of the natural environmental influences but also of treatment. If the firing were always accidental, it would be unnecessary to

The distribution of Peat Depths under heather stands of different age and origin

(based on 20 samples per area measured to the nearest 0.5cms)

Bamford (Systematically burned moor)

Peat depth. cms.	Age of heather stand. 3 yrs.	10 yrs.	17 yrs.
13	x		
12			x
11		x	
10		xxx x	
9	x x		xxx x
8	x x		xx
7			xx
6			xx
5	x	xxxx	x x
4	xxx xxx	x xxx x	xxx
3	xxx xx	xxx x	x
2	x xx	x	
1		x x	x xx

Ringinglow. (Irregularly burned moor)

cms.	2 yrs.	4 yrs. (previous stands) (of young heather)	10 yrs.	20+ yrs.
12				
11				
10	xx			x
9	x x			xx
8	x xx			xx
7	x x		xx x	xxxx
6	x x	xx	xxxxxx	x x
5	xxx xxxx	x xxxxxx	xx xx	xxx
4	x x	xxxxxxxx	x xxxxx	x xxx
3	x	xx x		
2				x
1				x

Lady Cannings.

cms.	20+ yrs.
13	
12	x
11	xxx
10	xx
9	x xx
8	x
7	xx
6	

Blacka. (Heather moors only since 1875 - 1900)

cms.	20+yrs.
13	x
12	
11	x
10	xx
9	x
8	x
7	x xx
6	xx

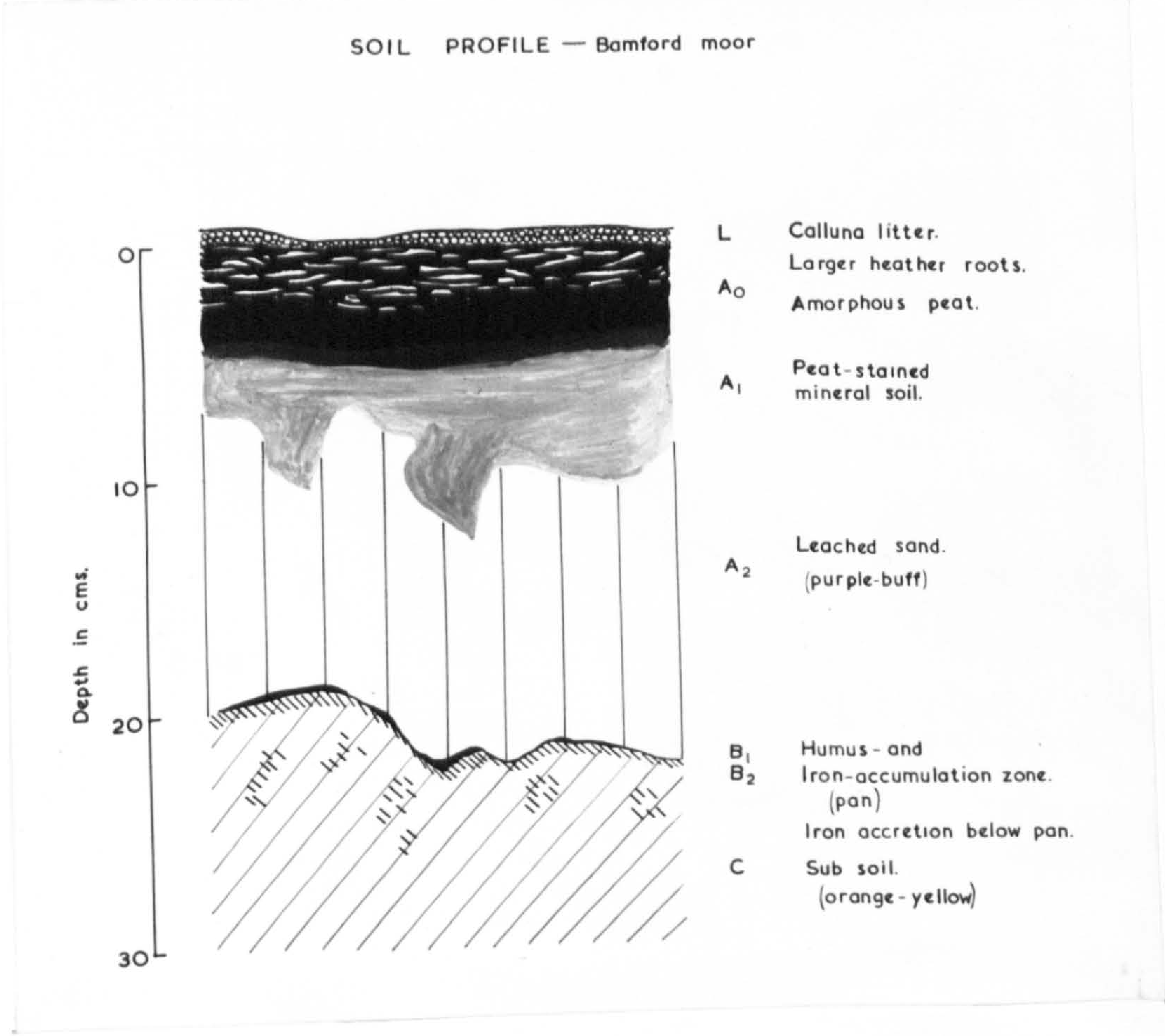
point out that the boundaries of a burned area rarely coincide with those of the previous burning. However, even in controlled burning tongues of fire may creep into adjacent heather stands before they can be extinguished, unless the boundary of the intended burn happens to abut on bare ground, or very young green heather with incomplete cover. Moreover, unless the contrast between adjacent stands is very clear because of considerable age differences, the boundaries become obscure, so that the intended burn may include stands of more than one origin. Even adjacent stands of considerable difference in age may merge into each other after a while, due to the shelter-effect of the more mature stand (Fritsch 33). The overall soil profile of a burned area may therefore be a mozaic, the result of superimposed burnings and other environmental influences.

When the attempt is made to use peat depth as a criterion of the absence of burning, further difficulties arise. An accidental fire under the appropriate conditions might well reduce the peat cover of a rarely burned moor, to a depth more

Lady Cannings. cms.	20+ yrs.	Blacka. (cont'd) 20+ yrs.
5	xxx x	xx x
4	x x	xx
3		xxx
2	x	

Fig. 5.

A typical soil profile.



The data for the Bamford and Ringinglow moors suggests that peat depth is not determined purely by the length of time that has elapsed since the last burning. When the data for the oldest stands at Bamford and Ringinglow is compared with that for Lady Canning's and Blacka moors, it is clear that well-defined differences in peat depth, in relation to the history of burning do not occur. Owing to the indecisiveness of these preliminary observations and when the many factors influencing peat depth were considered, it was decided not to investigate the problem further.

To conclude this section a general description of the podsols of the areas investigated, will be given. (N.B. fig. 5.) Commencing with the

L-F horizon. Consisting of recognisable plant remains this horizon is of variable depth, from zero where wind and rain-wash have effectively swept it away, or the area has never been colonised, to a loose carpet of as much as 3 cms. under old heather.

Ao. " Of black amorphous peat, which in the upper region is matted with heather roots. It is rarely less than 2 cms. deep and may be more than 10 cms. on occasions. The lower boundary is very difficult to determine as this horizon gradually merges into the next.

A1. " This is a black humus-stained horizon becoming progressively less peaty and more sandy with increasing depth. The large sand grains are typically leached white or grey.

A2. " A white, grey, buff or, under certain conditions of illumination and dampness, definitely purple-tinged horizon. The colour variation in different localities is not altogether unexpected in view of the heterogenous nature of the parent Millstone Grits. This is the leached horizon 'par excellence' being very porous and apparently leached free of iron and much of its original colouring matter. The upper limit is not always clearly defined, although possibly more so than the Ao-A1 boundary. Under certain conditions, for example extreme dryness or wetness, the upper limit is more difficult to determine.

B1. horizon. The first illuvial horizon. A compact layer, not always present - usually of extreme thinness - of humic material apparently accumulated from above and resting on the B2 horizon. Jacks (40) appears to consider this layer as the accumulation of decaying roots which have penetrated the eluvial horizons. There seems however no reason to suspect that this is anything but an accumulation of humic material carried down from the upper horizons in view of (a) the small amount of root growth below the Ao horizon and (b) its amorphous condition.

B2. " A compact horizon of dark-brown, reddish or even orange-colour, consisting of parent mineral material cemented by the eluviate from above. Referred to as hard-pan, this is of variable thickness and compactness, even within small compass being sometimes little more than a line to as much as 2 cms. thick. There may be contamination with humic material.

C. " A horizon of variable colour and structure. Always of a yellow tint - this may vary from canary-yellow to orange-red through dull-yellow, ochre etc.. The structure may be homogenously fine in texture but is usually characterised by its stoniness, the stones often standing out in the upper regions at least because of iron encrustation on their surface. This is much more apparent where the B2 is ill-defined.

It should be emphasised that this description of the soil profile is somewhat simplified. Sizeable rock fragments may be found in all horizons. When these occur in the A2 they are frequently reddish coloured, owing to the premature deposition of iron eluviate on their surfaces, whilst their presence in quantity in the lower horizons may entirely conceal the idealised structure described above. The incidence of large boulders, frequently just below the surface or barely breaking through the peat, leads to additional complications, so that it is possible to find profiles consisting of perfectly defined A horizons with no evidence at all of those of the B and C genera.

Exchangeable base.

Although Pearsall (59-60), Haines (37) and other workers have described the low concentration of mineral nutrients in acid moorland soils, it was felt that differences of base status between burned areas might be detected. As experience had shown that the bulk of heather roots were confined to the upper soil horizons, (see also Heath and Luckwill 38, Leach 47), particularly the amorphous peat of the Ao, it was concluded that this must be the region of active absorption and therefore of most interest from the fertility viewpoint. Consequently, investigations are largely confined to the determination of the base status of peats. The small amount of base present meant that a considerable amount of time was involved in attempting to devise suitable techniques for its determination.

One of the earliest methods employed, involved leaching the soil with ammonium-salt solutions. By suitable distillation of the resulting ammonium-saturated soil, the exchangeable-cation capacity of the soil was determined. The increased acidity of the leachate was determined by titration. The difference between this (the equivalent of exchangeable hydrogen) and the exchangeable-cation capacity, represents the exchangeable cations other than hydrogen in the soil sample (i.e. the bases). Although reproducibility of results for exchangeable-cation capacity was good, the determination of exchangeable hydrogen was not so satisfactory. Since the apparatus used was a modified Kjeldahl outfit, and not amenable to indefinite duplication, the bottleneck arising when a number of ammonium-saturated soils were awaiting distillation constituted a major disadvantage of the method. Moreover, in order to determine the exchangeable-cation capacity, it was essential to leach the soil completely. In view of the relatively low position of ammonium ions in the lyotropic series (Sigmond 70), it was necessary to use a large volume of leaching solution to ensure this. Leaching itself introduced a major difficulty, as finely-divided organic particles gravitated to the base of the soil mass and formed an impermeable coat. As a result the passage of solution became progressively more difficult. Since any form of assistance e.g. suction, merely aggravated the situation, it was necessary to wait an excessively long time in order to collect the leachate.

In order to reduce the volume of leaching solution required and thereby speed-up the process, a search was made for a method incorporating a replacing ion of greater efficiency than the ammonium ion. This was available in a method described by Mehlich (52) employing barium ions. It is only necessary to mention the advantages and disadvantages of this method. As the leaching solution is strongly buffered, replacement is ensured at a definite pH in all soils and results are therefore strictly comparable. The volume of leaching solution can be reduced from 1/5-1/10th of that necessary when an ammonium-salt solution is used, although leaching is still necessary as the method again involves the determination of the exchangeable base by difference. The procedure for the estimation of exchangeable-cation capacity (i.e. the displacement of barium ions in barium-saturated soil by potassium ions and the estimation of the barium spectrographically as chromate) was somewhat cumbersome, although the demand on apparatus was not so great as in the previous method.

Various modifications of the above methods were tried but all suffered the disadvantage that exchangeable base was determined by difference according to the formula;

Exchangeable-cation capacity — Total exchangeable hydrogen = Exchangeable base.

Consequently an error in the estimation of either the exchangeable-cation capacity or the exchangeable hydrogen leads to a complementary error in the estimate of exchangeable base.

It was therefore decided to employ the Brown rapid method (5) in which both the exchangeable hydrogen and base are determined experimentally, and which at the same time is reasonably speedy to operate. Although not so accurate as leaching methods, since ionic exchange only proceeds to equilibrium between soil and solution, the exchangeable hydrogen actually displaced from the soil is determined and not its equivalent in terms of standard alkali. Such equivalents may be considerably influenced by organic acids in the soil extract and amphoteric aluminium. Whilst in a highly acid soil the hydrogen : aluminium ratio is likely to be large, it should be remembered that it is in these soils that aluminium occurs in significant amounts (p. 94). In the Brown method, exchangeable base is determined by the difference in pH of an acid replacing solution before and after the introduction of a soil sample (i.e. the removal of hydrogen ions from the solution in effecting the detachment of cations from the soil, leads to an increase in pH of the solution equivalent to the basic cations liberated.).

The technique employed, varied slightly from that described originally by Brown. Owing to the acidity of the soils, the reduced ratio of 4 gms. peat : 100 mls. neutral N-ammonium acetate was employed, otherwise the depression of pH was so pronounced that readings came on to the flat part of the titrated hydrochloric acid-ammonium acetate calibration curve.

On the other hand the concentration of exchangeable base was so low that before a readable value could be obtained the ratio of soil : acetic acid had to be increased to 20 gms. : 100 mls. Fresh peat was used, after trials had shown that changes in the amounts of exchangeable base and hydrogen occurred during drying. Bulked samples (about 20 from each area) were used, after being thoroughly mixed by manually tearing the peat to pieces and passing it through a sieve. The soil : solution mixtures were shaken mechanically for 1 hour, in lieu of the 2 hours occasional shaking specified in the original method. As the moisture content of the peat from different areas varied, this was determined on portions of the bulked material.

Whilst the determination of exchangeable hydrogen was satisfactory, the measurement of base was more difficult. The inter-area differences were very small and it was obvious that the results were only of value when used comparatively in any one series. Any attempt to use these figures as absolute values would be unjustified. To illustrate this, occasions did arise when the inter-area differences in exchangeable base depended on variations in pH of 0.025 units, measured on an instrument graduated in 0.1 pH intervals. (A Cambridge pattern meter was available but this was mains-operated and fluctuations in the current were so great that the relatively small inter-area differences were obscured.).

The major disadvantage of the method however, is that the basic cations determined are not all mineral nutrients. The presence of aluminium and iron in particular, may be responsible for the over-estimation of 'genuine' bases. Consequently it was decided to estimate calcium and potassium only, as it was felt that these would give a better indication of the mineral nutrients in the soil than the values for total base. Calcium estimation was made possible by the description (and commercial supply of materials) of a technique employed in determining the hardness of water in the U.S.A. (3). Although a titration method this appears sufficiently sensitive to estimate the small differences in the calcium content of peat extracts, especially when the modified indicator described by Knight (44) is used. (Attempts to do this by precipitation as oxalate and titration with potassium permanganate (Williams 93) had proved that the experimental error was greater than the inter-area differences in calcium status). Potassium was estimated by flame-photometer in accordance with details given by Domingo and Klein (22), whilst, in view of the advantages already described, exchangeable hydrogen was estimated as in the previous method.

The main principles of the method were as follows. Samples of 4 gms. of fresh soil for hydrogen determination and 20 gms. for exchangeable base determination, each in 100 mls. of neutral N-ammonium acetate, were mechanically shaken for 1 hour.

The exchangeable hydrogen was determined as soon as possible after the soil had been collected (usually on the same day), whilst the soil : acetate mixture for base determination was centrifuged and filtered. The resulting solution was transferred to an evaporating-dish, taken to dryness and baked to decompose the acetate radicle. The dry solid was then digested on a water-bath in 10 mls. N-hydrochloric acid for 30 minutes, filtered, washed with hot distilled water and made up to 100 mls. In each case a 20 mls. sample was removed for the photometrical estimation of potassium and the remaining 80 mls. used for the estimation of calcium.

By and large the technique was satisfactory, although the treatment necessary to obtain a clear solution for the estimation of the 'bases' was somewhat protracted. In the absence of a clear solution the indicator changes were of course obscured, whilst any suspensions in the solution led to blockages of the flame-photometer feed-tube and atomiser.

Chemical analysis of the vegetation.

As it was desired to confirm the intra-cyclic trends in base status detected by soil analysis, it was decided to inspect the chemical composition of the heather leaves from different areas.

Although Lundegardh (50) is of the opinion that leaf analysis can not entirely replace soil analysis, since the supply of available minerals in the substrate is not always reflected by the amount accumulating in the leaves of plants growing thereon, he appreciates the advantages in this method of estimating soil fertility. Where the soils are essentially of similar origin, physical structure and chemical composition, it is clear that more confidence can be placed in the results of leaf analysis. In any event the critical factor in measuring fertility is surely the availability of minerals in the soil and their uptake by the vegetation under specific environmental conditions and not soil fertility per se.

Heather shoots from stands of different ages were collected and bagged separately. The leaves, with as little contamination by dead leaves etc., as possible, were then removed and placed loosely on paper trays in an oven of temperature 60 – 70'C. through which a current of air was passed. After several hours the material was removed, allowed to cool and reduced to a sufficiently fine powder to pass a '30' sieve. During this stage it was possible to sieve off any small stems that had been included. The powdered green material was then dried off at 100'C. until constant weight was attained. Accurately weighed samples of about 3 gms. were placed in crucibles, incinerated and the ash digested in 25 mls. of 0.1 N-hydrochloric acid. To prevent excessive loss of vapour, the crucibles were covered with watch glasses and digestion was continued for 30 minutes on a water bath. Since the volume of solution was not allowed to decrease unduly, only water was lost by evaporation. (The strength of constant boiling hydrochloric acid at laboratory pressures is between 5 and 6N., Vogel 87). This was of course confirmed by repeated checks with blank solutions. The contents of the crucibles were then filtered through Watmann No. 44 filter papers and the filtrates collected. Crucibles and residues were washed at least three times with hot distilled water. In order to reduce the bulk of the filtrate, it was slowly evaporated on a water-bath to approximately 25 mls. volume. Since some of the acid is neutralised by the base present in the extract, this can be determined by the difference in the quantity of standard alkali required to neutralise the remaining acid, and the quantity required to neutralise the acid originally present. The difference in the two titrations represents the equivalent of base in the sample used.

In the very first series of analyses (table 15 Ringinglow), the excess acid was neutralised with 0.1 N-sodium hydroxide using phenolphthalein as indicator. Long before the end-point however, a white precipitate appeared which on analysis proved to be aluminium hydroxide. As this tended to interfere with the end-point by redissolving to form sodium aluminate, 0.1 N-ammonium hydroxide with methyl-red (pH 4.2-6.3) as indicator was subsequently used. By curtailing the titration at the first colour change, little precipitate appeared and the end-point was more definite. (Aluminium hydroxide begins to precipitate at about pH 5, Vogel 87).

Although roughly substantiating the observed soil differences, it was felt that base values per unit dry-weight of green material had little meaning, since it was probable that the latter represented the crop of varying areas of soil surface in the different stands. A more intensive investigation was therefore instituted.

The aerial parts of heather plants from unit areas were collected and bagged individually. In each stand 9 samples were taken in 3 groups of three. The three groups were widely separated and entirely at random. Unfortunately, in the younger stands, the three samples of each group could not be taken entirely at random since the inclusion of bare ground in a quadrat would influence the yield of green material. However, the quadrats were taken at random on adjacent patches of continuous heather cover. In the case of very old and senescent stands of heather the open condition of the cover made the previous routine impossible. Six sites were therefore taken at random in the stand and the quadrat placed on the nearest continuous heather cover. By adopting this technique, it was felt that the crops of unit areas were serving as phytometers.

The quadrat size of 20 cms. x 20 cms. was possibly a little small but this was chosen to facilitate more random sampling in those stands where the heather cover was discontinuous. The small size also kept the quantity of material to be handled to manageable proportions.

The individual samples were stripped by hand, a somewhat laborious process, and the green material spread out on paper trays in a constant temperature room at 30'C. for 48 hours. At the end of this period the material was sufficiently dry for it to be rubbed by hand to separate the leaves from the stems. Since it was inevitable that some fruit capsules, flowers and finer stems were included in the green material at this stage, these were largely removed by sieving and lightly 'winnowing' the petals by means of a fan. The resulting material, almost pure leaf, was subsequently dried for several days at 100-105'C. until it attained constant weight. Each sample was weighed to the nearest 0.05 gms. and then placed in an air-tight bottle until required.

In order to reduce the number of samples to be analysed the three samples of each group were bulked. Where six samples only were collected for an area, the bulking was done in pairs according to similarity in weight. Bulked material was pestelled and mortared into a fine powder and sieved several times to thoroughly mix it.

Small quantities of the material were then dried at 105'C. for 12-24 hours and 5 gms. samples and duplicates weighed into crucibles. The crucibles and their contents were then transferred in batches of eight to a muffle-furnace, where they were carefully dry-ashed for several hours. (see Piper 64, and

Wright 97). (Wet-ashing with sulphuric, nitric and perchloric acids had proved most unsatisfactory, probably because of the large amount of resinous compounds in the material, and the method did not appear to have any advantages in speed or control over the dry-ashing method.). When cool, the ash was digested in 10 mls. of N-hydrochloric acid for 30 mins. over a water-bath and filtered through a Watmann No. 44 filter-paper. The residue and crucible were repeatedly washed with hot distilled water and the filtrate collected in a 100 mls. flask. After at least three washings the filtrate was made up to the mark. Aliquots of 25 mls. were withdrawn for calcium estimation and one sample of 20 mls. for potassium estimation from each flask. These elements were estimated as previously described (p. 33).

Leaching experiments.

One further series of experiments needs to be explained. As the result of observations on the intra-cyclic changes in soil base status, it was clear that data on leaching would be valuable. Accordingly a pilot experiment was undertaken to determine whether changes in the mineral composition of the leachate occurred after the vegetation had been burned and if these could be detected by the methods availalle. A large tin of 9" x 9" and 14" depth, with holes punched in the base, was taken into the field. A block of soil, plus vegetation, slightly larger than the size of the box was then dug out of the ground and guided into the box. After several attempts this was eventually achieved without breaking the block. The box plus contents was then placed in the greenhouse on an enamel tray to collect the leachate. At intervals the equivalent in distilled water of 1" rainfall was poured over the soil and the leachate was collected after 48 hours. The leachate was then filtered, evaporated to dryness and the residue baked on the hot-plate for about 30 minutes. The dry solid was then treated in the same way as the ashed green material described on page 35 and the base determined by titration with ammonium hydroxide as detailed on page 36. After two or three preliminary leachings, the vegetation was burned (p. 42) and leaching continued.

The encouraging results obtained warranted an expansion of the experiment. Four boxes were therefore made of slightly less size (the pilot box had been rather bulky to handle), viz. 7" x 7" and depth 14" as before. These were constructed with removable, perforated bases to overcome the previous difficulty of introducing the soil into the box without disturbing its structure. Prior to taking the tins into the field their interiors were lined with paraffin-wax so that this could be melted once the soil was in position and an efficient seal down the sides of the box obtained. From a stand of old heather at Ringinglow, four areas with, so far as could be determined, similar heather cover, were trenched around to leave a pillar of soil slightly larger than the dimensions of a box. A box, minus base, was then thrust down over each soil column until the soil-surface was about 2" below the lip of the box. The cutting-edge of the box effected so good a seal that the paraffin lining was scraped away. The bases of the soil columns were then chopped off below the tins, trimmed flush and the perforated bases with their layer of glass-wool fitted into position. The four tins were then brought into the greenhouse and placed over enamel trays in readiness for leaching. After a period of acclimatisation and moistening to bed-down the soil, leaching was conducted as in the pilot experiment. After each block had been leached several times, the vegetation of two of the blocks was burned leaving two blocks as controls. The leaching was then continued and the third and fourth blocks burned at intervals during the later part of the experiment. During the first part of the experiment, the same method of determining base was employed as in the pilot experiment. Unfortunately the results after burning were not so conclusive as in the pilot experiment. However, the value of the experiment was recovered by the description of the 'Versene' method of estimating calcium and for the final part of the experiment calcium and potassium were determined as representative of the base in the leachate.

Under the circumstances the experiment was continued longer than originally intended and some criticism may be levelled at keeping the blocks in the greenhouse for so long, since changes in the soil might occur. However, it is unlikely that such criticism could nullify the conservative conclusions which are drawn. Another criticism of the method is that by the end of the experiment the tins, having been in contact with moist soil for so long, had become rusted and some of the rust may have passed into the leachate. A refinement in this respect would be the use of transparent plastic boxes, preferably with a detachable receptacle at the base. By this means it would be possible to guard against rust, contamination by dirt etc., and also to see that the soil remained in close contact with the walls of the container, as there appeared to be a slight settling of the soil in the later stages of the above experiment. Another method might be to cover the soil column in the field with a stout layer of wax, transport this in a box of convenient size to protect it and in the actual experiment use the wax itself as the container.

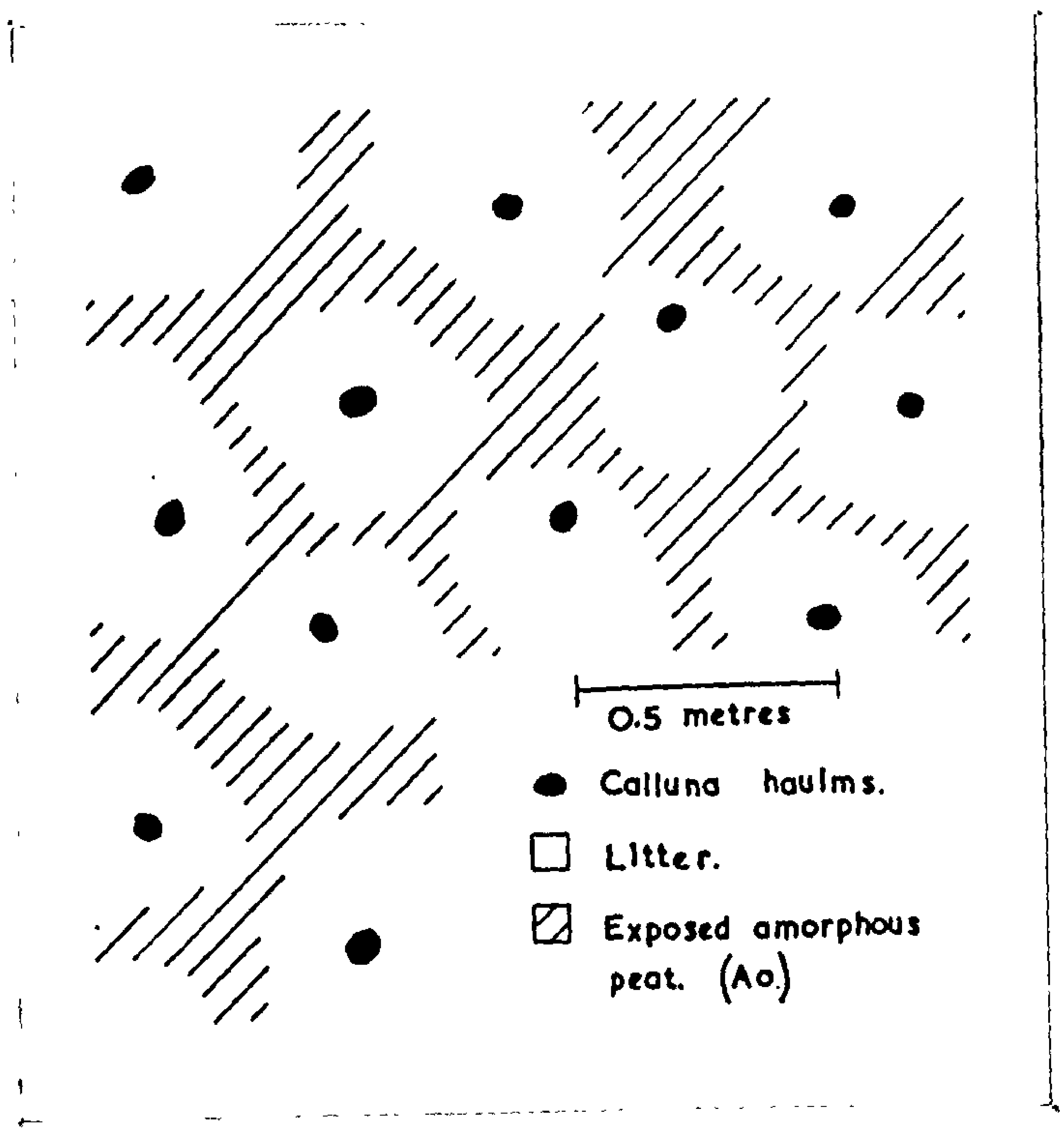
Since the methods of burning the vegetation differed in the two experiments an account will be given of these. In the pilot experiment, the crop was removed to soil level and ignited independently in a large porcelain dish. The ash obtained was thoroughly mixed and a small sample removed. This was digested in N-hydrochloric acid, filtered and the filtrate evaporated to dryness. A second sample was also removed, shaken at intervals for ten minutes with the equivalent in distilled water of 1" rainfall, filtered and the filtrate evaporated to dryness. At intervals of several days, the residue was treated with the equivalent of a second and third inch of rainfall, and the filtrates evaporated to dryness. In each case the dry extract was digested in 25 mls. 0.1 N-hydrochloric acid according to the details on page 35 and the base determined. By this means the base content and the water-soluble base of the ash applied to the soil surface, were respectively estimated.

In order to simulate burning in the field it was therefore necessary to 'hose' the soil-surface with a Bunsen burner. The balance of the ash was then spread evenly over the soil-surface and the experiment conducted as if the vegetation had been burned in situ.

When it was decided to burn the heather of a soil block in the main experiment, the tin was transferred to a fume cupboard. The vegetation was then ignited in several places by means of a burner and allowed to burn itself out. It was felt that this closely reproduced conditions of burning in the field. During burning, several interesting observations were made. Firstly, despite the lack of wind a large amount of the ash floated away into the laboratory. This in itself probably contributes to a loss of base potential at burning,

Fig. 6.

Appearance of the soil surface of an old heather stand almost one year after burning.



Field sketch at Bamford moor.

since the same thing undoubtedly occurs in the field. On one occasion during autumn burning, particles of ash from a fire almost a mile distant, were constantly drifting over Ringinglow. On this particular day there seemed to be comparatively little wind to carry the ash so far, although convection currents may have been largely responsible for this. Secondly, although the sides of the box above soil-level became too hot to touch, that part at and below soil-level remained surprisingly cool. It therefore seems probable that burning, except under extreme conditions, does not produce excessive temperatures in the peat horizon. This is substantiated by the fact that litter on the soil-surface was apparently little damaged by burning in these tins, whilst its resistance to burning in the field, particularly when old stands have been burned, has been noted many times.(see fig. 6) In the pilot experiment althought the surface of the soil was subjected to the drastic treatment of 'hosing' with a Bunsen burner, it was difficult to make the litter glow.

PART III.

The short-term effects of burning.

Effects on the vegetation.

In order to avoid undue repetition of details on the individual areas, these are summarised in Appendix 2. Observations on the short-term changes in the vegetation as the result of burning are drawn from the following data:

a. Frequency analysis - tables 1 - 8.

b. Percentage cover values - table 9.

c. Histograms for the individual areas - figs.7-14.

Observations on the effects of burning on the individual species in the Callunetum.

Fraser (32) has classified the more important moorland species into two main groups, according to their response to burning; viz.

1. Caespitose species in which winter buds and food stores are protected by a dead matting of leaf-sheaths and last years leaves (e.g. *Eriophorum vaginatum*) and plants whose winter buds and reserve food stores lie below the surface of the ground (e.g. *E. angustifolium*). Plants of this group are scarcely affected by fire. Even when burned in the early growing season they are only defoliated and soon recover.

2. Sub-Shrubs and other plants with winter buds

Photo. 1.

The recovery of heather by rootstock regeneration after 12 years old plants have been burned.

The photograph was taken about 9 months after burning. Some of the young shoots were 10-12 inches in length. (The box is 9" x 9".)

at or near the surface of the ground and with their food reserves stored in the stem, and which do not regenerate readily from roots. Such plants may be completely destroyed by fire (e.g. Calluna).

Certain plants are intermediate between these two groups (e.g. Vaccinium myrtillus) in which winter buds occur not only on the aerial stems but also on rhizomes. These plants, although the aerial parts may be destroyed by fire, quickly repair the damage by new growth from the underground stems.

Whilst agreeing with this summary, it is felt that further information on the response of the individual species to burning is required. Commencing therefore with heather, Calluna. When heather is burned the plants may be completely destroyed, in which case recovery will be dependent on seedlings. If however, the plant is not completely destroyed, new shoots may spring from the surviving parts almost immediately. This is referred to as 'rootstock regeneration'. Fritsch (33) although familiar with the fact that this type of regeneration only occurred in the younger heather stands, concluded that this was related not so much to the youth and vigour of the heather prior to burning as to the secondary effect of the different intensities of the heat of combustion in stands of different ages. This deduction seems to be based on the observation that in old stands, although a certain number of young plants are often present, regeneration after burning is usually by seeding. Further, that where rootstock regeneration did occur the crown of the stem was buried below the peat or otherwise protected from fire damage. This suggested to Fritsch that the degree of damage and not the age of the plant at burning governed the capacity to regenerate vegetatively. The degree of damage, he explained, depended on the intensity of the heat at burning, i.e. in old stands the amount of combustible material is greater than that present in young stands and therefore the greater will be the heat and destruction of plants.

It should be pointed out that Fritsch's observations do not entirely agree with those made in this district. Firstly, although regeneration is almost entirely by seeding when old heather (15 - 20+ years) is burned, some regeneration does occur from rootstock. This is undoubtedly related to the proportion of young plants present in the original stand (see the age scatter in old stands - Appendix 3). Secondly, some keepers deliberately burn old heather 'with the wind' in order to retain the haulms, by which it is supposed that sheep are deterred from grazing and uprooting the young seedlings. Under these conditions the fire passes across the stand so rapidly that only the finest branches are removed. If age is not the factor governing rootstock regeneration, why does it not occur in these circumstances? Finally it is difficult to accept Fritsch's hypothesis that the intensity of burning is greater in old stands than in younger ones. When young stands are burned, the slender closely-packed stems are consumed to ground-level under widely different conditions of burning and yet it is these stands which show the highest proportion of vegetative recovery. On the other hand, the burn must be very severe or carried out by special methods (e.g. burning 'against the grain', or 'backburning' against the wind) to remove the stout old stems to ground-level. There seems little doubt that although the intensity of burning is governed by several factors, regeneration from rootstock is governed by only one, the age of the plant at burning. However it is not denied that under abnormally dry conditions, e.g. accidental summer burning, the destruction of the vegetation and peat may be such that even in young stands rootstock regeneration is suppressed.

The age at which this type of regeneration fails can be roughly determined. The oldest stand at Bamford (18 yrs.) showed little if any regeneration from rootstock on being burned. However, when the stand was burned, a small part of the adjacent medium-aged stand was damaged and this showed regeneration from rootstock. It can therefore be deduced that regeneration fails at Bamford, before the heather is 18 years old but not before it is 9 – 10 years old. The age of the stand from which the present 8 years old Toadsmouth stand was derived, could not have been less than 12 years when burning occurred. Similarly the age of the stand giving rise to the present Ringinglow 9 years-old stand could not have been less than 12 - 13 years at the time of burning. (Appendix 2). Since the appearance (next para.) and age distributions of both of these stands suggest regeneration from rootstock, it seems reasonable to assume that this type of regeneration fails, in this district and on this type of moor, when heather is burned between the age of 12 and 18 years. Probably about 15 years is the maximum age at which regeneration from rootstock can be expected, although this will undoubtedly be modified under different environmental conditions. Even generalisations of this nature can only be applied to heather stands as a whole, as differences in physiological state will probably occur among the individual plants in a particular stand. Furthermore, even when stands are considered as an entity, it seems probable that in view of the age distribution of the plants composing the stand the power to regenerate by rootstock will not decline abruptly at a given time after burning, but fade out gradually.

In general however, it can be said that when heather is burned before it is 15 years old a high proportion of rootstock regeneration can be expected.

The differences in origin of the heather plants tend to produce two distinct forms in older plants. When a plant has arisen as the result of rootstock regeneration it is character-

Photo. 2.

Heather plants (aged 12-15 years) showing the 'tree' form of growth.

This growth form appears to be characteristic of plants which have originated from seedlings.

Photo. 3.

Heather plants (aged 12-15 years) showing the ' bush ' form of growth.

This growth form is characteristic of plants which have regenerated from rootstock. Numerous branches arise from ground level. There is no well-defined main stem.

ised by the 'bush' form of growth (photo. 3), whilst one that has arisen from seedling exhibits the 'tree' form of growth (photo. 2). The latter form is not always as obvious as in the photograph since the main axis may vary greatly in length and prostration with different conditions of topography and exposure. Although Gimingham (34) has shown that grazing can to a large extent affect the growth-form of the young plant, the above mentioned forms appear to be quite unrelated to this factor. The bush form is present at Lodge Moor where no grazing occurs, whilst at Ringinglow with relatively heavy grazing the difference in growth forms is seen in the 5 years and 3 years-old stands. Another feature associated with regeneration from rootstock is the dense and very uniform growth of heather over the whole area.

With regard to the duration of the heather cover after burning, the following points have to be considered. Since it is not until about 10 years after burning that complete cover is achieved (p. 59). (Lovat 49, suggests that 9 years is a good average for moors of this type), it is possible, although not very probable that seedlings may become established as late in the cycle as 9 - 10 years after burning. (In practice the age distributions of the older stands only show a scatter of 6 - 8 years at most, so that it is unlikely that seedlings become established later than about 7 -8 years after burning). (Appendix 3).

Complete cover is then maintained for at least 10 years (Bamford 17 years fig. 7), and it is not until about 20-25 years after burning that degeneration of cover begins (Toadsmouth 20+ years), due presumably to the death of the plants which were first established after burning. At this stage however it is possible for plants as young as 10 - 15 years to be present in the stand, so that if the life span of the individual plants is approximately 20 - 25 years the last-established plants would not die until about 30 - 35 years after burning. Whether natural regeneration by seeding would then occur as it appears to do on some of the lowland heaths in the absence of burning, is difficult to determine. Certainly this has not been observed in the oldest stands investigated, although it is doubtful if any of these were much older than about 30 years. The oldest plants encountered were at Houndkirk Hill and showed 24 annual rings, but here the cover was fairly continuous due to the abundance of associated species and little if any colonisable ground was available on which seedlings could become established. Even in the presence of an open canopy in very old stands, it seems doubtful whether colonisation by seedlings could occur unless the area was sufficiently exposed for wind and rain to remove the accumulated litter. When the heather has been burned, it is only in those places where the litter has been removed and the amorphous peat exposed, that seedlings can become established (N.B. Wallace 89). Fig. 6 illustrates the restriction of this colonisable ground in an old heather stand even after burning has exposed the soil surface to increased 'weathering'. This condition may continue for the whole of the first season after burning and where the litter is more persistent colonisation by seedlings may be considerably retarded.

Erica tetralix. This species is almost too infrequent to mention, except to point out that its presence on the moor is clearly related to locally increased moisture content in the peat. There is however no reason to suppose that its response to burning is any different from that of Calluna, i.e. it may be completely destroyed or only partly damaged in which case vegetative regeneration may occur. The latter conclusion is however based on only one observation at Lodge Moor, where, in a stand in which heather regenerated from rootstock, several bushy plants were noted which seemed unlikely to have reached such a stage of development had they been derived from seedlings.

Empetrum nigrum. Consideration of table 7 suggests that this species is eliminated as the result of burning. With the exception of the Bamford 2 - 4 years stand, it is absent from all young stands investigated. Although not common to all the moors, where it does occur it does not reappear until about 10 years after burning. It seems therefore that its re-establishment is normally dependent on seedlings. The exceptional occurence of this species in the young Bamford stand, (B. 2 - 4 years) may be explained by the presence of scattered rubble from an old shooting-butt which may have resulted in a number of plants escaping the effects of burning altogether, or being only partly damaged and regenerating vegetatively. The occurrence of this species on both irregularly burned and systematically burned moors, suggests that the effect of burning is only transitory and that repeated burning does not lead to its permanent elimination from the vegetation.

Vaccinium myrtillus and V. vitis-idaea. Table 7 shows the small representation of both these species on the systematically burned moors. This in itself suggests that burning is detrimental to their well-being, but this can be observed directly by inspecting data taken from the irregularly burned moors on which the Vaccinia are better represented. (table 6).

It has already been mentioned that although the aerial parts of V. myrtillus may be destroyed by burning, the damage is quickly repaired by new growth from underground stems. This is clearly shown by comparison of Houndkirk Hill 20 years-and 1 year-old stands. (N.B. The recovery may not be entirely due to the sprouting of underground shoots since some of the original Vaccinia 'mats' may have been so extensive that the aerial parts of the plants were not completely destroyed by burning). However, the species not only quickly recovers from the effect of burning but appears to be stimulated by it, R. 20 cf. R 1-3 (table 6) and fig. 10 20 years cf. 2-3 years. This response is probably best summarised by Tansley (78, p. 756) in the statement that "where V. myrtillus does occur in quantity it often asserts itself after burning by sprouting from underground rhizomes before the heather returns". Although Vaccinium myrtillus increases its coverage after burning, it does not normally reach a state of dominance over heather as described by Leach (46), Elgee (23) and others.

The effect of a second burning soon after the first is less easily interpreted, since the rate of heather recovery is more rapid and will tend to curtail any post-burning capacity in V. myrtillus to increase its cover. Fig. 12 (2 years cf. 1 year) suggests that this treatment is detrimental to V. myrtillus and whilst some recovery can be expected after a year or two, (fig. 10 4-5 years cf. 2-3 years), it is clear that this is not of the same order as observed above. These short-term observations would be in keeping with the deduction that the more frequent the burning, the greater must be the drain on the food reserves of the plant in putting out new shoots to replace those destroyed by burning.

The fate of V. vitis-idaea is much simpler to follow (table 6). Clearly the effect of burning is to reduce the frequency of this species (R 20 cf. R 1-3 and H.H. 20 cf. H.H. 1).

When a second burning closely succeeds the first, it is eliminated from the early stages of recovery (R 4-5 cf. R 1-3, H.H. 2 cf. H.H. 1, L. 11-12 cf. L. 2-4). The effect is shown particularly clearly in the data for percentage cover (table 9) and the appropriate histograms. It is difficult to decide why *V. vitis-idaea* should be so much more susceptible to burning than *V. myrtillus*. Like V. myrtillus it has underground stems although these are much nearer the surface and may therefore be more susceptible to fire damage, whilst the fact that, unlike *V. myrtillus*, it is in possession of its leaves when burning normally occurs (in spring) may be significant.

Deschampsia flexuosa. The comparatively small difference in the amounts of this species between the youngest stands and those from which these were derived suggests that burning has little direct effect on it (fig. 7a.17 yrs. cf. 7b.1 yr., fig. 9.9 yrs. cf. 1 yr., fig. 12.20 yrs. cf. 1 yr.) Like *V. myrtillus* its ability to recover from the effects of burning is greater than that of Calluna so that a temporary increase in cover occurs in the early part of the cycle. Although a good deal of this is undoubtedly due to the expansion of established plants there seems little doubt that some of the increase is due to colonisation by seedlings. Although better represented on the irregularly burned moors than the systematically managed ones, (Ringinglow cf. Bamford histograms), this is undoubtedly more a reflection of the continuity of treatment than the result of fire damage, and will be discussed later. The fact that Deschampsia manages to survive in stands of all ages and under all types of treatment indicates that it is one of the most resilient of the associates of Calluna.

Agrostis tenuis. Where this species occurs, it is restricted to the very early stages in the burn subsere (table 7) a not unexpected observation in view of its intolerance of shading. Its presence may however be related to soil fertility as it has not been observed in old stands with discontinuous cover.

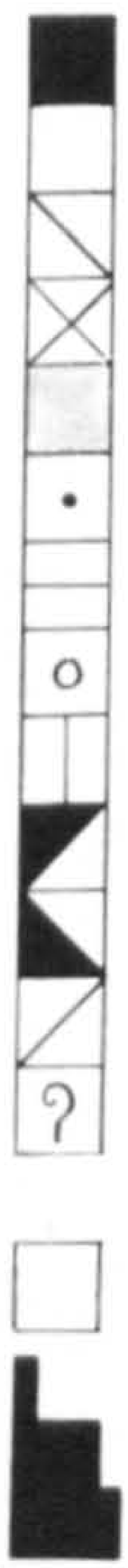
Eriophorum vaginatum, E. angustifolium, Juncus squarrosus and Nardus stricta, occur in such variable amounts and so irregularly that inferences concerning them are hazardous. However from general observations they, like some of the previous species, seem to be relatively little affected by burning per se. For example, stands containing much E. vaginatum usually show little change in the amount of this species after burning. If any change does occur it is likely to be degenerative so far as these species are concerned. It seems most unlikely that increased representation due to the establishment of seedlings occurs, since even in stands where heather recovery was by seedlings no marked increase in the representation of these species has been observed. This holds good even when the proximity of mixed moor would be expected to increase the chances of inoculation by seeds. In this connection however, it is as well to note that in the competitive colonisation of burned ground by seedlings, the high seed-production of heather (Beijerinck 2, Elgee 24, Smith 72) relative to that of other moorland species must favour heather dominated cover, if conditions of germination and development are at all suitable (Wallace 89, Smith 72).

In general it would appear that the part played by seedlings in colonising ground, is with the exception of those of Calluna, Empetrum and Deschampsia, of secondary importance to vegetative exploitation by established plants. This in turn suggests that although isolated burnings do not radically alter the composition of the vegetation, the chances of individual plants being eliminated as the result of fire-damage increase with the frequency of burning. This must ultimately result in the restriction of the associates of heather to more and more localised 'niches' on the moor, and in the case of the majority of associated species these must represent the 'survivors' of formerly more important components of the vegetation. This, however, is actually related to the long-term effects and will be reconsidered later.

Changes in the composition of the vegetation as the result of burning.

An inspection of the percentage cover values of the individual species (table 9) shows that even on those moors with the most varied vegetation the representation of heather is

KEY to HISTOGRAM SYMBOLS



Calluna vulgaris
Deschampsia flexuosa
Empetrum nigrum
Erica tetralix
Vaccinium myrtillus
Vaccinium vitis-idaea
Eriophorum angustifolium
Eriophorum vaginatum
Carex nigra
Juncus squarrosus
Agrostis tenuis
Nardus stricta
Pteridium aquilinum

Bare ground — inverted

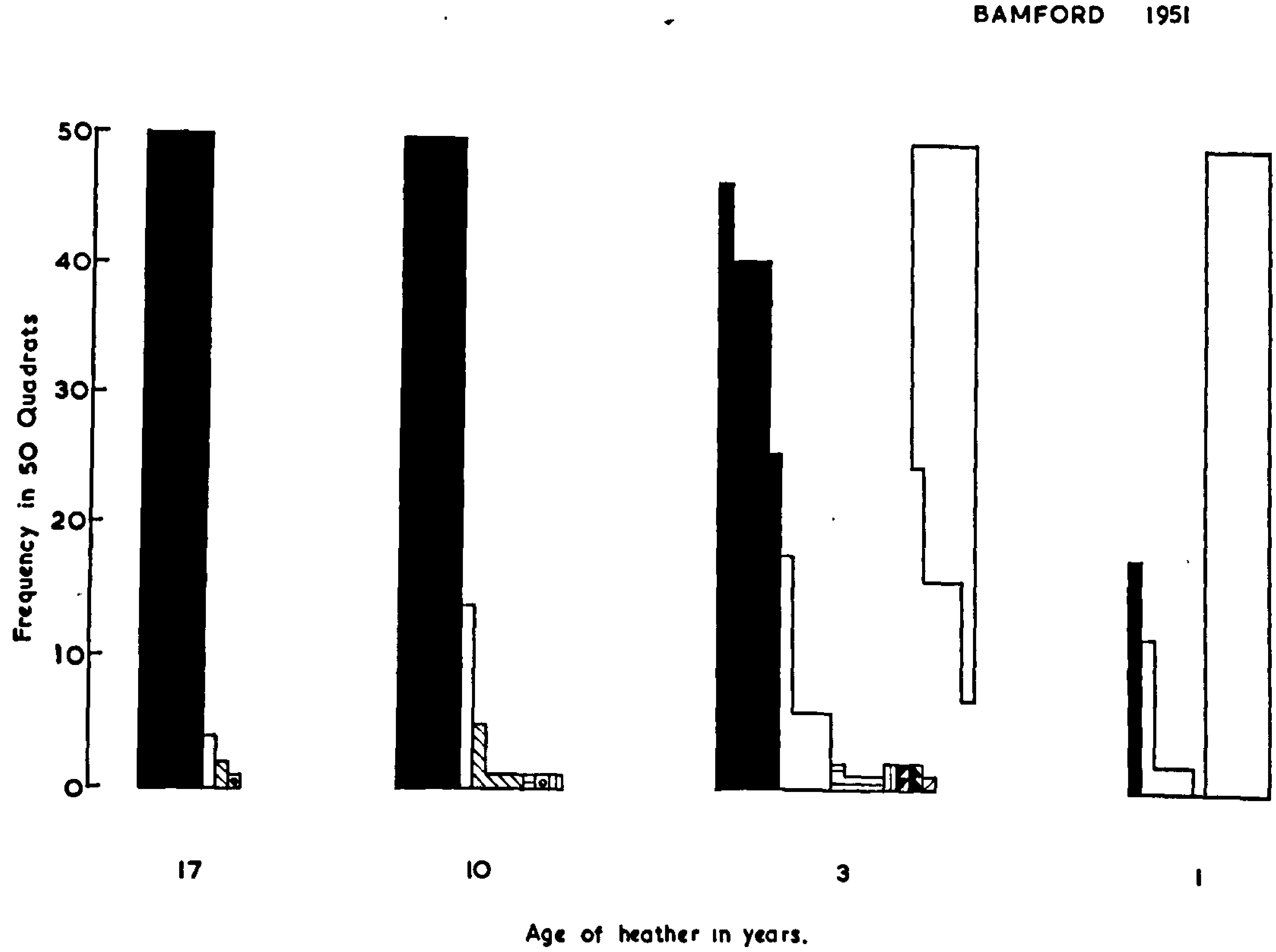
10% or less
10%-50% } Cover
50% or more

Fig. 7a.

A series of four heather stands of different ages. All have arisen as the result of regeneration by seeding.

Fig. 7b.

The same stands as shown in 7a after a further season's growth. The 1 year old stand has resulted from the burning of the oldest stand of 7a.


BAMFORD 1951
50
40
30
20
10
0
Frequency in 50 Quadrats
17
10
3
1
Age of heather in years.

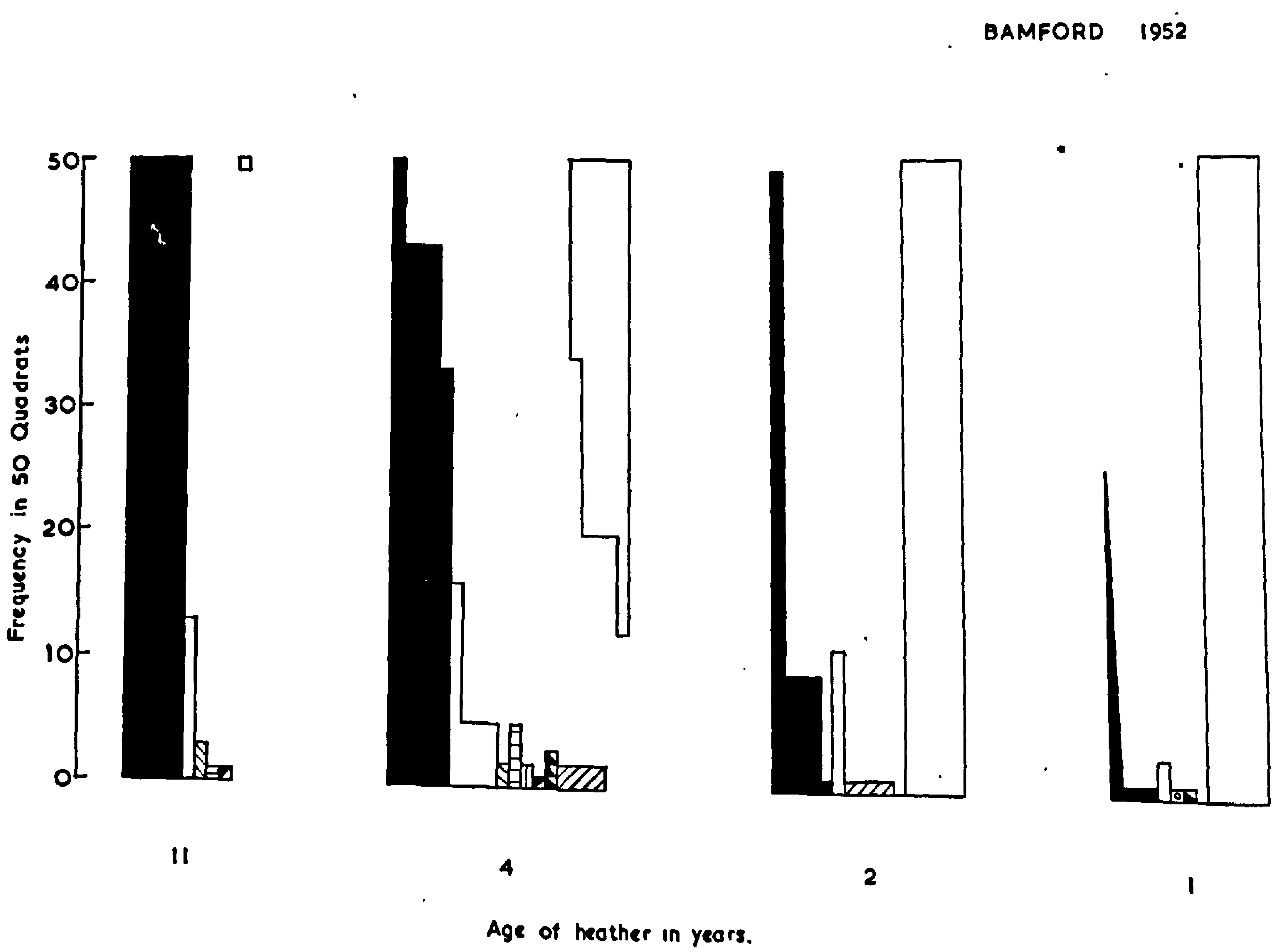

BAMFORD 1952
50
40
30
20
10
0
Frequency in 50 Quadrats
11
4
2
1
Age of heather in years.

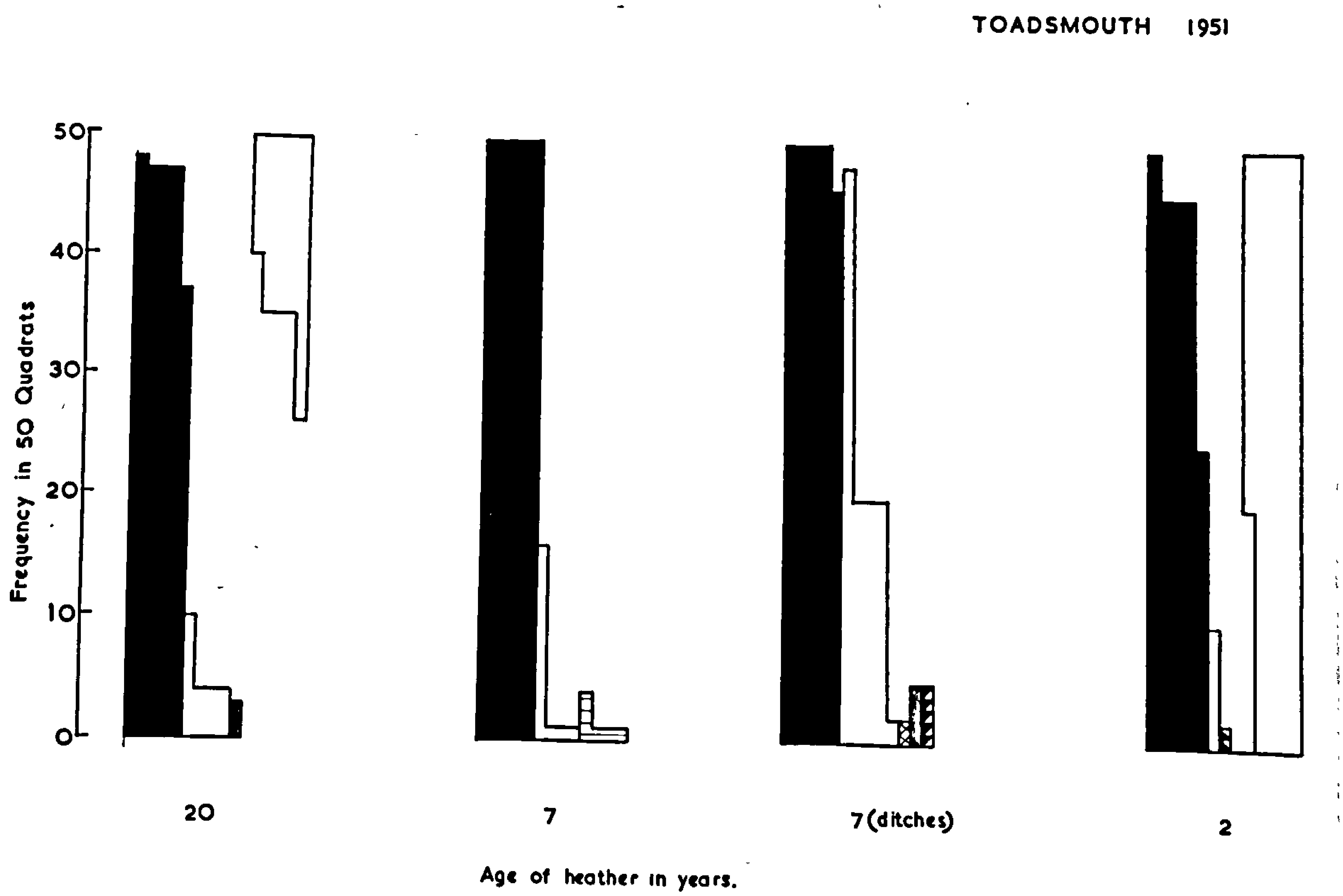
Fig. 8a.

The 7 and 2 years old stands have resulted from rootstock regeneration. The composition of the vegetation in the drainage channels of the 7 years old stand is shown in the histogram labelled 'ditches'.

Fig. 8b.

With the exception of the ditches, the composition of the stands of 8a are shown one year later. The structure of an additional stand (1 year) is shown. This regenerated by seeding.

The 3 years and 1 year old stands were burned at the same time, the difference in composition arising from differences in the rates of recovery when regeneration is by rootstock and seeding.


TOADSMOUTH 1951
Frequency in 50 Quadrats
50
40
30
20
10
0
20
7
7 (ditches)
2
Age of heather in years.

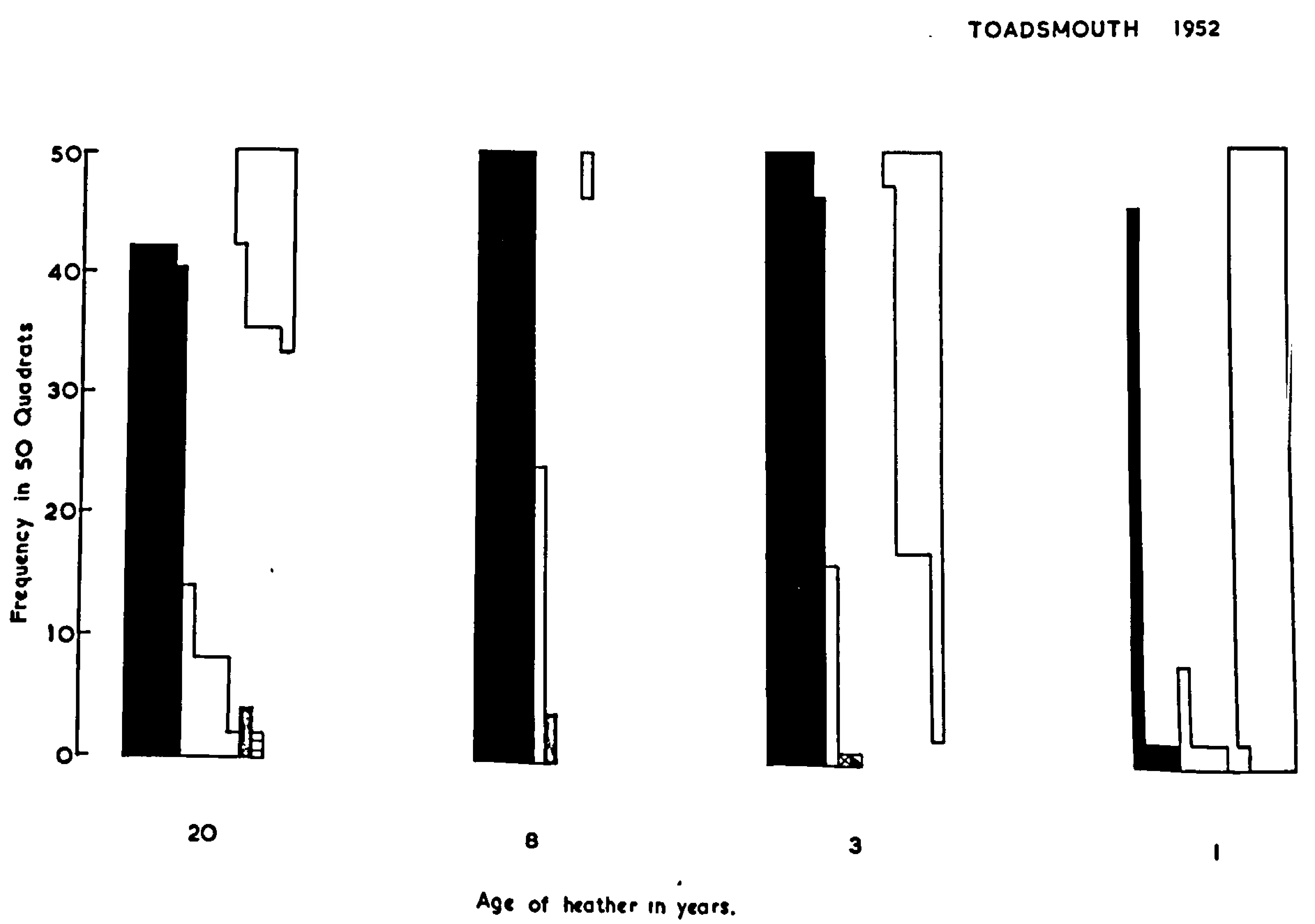
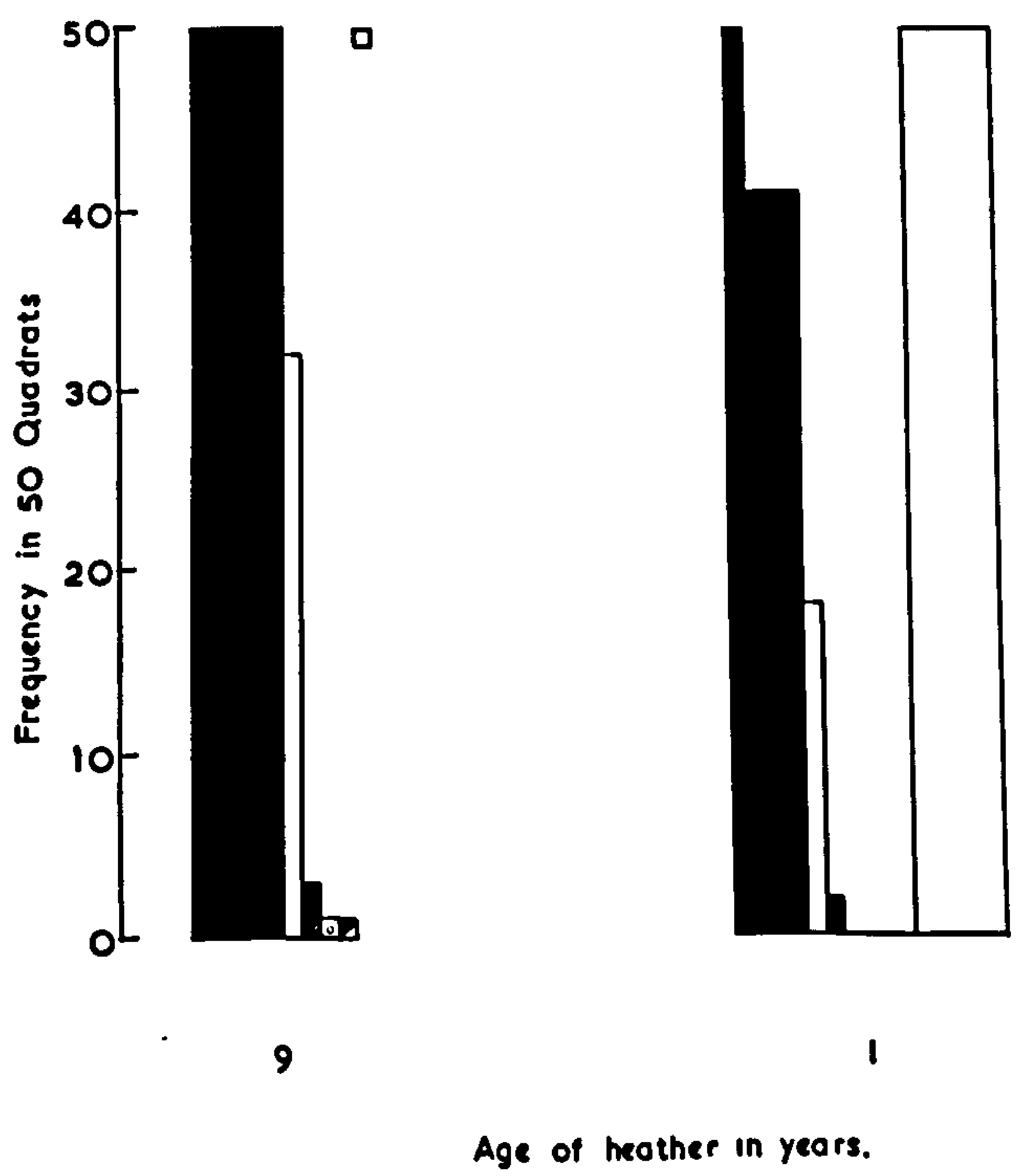

TOADSMOUTH 1952
Frequency in 50 Quadrats
50
40
30
20
10
0
20
8
3
1
Age of heather in years.

Fig. 9.

The 1 year old stand has been derived from the 9 years old. Both owe their origin to rootstock regeneration.

HALLAM. 1952



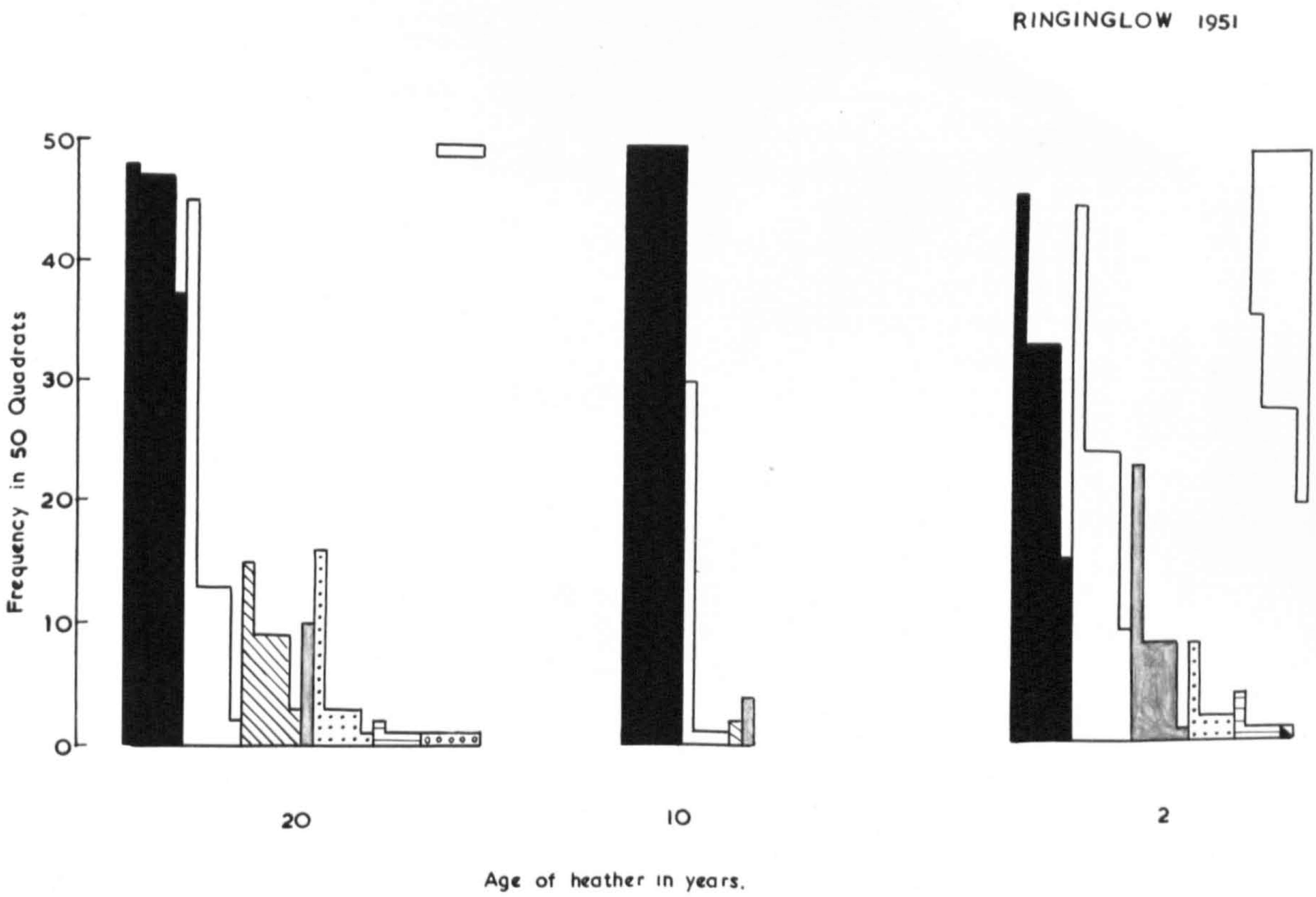
Frequency in 50 Quadrats
50
40
30
20
10
0
9
1
Age of heather in years.

Fig. 10a.

The 10 and 2 years old stands are both derived from the oldest stand. The former resulted from regeneration by rootstock and the latter by seeding.

Fig. 10b.

The stands shown in the previous figure one year later. In the oldest stand the proportion of the heather cover due to dead branches is indicated.


RINGINGLOW 1951
Frequency in 50 Quadrats
0
10
20
30
40
50
20
10
2
Age of heather in years.

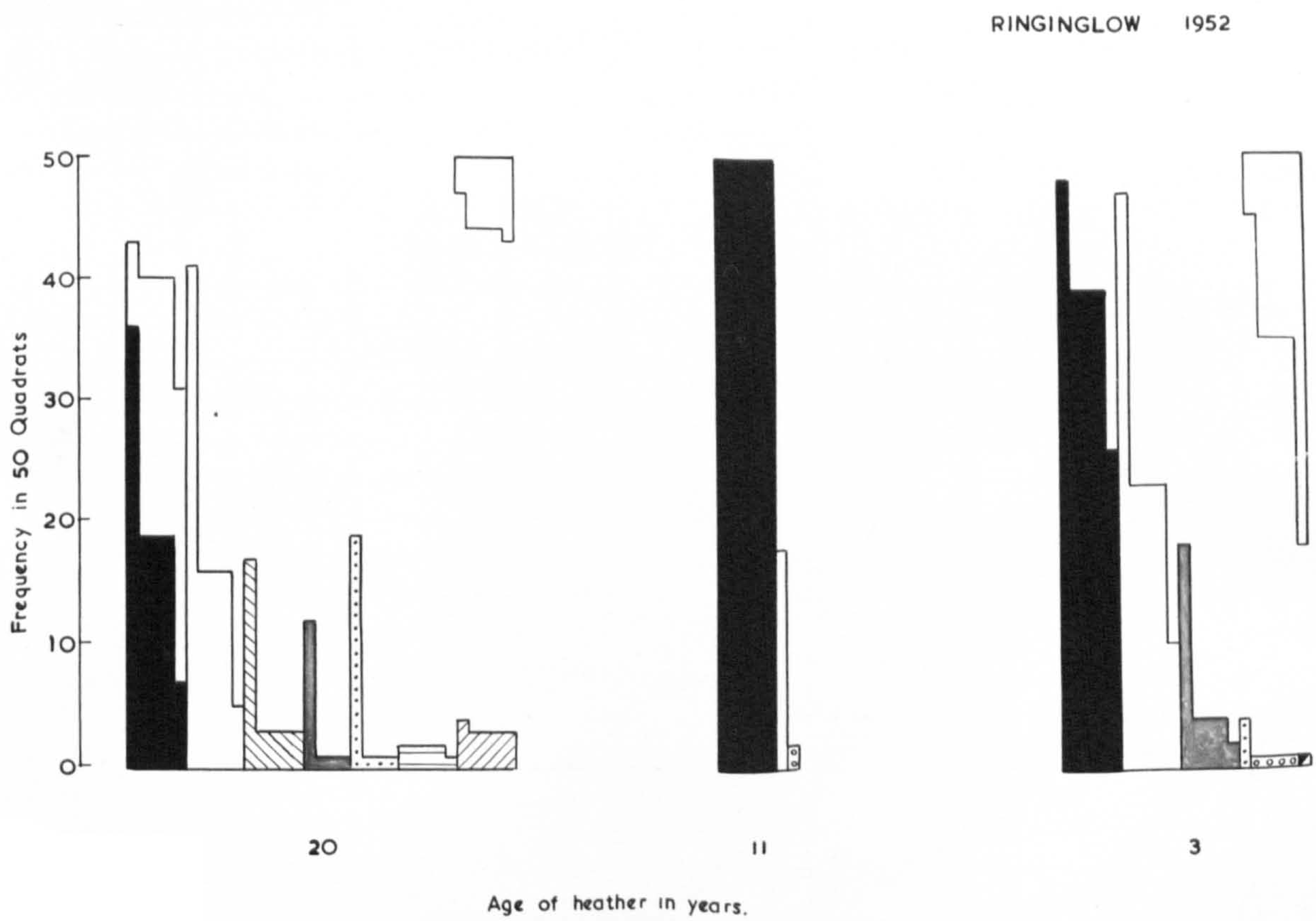

RINGINGLOW 1952
Frequency in 50 Quadrats
0
10
20
30
40
50
20
11
3
Age of heather in years.

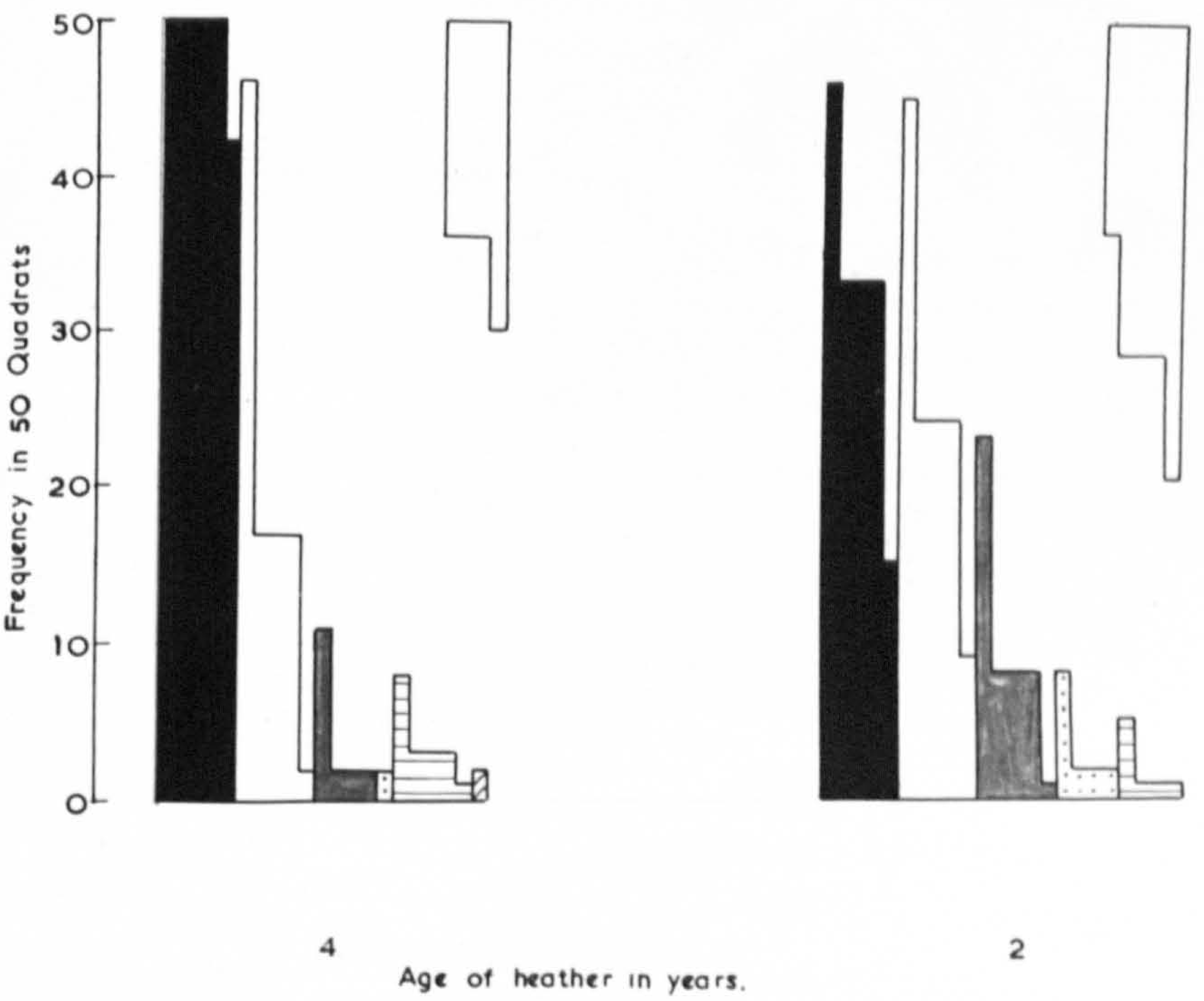
Fig. 10c.

Comparison of two stands burned at the same time. The 4 years old resulted from rootstock regeneration whilst the 2 years old regenerated by seeding. The 2 years old stand is the one shown in fig. 10a.

Fig. 10d.

The same stands as in 10c, one year later. The stand regenerating from rootstock shows almost complete cover.

RINGINGLOW 1951



RINGINGLOW 1952

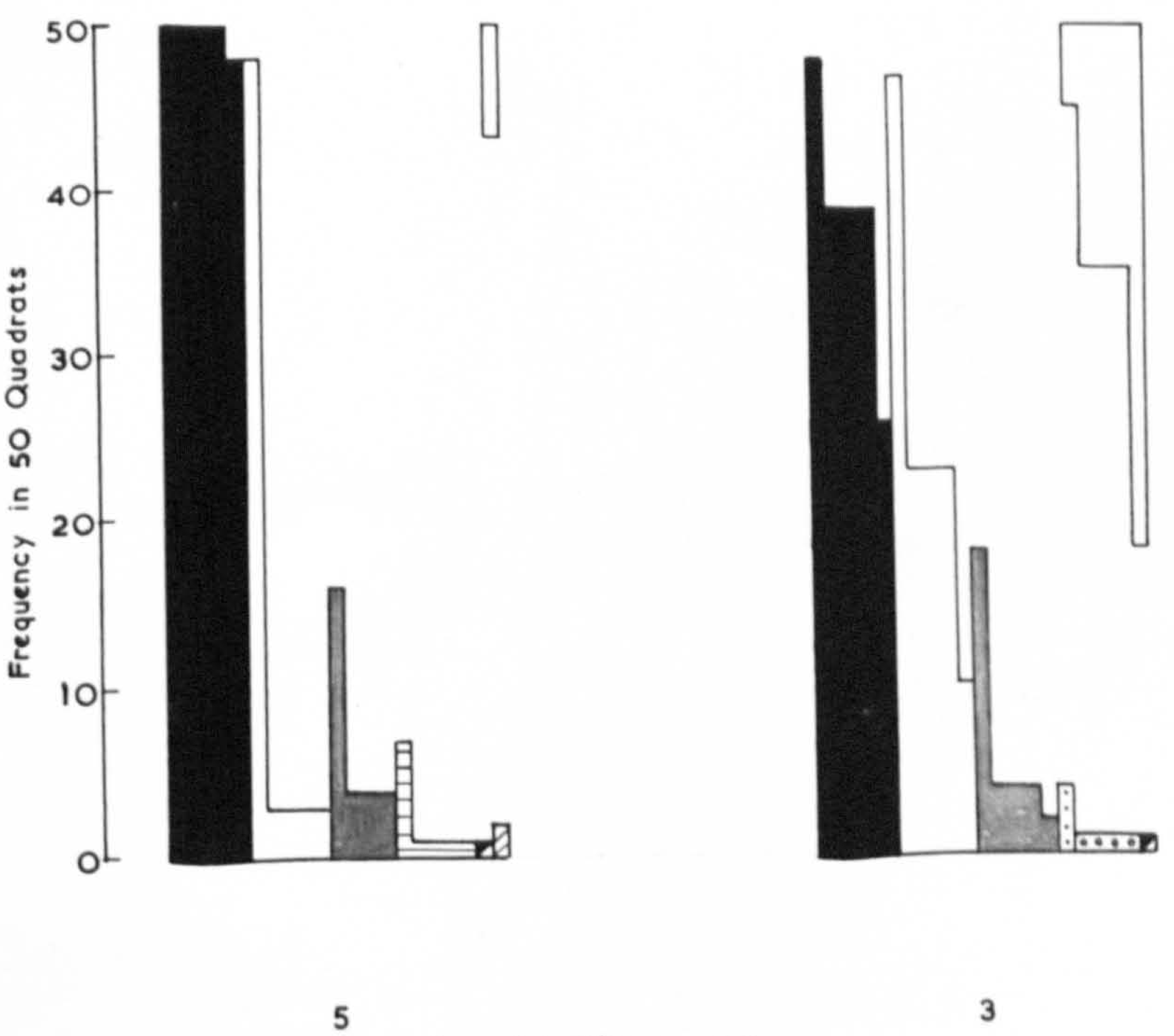
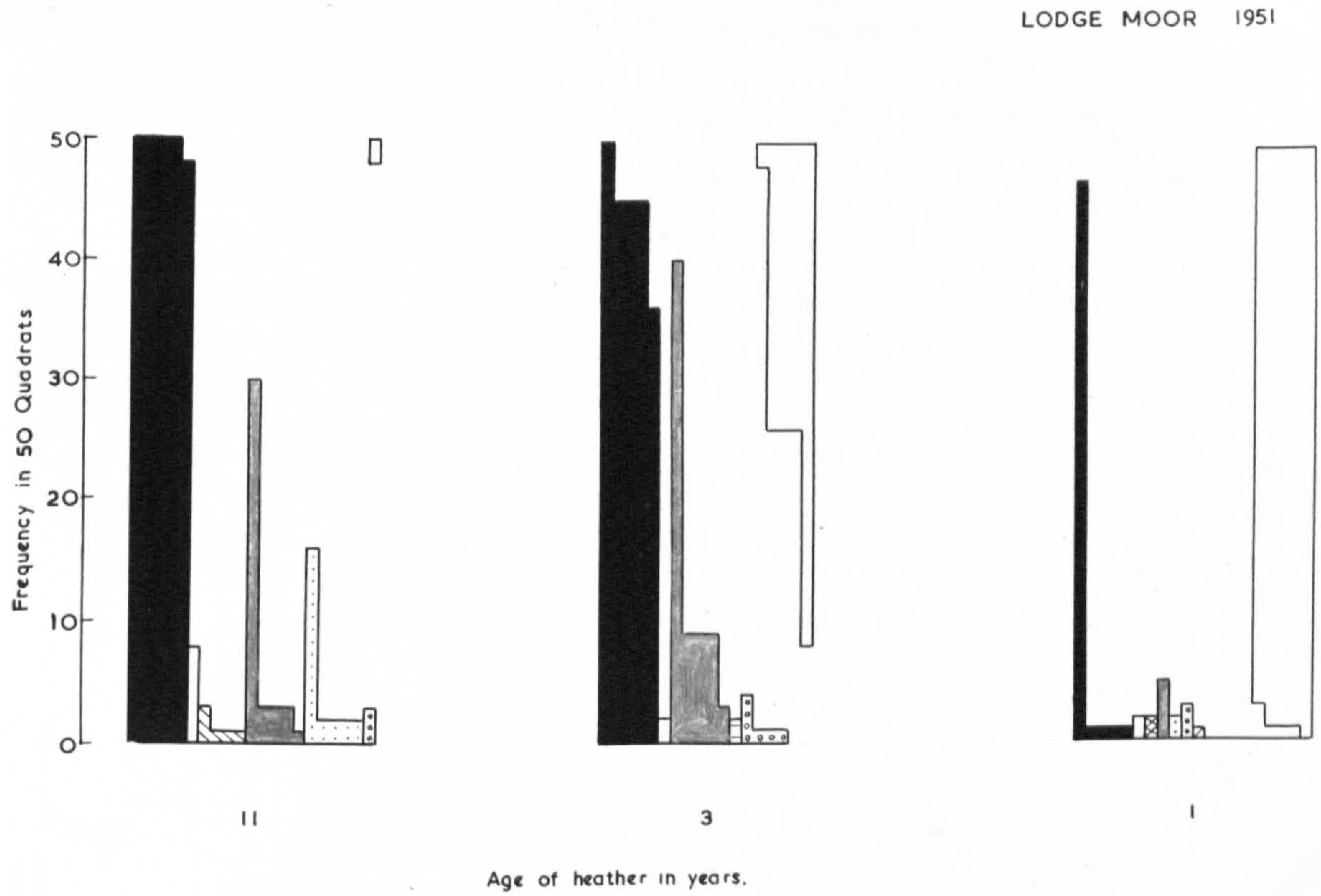


Fig. 11a.

The 3 years old stand is derived from the 11 years old as the result of rootstock regeneration. The 1 year old stand was derived from an old stand which was completely destroyed at burning. Although the 1 year old stand was burned at the same time as the 3 years old, regeneration is by seeding.

Fig. 11b.

The two younger stands only of 11a are shown after an interval of one year.


LODGE MOOR 1951
Frequency in 50 Quadrats
50
40
30
20
10
0
11
3
1
Age of heather in years.

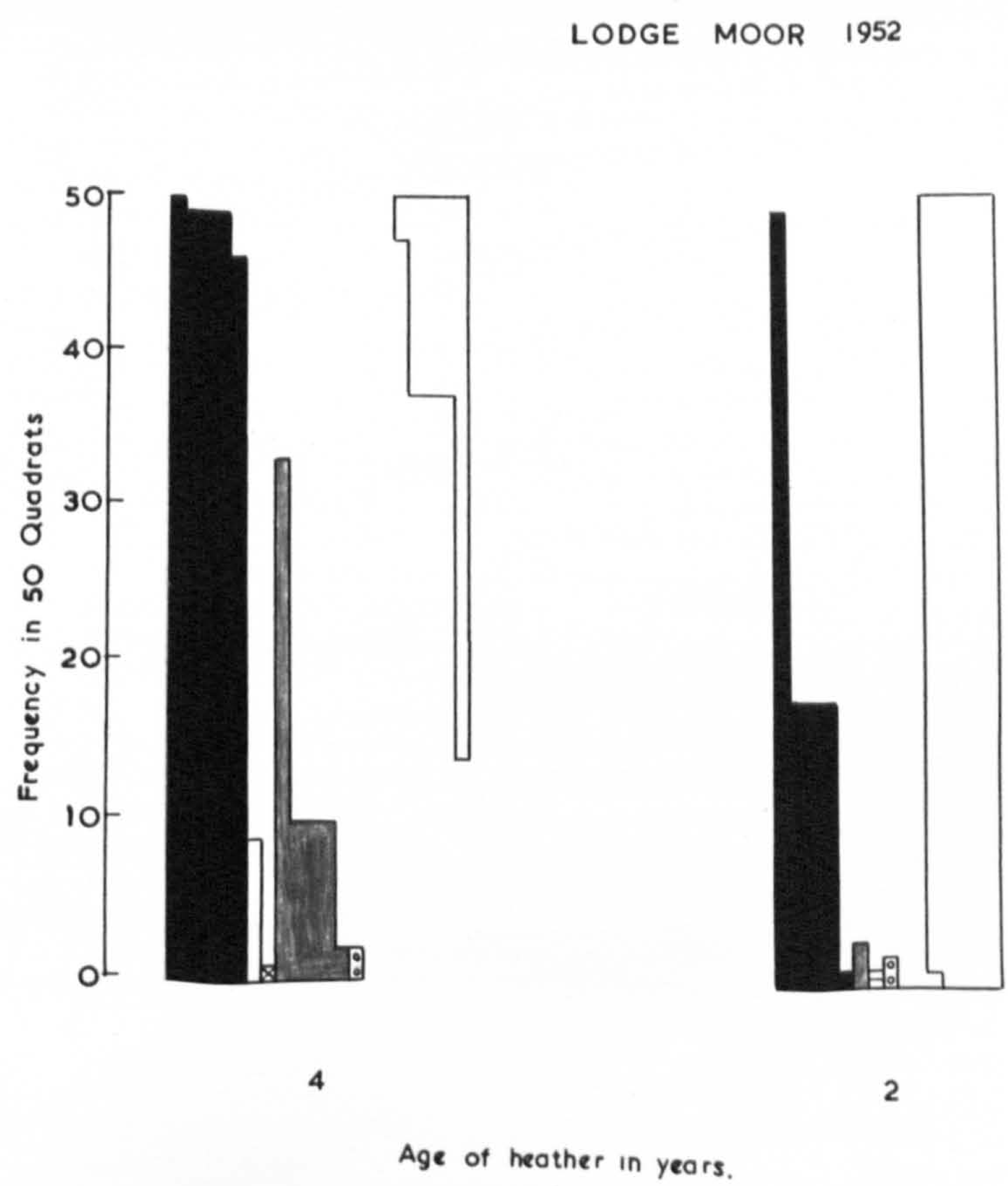

LODGE MOOR 1952
Frequency in 50 Quadrats
50
40
30
20
10
0
4
2
Age of heather in years.

Fig. 12.

The 1 year old stand is derived directly from the oldest stand; the 2 years old from a young stand which was previously derived from the 20 years old one. Regeneration in the 1 year and 2 years old stands is by seeding and rootstock respectively.

HOUNDKIRK HILL

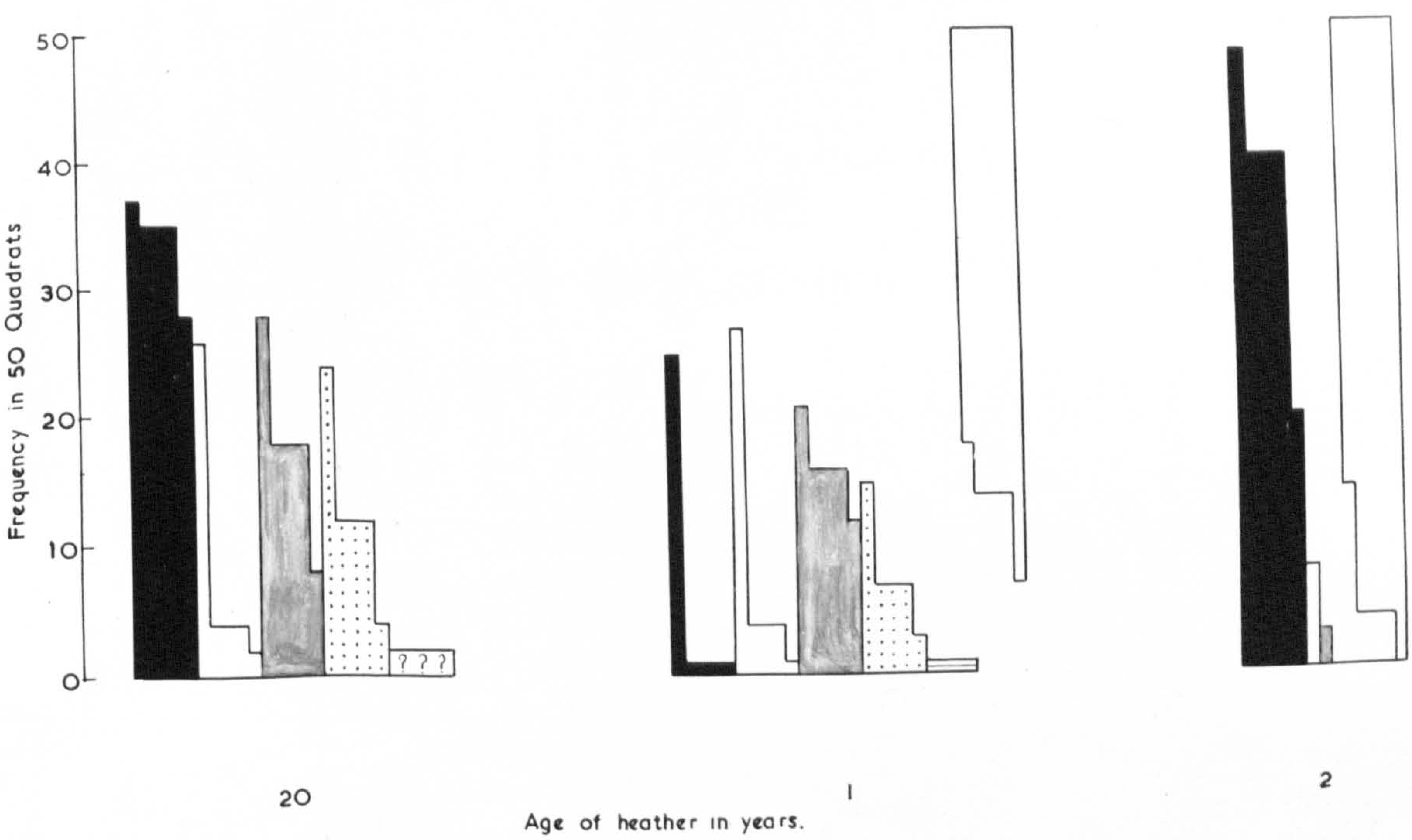
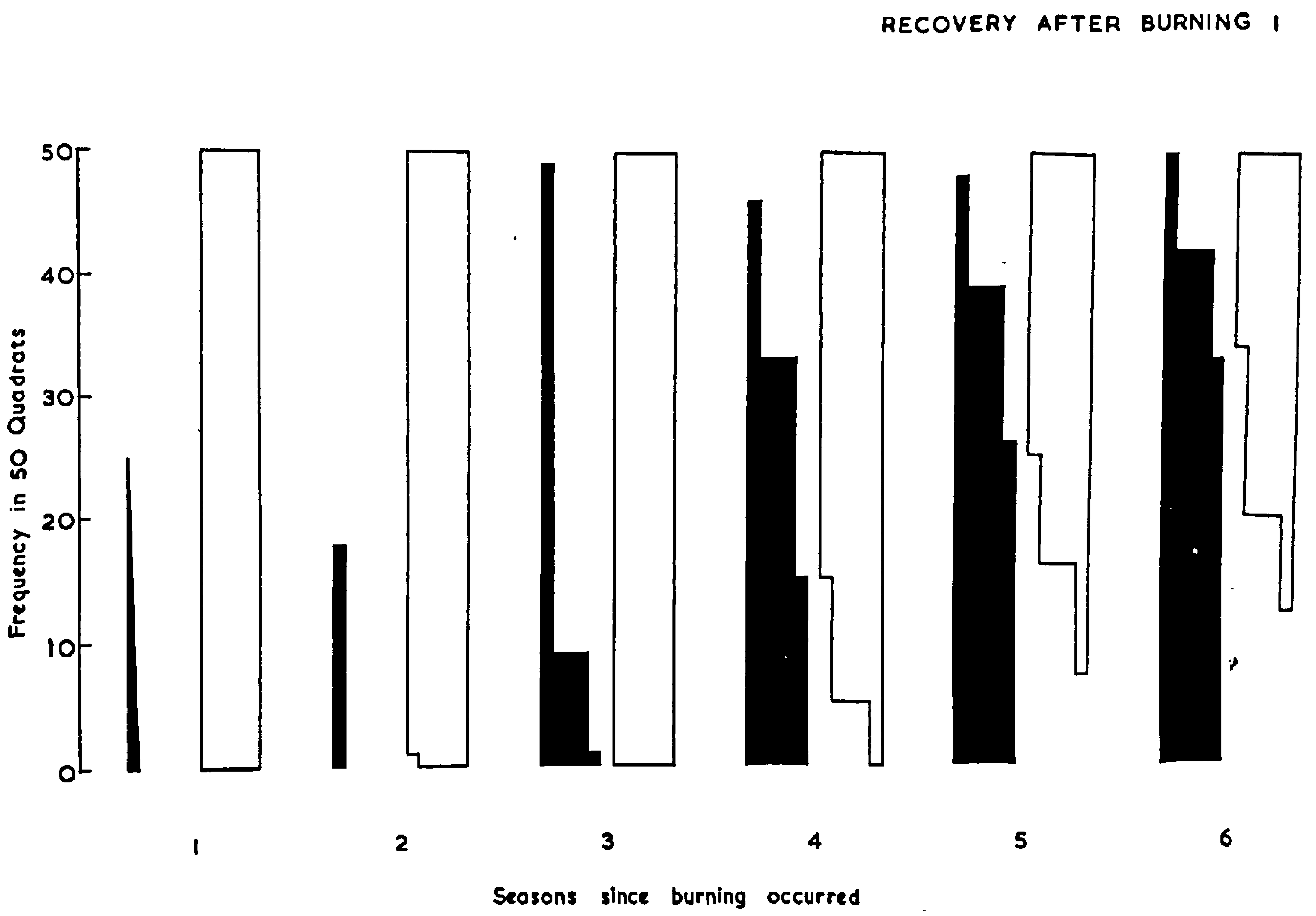


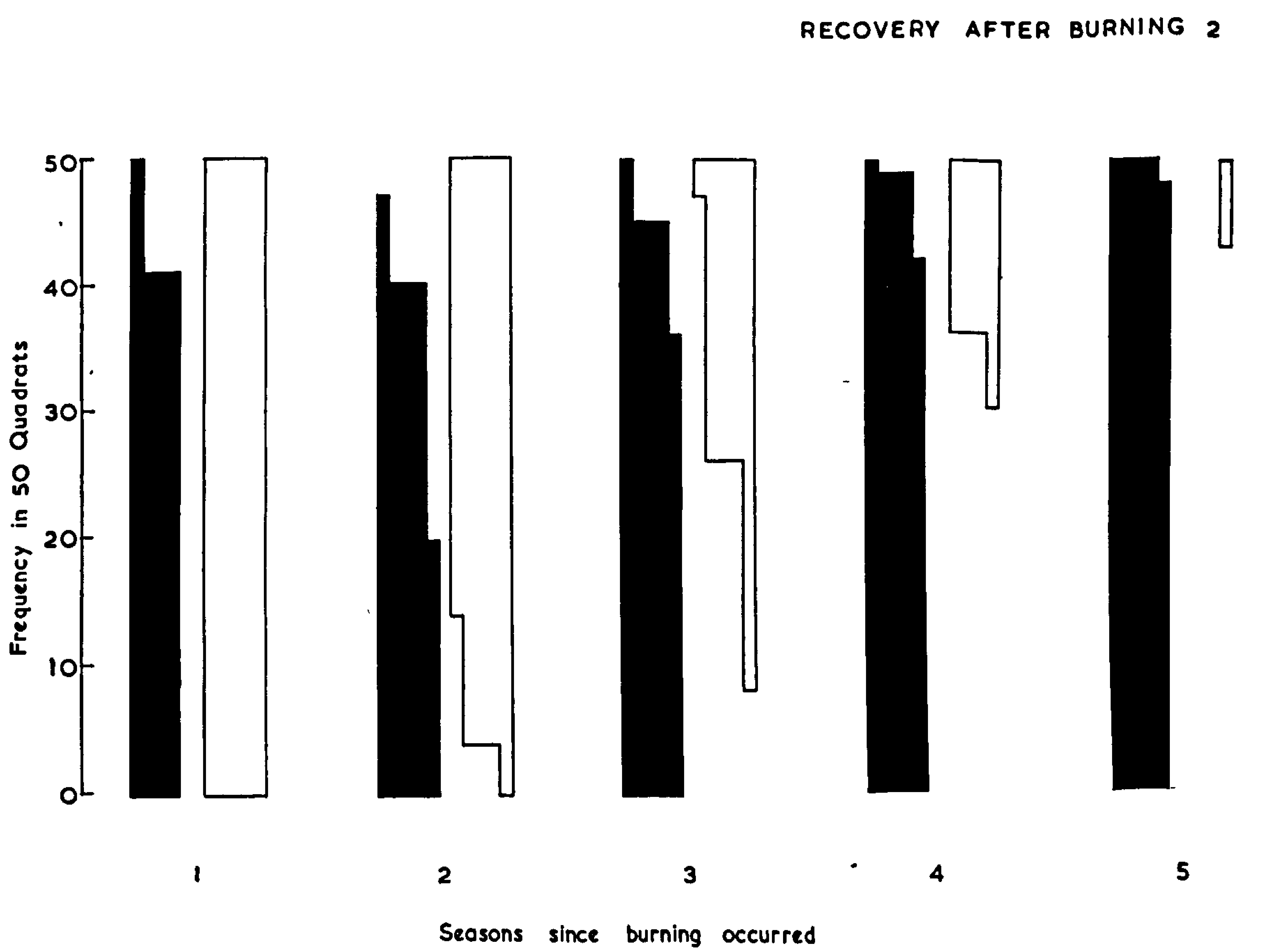
Fig. 13.

Showing the early stages of heather recovery after an old stand has been burned. Regeneration under these conditions is primarily by seeding. The figure has been reconstructed directly from figs. 7-12.

Fig. 14.

Showing the early stages of heather recovery after a young stand has been burned. Regeneration in these circumstances is primarily from rootstock. This figure is also synthesised from figs. 7-12.


RECOVERY AFTER BURNING 1
Frequency in 50 Quadrats
0
10
20
30
40
50
1
2
3
4
5
6
Seasons since burning occurred


RECOVERY AFTER BURNING 2
Frequency in 50 Quadrats
0
10
20
30
40
50
1
2
3
4
5
Seasons since burning occurred

such that it is essential to understand its influence on the vegetation during the cycle, before any progress can be made in the interpretation of over-all changes in vegetative composition after burning.

Lovat 49, Wallace 89, Smith 72 and others, have described the different rates of heather recovery in relation to the youth and vigour of the heather burned. This is illustrated in figs. 13 and 14 which have been constructed according to the origin of the individual stands to compare the effects of burning under long- and short-cycles respectively. The histograms have been taken directly from figs. 7-12 and the individual stages in each series may not therefore combine to form a perfect sequence, since adjacent histograms may represent stands from different moors with different environmental conditions. The two series are only intended to illustrate the general trend of heather recovery under different burning regimes.

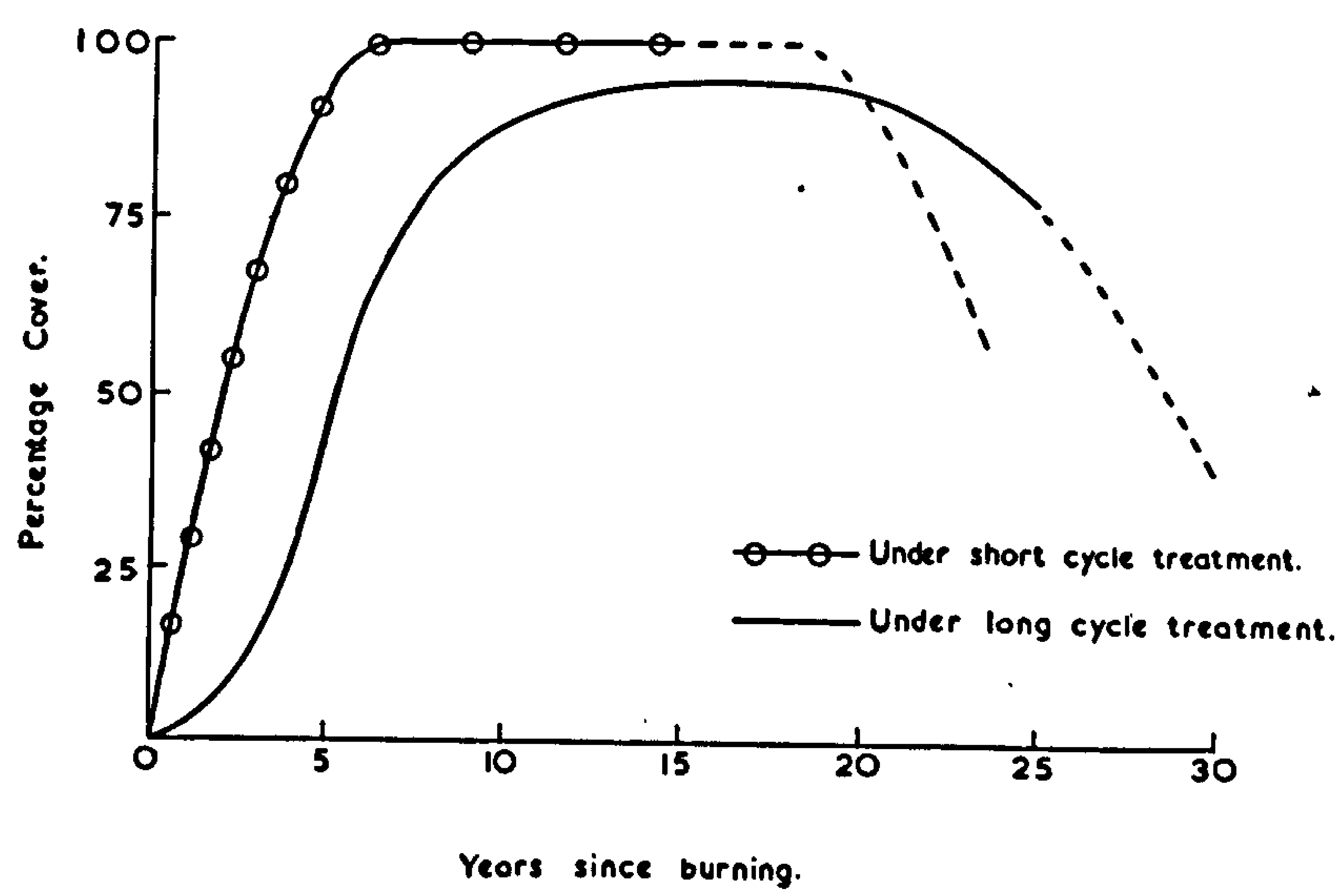
When young heather is burned (fig. 14) complete cover is achieved at about 5 seasons after burning (negligible amounts of bare ground). Even by the third season after burning, the heather cover is comparable with that of a stand arising from long-cycle treatment at 6 seasons after burning. (fig. 13). When old heather is burned it is not until about three seasons later that 100% frequency is attained by heather whilst even after 6 seasons one third of the quadrats have bare ground occupying 50% or more of their area. It seems that a closed community is not achieved under long-cycle treatment until about 10 years after burning (fig. 7, 10 years).

Once the community is closed, it is certain that the associates of heather will become progressively weakened and even eliminated from the vegetation unless they are shade-tolerant or able to exploit different soil horizons to those of the heather. As a result the heather cover will continue to increase, even after complete cover has become established, until it reaches a maximum value. This condition will persist for a time until at approximately 20 - 25 years after burning. individual plants in the stand begin to die out and the heather cover declines. (figs. 10 and 12, 20 years stands.) This cycle is not however, always completed, since the aim in systematic management is to burn the heather before the cover begins to decline. (fig. 7, 17 years). However, if burning should be delayed on a systematically managed moor for any reason, the heather cover will disintegrate in the same way as in old stands under non-systematic management (fig. 8, 20 years).

Since the sequence of recovery, particularly the period required to attain maximum heather cover, can be modified by burning the heather before it is 15 years old, (p. 49 and above) it is obvious that this factor must be taken into

Diag. 1.

Illustrating the inferred changes in average percentage cover of Calluna during a single burning cycle.



Comparison is made of the changes in heather cover under extremes of treatment, i.e. systematic burning in short cycles and irregular burning in long cycles. Fundamentally the curves reflect the influence of sustained short-cycle treatment (with regeneration from rootstock) and long-cycle treatment (with regeneration by seeding).

An intermediate treatment is seen at Bamford where burning, although systematic, is in long cycles of 20 years and regeneration is primarily by seeding. The heather cover follows the long cycle pattern above but approaches nearer to 100% at maximum heather cover. (see diag. 4).

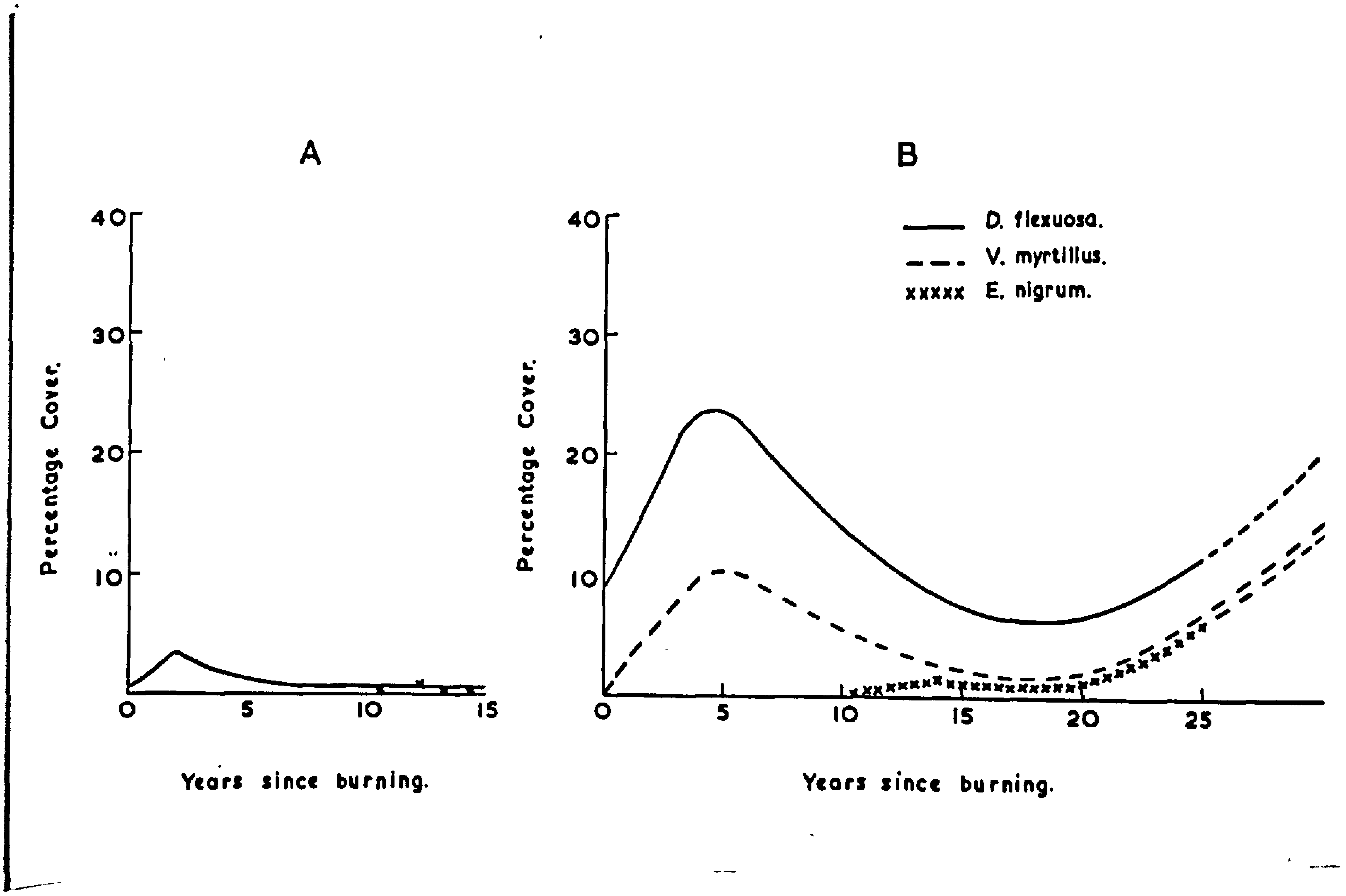
consideration when investigating changes in vegetative composition. The difference in the intra-cyclic sequences of heather cover arising from short- and long-cyclic treatment (i.e. burning before and after the heather is 15 years old) is summarised in diagram 1.

When the part played by the associates of Calluna during the cycle are considered, it is clear that this will be related not only to the stage in the previous cycle at which the heather was burned but also to the frequency with which the moor has been burned in the past (tables 7 and 8).

Unfortunately, only the Bamford data provide material for reconstructing more or less directly the intra-cyclic changes in vegetative composition, since it is the only series uncomplicated by 'overburning'. It is clear from figs. 7a and 7b that the burn subsere is dominated by the intra-cyclic recovery of heather to an exceptional degree. Of the associates only <u>Deschampsia flexuosa</u> plays a part. It has already been noted that <u>D. flexuosa</u> exhibits little change in cover as the direct result of burning (p. 55). However, it increases in cover and frequency in the early part of the cycle at least up to 6 years after burning, but at approximately 10 years it has begun to lose ground, presumably continuing to do so until the end of the cycle. On this type of systematically burned moor under cycles of 15 - 20 years it seems clear that the subsere is characterised by a grassy phase at the beginning

Diag. 2.

Illustrating the inferred changes in average percentage cover of the main associates of Calluna during a single burning cycle under A. short-cycle treatment and B. long-cycle treatment.



Comparison is made of the status of the main associates of heather under the extremes of treatment mentioned in the legend for diag. 1.

considered as the extremities of the burn sub-sere under long-cycle treatment. In the absence of other stands at Ringinglow resulting from the burning of old heather, the 11 years old stand at Lodge Moor (fig. 11) can be used to represent approximately a stage intermediate between the two Ringinglow ones, since it also was derived from an old heather stand on an irregularly burned moor. (The Lodge Moor stand must be only used as an estimate of the composition of a similarly aged stand at Ringinglow since there is no guarantee that the past treatment of the two moors has been identical or that present environmental factors are the same). It seems however reasonable to deduce that the associated species are sufficiently well represented at the beginning of the cycle to survive the period of maximum heather cover and thereby be in a favourable position to extend their cover when that of the heather begins to disintegrate. This would in turn ensure a good representation of associates after burning in the next cycle (p. 57). Provided that the next cycle was long, little fundamental change would be expected in vegetative composition. Schema- diagram 2B depicts the change in cover of the major associates of Calluna during a single burning cycle on moors that have been maintained on long-cycle treatment. The corresponding heather cover is illustrated in diagram 1 (long cycle).

It is therefore possible, by comparing diagrams 4 and 2B, to examine the changes in cover of the main associates of heather on systematically and irregularly burned moors when both are under long-cycle treatment (i.e. cycles of more than about 15 years). In both cases heather recovery after burning is slow since this is primarily dependent on seedling regeneration and the differences in the representation of species is largely the result of the long-term effect of repeatedly curtailing the heather cycle at about 20 years on the systematically managed moor.

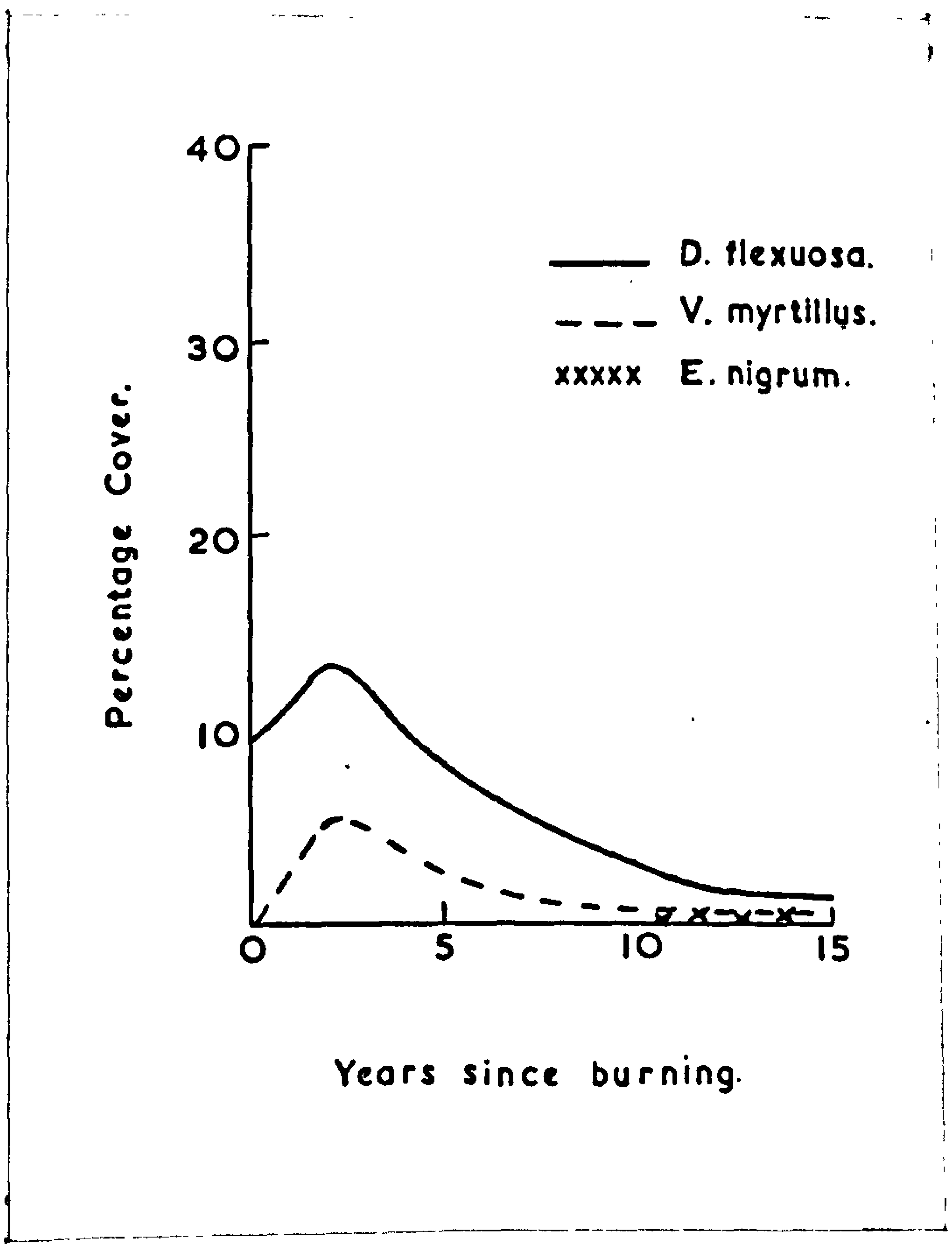
Systematic burning in cycles of more than 15 years means that the recovery of heather is dependent primarily on seedlings and therefore follows the pattern illustrated in diagram 1 (long cycle). However, when this type of burning is in short cycles (i.e. less than 15 years) the accelerated recovery of heather (diagram 1 short cycles) can be expected to reduce the *Deschampsia* phase of the systematically burned moor to even more insignificant proportions than that shown in diagram 4 and an estimate of this based on data taken from Toadsmouth moor is provided in diagram 2A.

The contrast, is shown in schematic diagram 2, of the changes in cover during a single burning cycle of the major associates of Calluna under (A) short cycle and (B) long cycle treatment.

The relationship between the Ringinglow stands of 4 - 5 years and 10 - 11 years (fig. 10) is worth considering. These stands both owe their origin to regeneration by root-

Diag. 3.

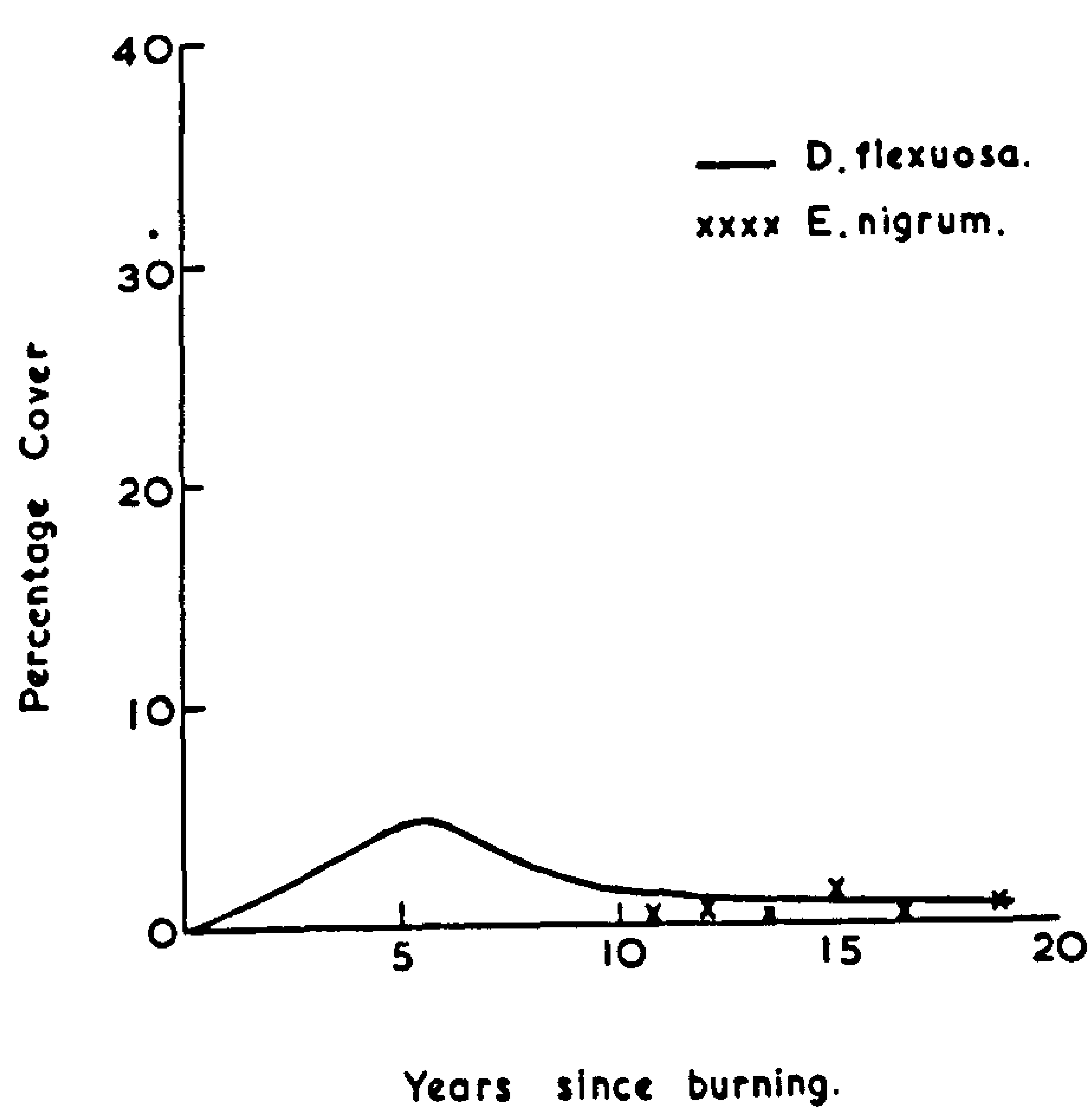
Illustrating the inferred changes in the average percentage cover of the main associates of heather during the first burning cycle when a moor which has been burned in long cycles is placed under short-cycle treatment.



This represents the first stage in the transition B.- A. (diag. 2)

Diag. 4.

Illustrating the inferred changes in the average percentage cover of the main associates of heather during a single burning cycle on a systematically burned moor under long-cycle treatment.



Comparison of the status of the associates with that shown in diag. 2A represents in the main the influence of the continued regeneration of heather by seeding and rootstock respectively. Comparison with diag. 2B primarily represents the long-term effect of systematic burning.

stock after the burning of the young stands of a moor under long-cycle treatment. (p. 61). A stand of similar origin is the 2 years old one at Houndkirk Hill. (fig. 12). Chronologically arranged this series can therefore be considered to illustrate the first cycle in the transfer of an irregularly burned moor to short-cycle burning. Quite clearly, a considerable change in the representation of the associates has occurred. V. vitis-idaea is not represented, and V. myrtillus and D. flexuosa are less conspicuous than under long-cycle burning. A remarkable suppression of associates at maximum heather cover is indicated. (fig. 10., 10 - 11 years). The changes in cover of the major associates of Calluna during the first cycle of this transfer are shown in diagram 3.

If the institution of short-cycle treatment can produce this kind of change in the vegetation so rapidly it must be assumed that not many short-cycle burnings separate the apparently distinctive systematic and irregularly burned moors.

In general therefore it may be said that those associates not fatally damaged by burning can be expected to exhibit a phase of expansion of cover in the early part of the cycle until this is curtailed by the more slowly recovering heather. Once continuous cover is established, the associates and heather come into direct competition and there seems little doubt that the balance is heavily weighted in favour of heather supremacy. Consequently the associates suffer a reverse, although on the irregularly burned moors in view of their better representation than on the systematically burned moors, they are not so completely suppressed. If the moor is not systematically managed, the heather cover will deteriorate and the associates be afforded an opportunity to recover lost ground to some extent at the end of the cycle. As moors do not appear to be left unburned for more than about 30 years, the expansion of the associates can not continue indefinitely before burning initiates another cycle of heather dominated vegetation. If the moor is systematically managed, the continuity of this treatment will have reduced the representation of the associated species and their influence during the cycle will be limited to an insignificant temporary increase in cover immediately after burning, before the heather reasserts itself.

The intra-cyclic changes in the composition of the vegetation on South Pennine moors are probably best summarised by the scheme described by Adamson (1), viz.

Phase 1. D. flexuosa (+, or replaced by N. stricta).

" 2. V. myrtillus becoming mixed with V. vitis-idaea.

" 3. E. nigrum (with young Calluna) - Calluna dominant.

In the case of the irregularly burned moors, this sequence is essentially true. (N.B. That Nardus does not appear to replace Deschampsia except where redistributed peat occurs - Smith 73). Where the moors have been systematically managed for a considerable time Phase 2 is eliminated and the intra-cyclic sequence passes directly from Phase 1 to 3. If an irregularly burned moor is placed under short-cycle burning, Phase 2 will show signs of suppression.

Effects on the soil.

Soil base status.

For reasons already discussed, (p. 28) initial investigations on soil base status were confined to the amorphous peat horizon (Ao).

The results of analysis employing the Brown rapid method of exchangeable hydrogen and base determination are shown in table 10. The soils of the systematically burned moors, Bamford and Toadsmouth, show a definite decline in % base-saturation with increasing age of the heather stand. An essentially similar trend, although less pronounced, occurs in the soils of the remaining irregularly burned moors, although in the oldest stand in each case, there appears to be an increase in % base-saturation.

Values are also given in table 10 for exchangeable hydrogen and base per unit weight fresh and dry soils respectively. It is felt however, that the only comparisons of value that can be made are between fresh soil results. Clearly, although the peat:water ratio varies in the soils of different areas (table 14), since upwards of 60% by weight of these soils is water and of the residue 60% or more is organic material, equal weights of fresh soil must represent more accurately than do dry weights, equal volumes of soil in situ. Moreover, the particular soil:water ratio at sampling must be dependent on factors characteristic for the particular soil at that particular time. Base status values founded on comparisons of unit weights of fresh soil must therefore be a better measure of conditions in the 'living' soil, than those founded on the purely artificial comparisons of equal dry weights.

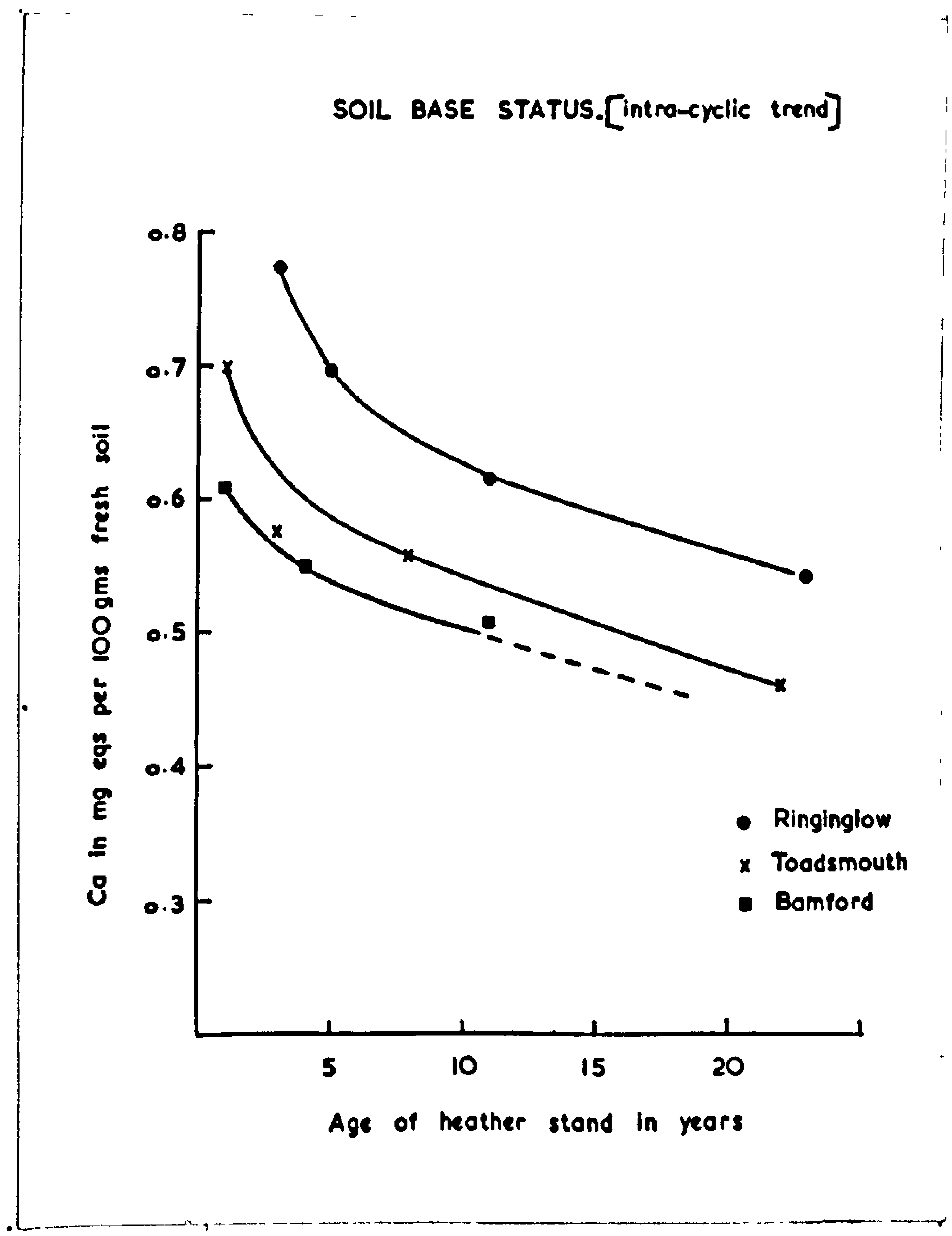
When the values for exchangeable base per unit weight of fresh soil are inspected, it is clear that these also decrease throughout the cycle. The apparent increase in % base saturation in the soils of the oldest stands of the irregularly burned moors is therefore dependent on a relative decrease in the amount of exchangeable hydrogen rather than a real increase in the fertility.

It is not proposed to inspect total base values further than this as it should be remembered that cations other than those regarded as mineral nutrients are included in the 'base' values. It is not impossible that the observed differences are due to intra-cyclic changes in the amounts of these non-nutritional cations rather than of the 'true' bases.

It was therefore desirable to obtain results which reflected the status of exchangeable nutrients as such. This was assayed by determining exchangeable calcium and potassium in the soils and using these cations as representative of the 'true' base status. The two elements were determined according

Fig. 15.

The intra-cyclic trend of exchangeable calcium per unit weight of fresh soil.



to the method described on page 34, and the results are presented in table 13. Although estimations are shown for several horizons, it is felt that little confidence can be placed in those relating to the B and C horizons, since in these the inter-area differences in base were so small as to be almost indetectable. The values are however shown as they indicate the level of base saturation.

The trends of % base saturation and of calcium and potassium per unit weight of fresh soil, are clearly similar to those detected by the Brown method. This general trend applies not only to the Ao but also to the A2 horizon. The intra-cyclic trend of exchangeable calcium per unit weight of fresh soil (Ao) is illustrated in fig. 15. Detailed consideration of this will be deferred until later.

To sum up, the balance of evidence suggests that fertility in the surface soil progressively declines throughout the cycle, whether this is measured in terms of % base saturation or absolute values of exchangeable base. This conclusion is further substantiated by considering the results of leaf analysis.

It will be recalled that these analyses express the calcium status of the green material per unit area of continuous heather cover (p 37). For three moors the calcium content per unit weight of green material is shown in table 16, and the dry weights of green material per unit area in table 17

Fig. 16.

Distribution of the dry weights of green material from unit areas of continuous heather of different age.

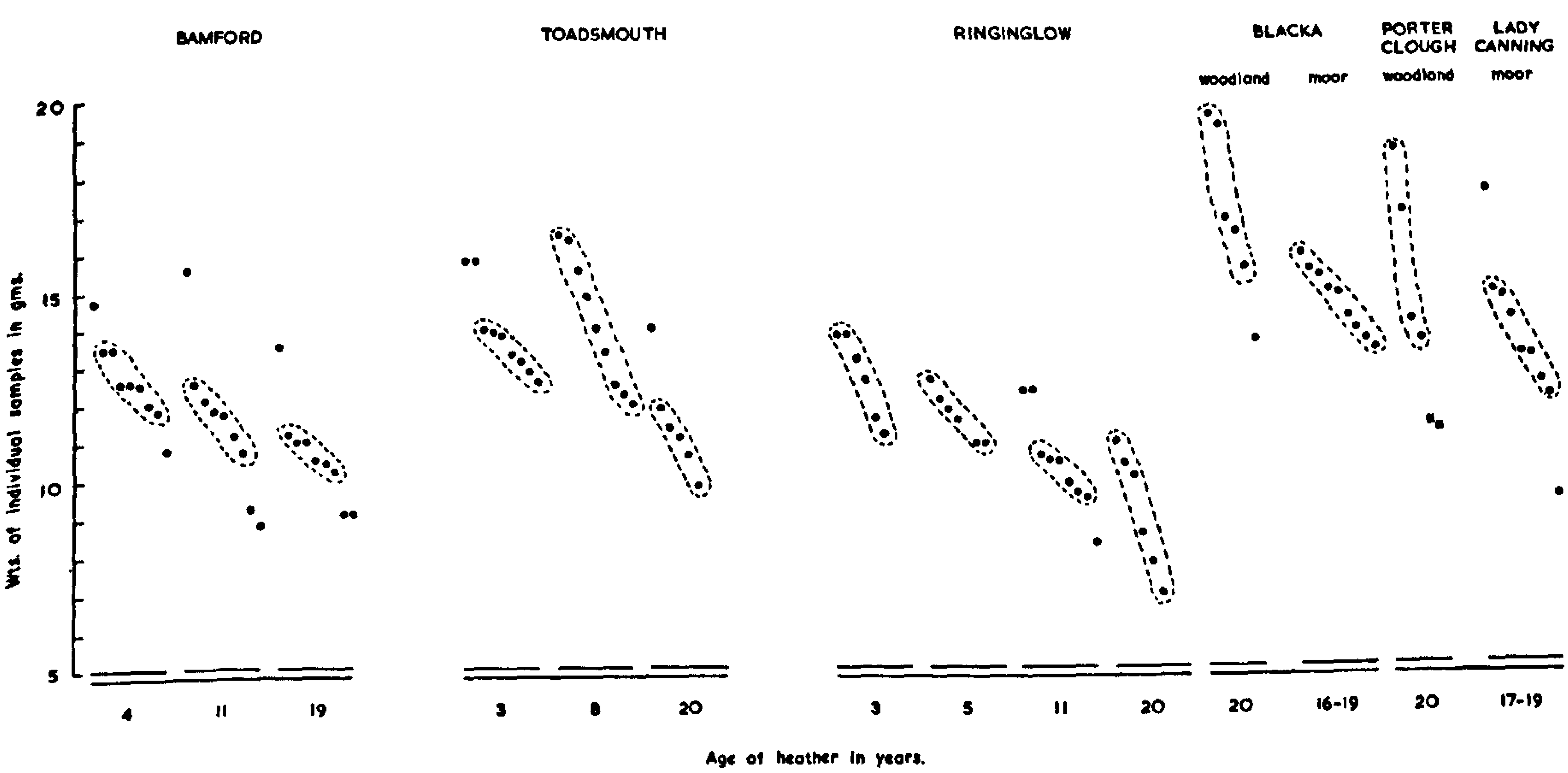
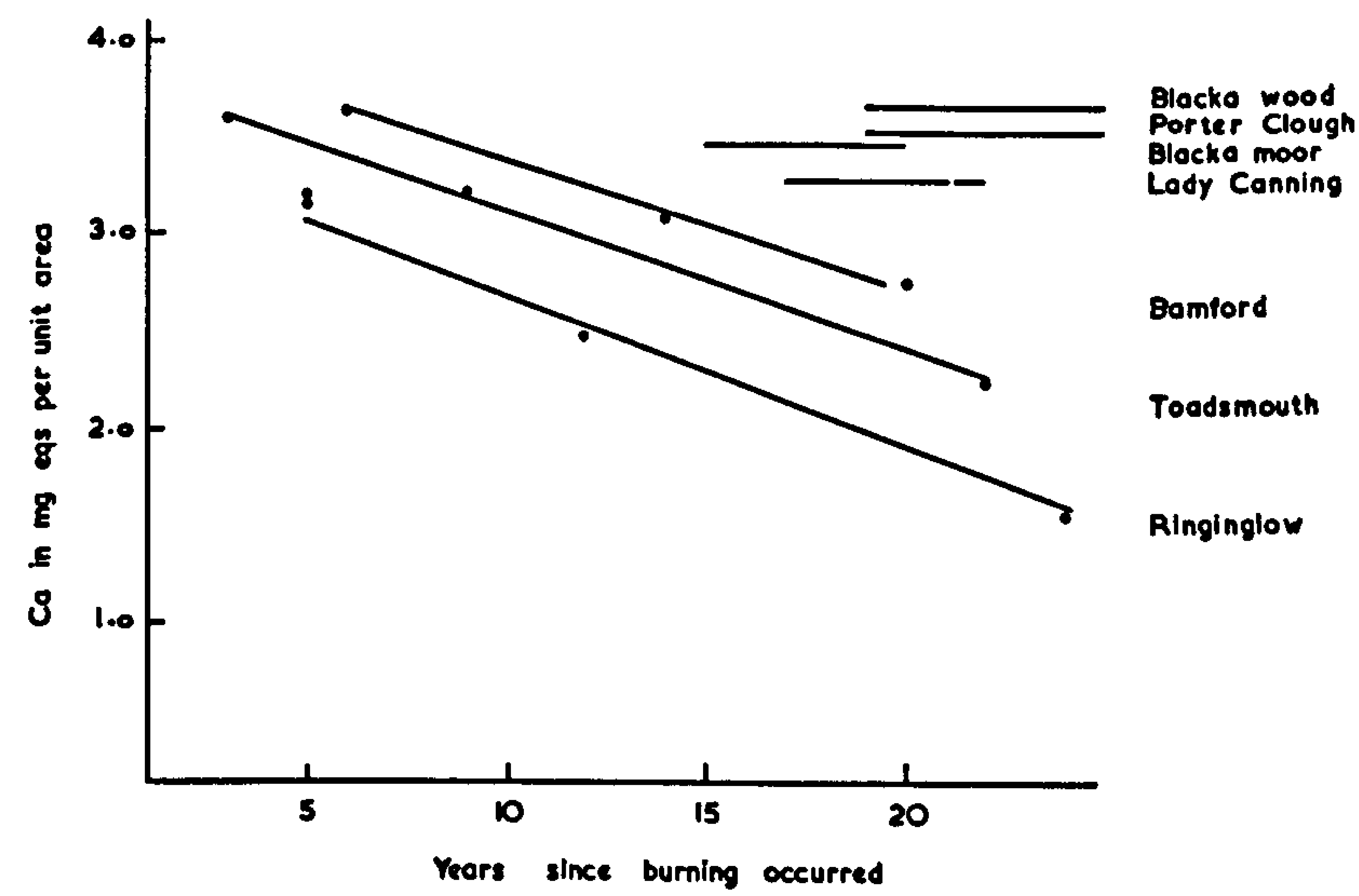


Fig. 17.

Calcium content of the green material from unit areas of continuous heather cover in relation to the time since the heather was burned.



(in the case of Blacka wood and Porter Clough, the calcium content is related to the age of the heather.)

and fig. 16. Table 17 expresses the summarised data as calcium per unit area of vegetation for the individual moors, whilst fig. 17 depicts this in graph form. It is clear that the accumulation of calcium in the vegetation of unit areas, falls off steadily with increasing age in all 3 series. (The same general trend is true of the quality of the green material (tables 15 (total base) and 16 (calcium)) so that this is not purely a function of decreasing crop weight as the distribution of dry weights might suggest (fig. 16). It is therefore difficult not to accept the explanation that this decline is due to progressively smaller quantities of base being available in the soil as the cycle proceeds, particularly as a parallel decline occurs in the soil base-status.

It is realised that the decline in base content of the green material could be related to the ageing of the plant and a general falling-off in physiological vigour rather than to differences in the available base-supply of the soil. An attempt was made to investigate this possibility by collecting heather plants of different ages from the same habitat (woodland) where burning had not occurred, so that base content relative to the age of the plant alone, could be determined. Unfortunately only one wood was discovered containing heather in sufficient quantity and of sufficiently varied appearance to warrant further investigation. After relatively few ring counts had been made it became apparent that the ages of the plants fell into two classes. Obviously burning had occurred at some previous date and as a consequence edaphic variation could be expected within the habitat. The material was not therefore analysed.

In the absence of evidence to the contrary, it seems fair to conclude that the parallel evidence of soil and leaf analysis indicates a decline in fertility throughout the burning cycle.

In interpreting these results the following is probably a fair summary. The primary effect of burning is to liberate on the soil surface those bases formerly organically bound in the vegetation of the area (and in the peat if this should also be damaged). Rainfall will result in the solution of the bases and their removal from the soil surface either as the result of run-off on the steeper slopes or washing into the soil on the more gentle ones. Clearly the result of the latter process will be to increase the base status of the surface horizons. With the passage of time, leaching will result in the migration of bases to the lower horizons with corresponding decrease in the base status of the upper. This deterioration of the upper soil could be expected to continue uninhibited until the vegetation began to re-establish itself. With the closing of cover, increased protection against leaching could be expected as the result of (a) the physical protection afforded by the closing canopy - i.e. the dissipation of some of the rainfall by evaporation on the aerial parts and (b) reduction in the amount of water passing through the soil due to the drying-out effect of a more extensive root system. This conserving effect on the base supply would however be partly offset by the enhanced rate of removal of base by the vegetation. Even when the canopy was complete, leaching and the absorption of bases by roots would continue to impoverish the surface soil.

The above explanation neglects the possibility of bases arriving from external sources to enhance soil fertility although there is no evidence to suggest that this does in fact occur. In certain situations, erosion of mineral soils higher up a slope might lead to local base enrichment, but this would seem to be an exceptional circumstance on the gentle typical slope. The failure of heather roots to exploit the lower soil horizons must severely restrict the return of bases washed down (or produced by weathering) to the upper soil horizons. Although some peat decomposition may occur the effect of this on the mineral supply must be insignificant (Waksman 88).

The inevitable conclusion to be drawn is that the vegetation-peat profile represents a 'closed' system, founded on a restricted 'base potential'. To explain this a little further -- in an old heather stand the major part of the base potential is 'bound' in the standing vegetation, undecomposed plant remains or the peat itself, only an insignificant part remains as exchangeable base adsorbed on the peat. On burning the position is reversed, so that most of the base potential is present in the ash deposited on the soil surface. Only the fraction bound in the unburned peat, litter and vegetation is immune from the effects of leaching and surface run-off. As the cycle proceeds the soluble base will disappear from the surface and upper horizons of the soil as the result of root absorption, being lost in the run-off, or becoming leached into the lower soil horizons. Even if the base does not appear in drainage water as the result of leaching much of it may become isolated in the B. horizons and unavailable to the shallow rooting heather plants, thereby constituting an irretrievable loss to the 'system'. It would seem therefore that successive burnings can only lead to progressive reduction of the 'base potential' owing to the cumulative loss of base arising from each burning. Evidence is required that the base is in fact lost entirely to the system and this will be dealt with in the following section.

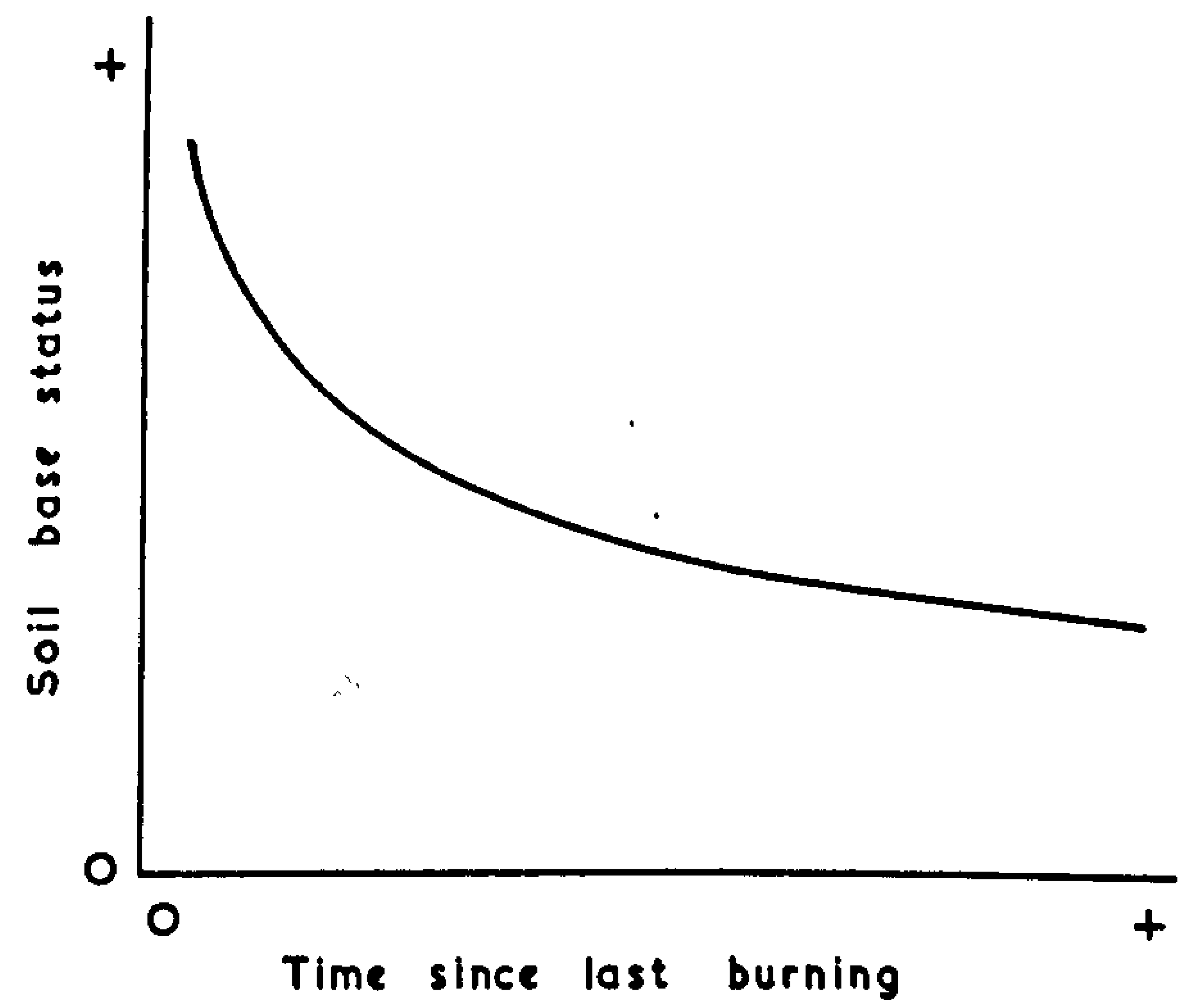
Before leaving the subject of intra-cyclic changes in soil base-status, the calcium trends in fig. 15 will be considered.

Fig. 17 indicates that under continuous heather cover the uptake of base declines almost proportionally to the interval since burning. However when burned areas as a whole are considered vegetational cover is not continuous from the beginning of the cycle but varies according to the age of the stand and its origin. The removal of base from an area as a whole would therefore be a function of, declining uptake by the vegetation where the cover is continuous, accelerated uptake due to expanding cover and falling off in loss due to leaching as the cover becomes complete. The nett result of these interacting factors is probably illustrated by the Bamford curve (fig. 15). (The projected part of the curve seems justified, in view of the linear decline in the uptake of base, (fig. 17) once continuous cover has been established). The Ringinglow and Toadsmouth curves can not however be accepted at face value, since overburning has occurred in the two middle stands in each case. Consequently these show considerably greater cover or have attained maximum cover at an earlier date, than stands of a similar age under longer cycle treatment, i.e. they are potentially older than the estimate of their ages would indicate, relative to the youngest and oldest stands. It is not possible to correct the intermediate points on the curves in view of the many factors involved although clearly their displacement to the right by two or three years would do much towards indicating the trends to be expected in the absence of overburning. The resulting more gentle curves would bear a close resemblance to that of Bamford.

The intra-cyclic trend in soil base status of the upper

Diag. 5.

Illustrating the general trend in soil fertility during a single burning cycle.



Diag. 6.

Illustrating two possible sequences of soil fertility through several cycles.

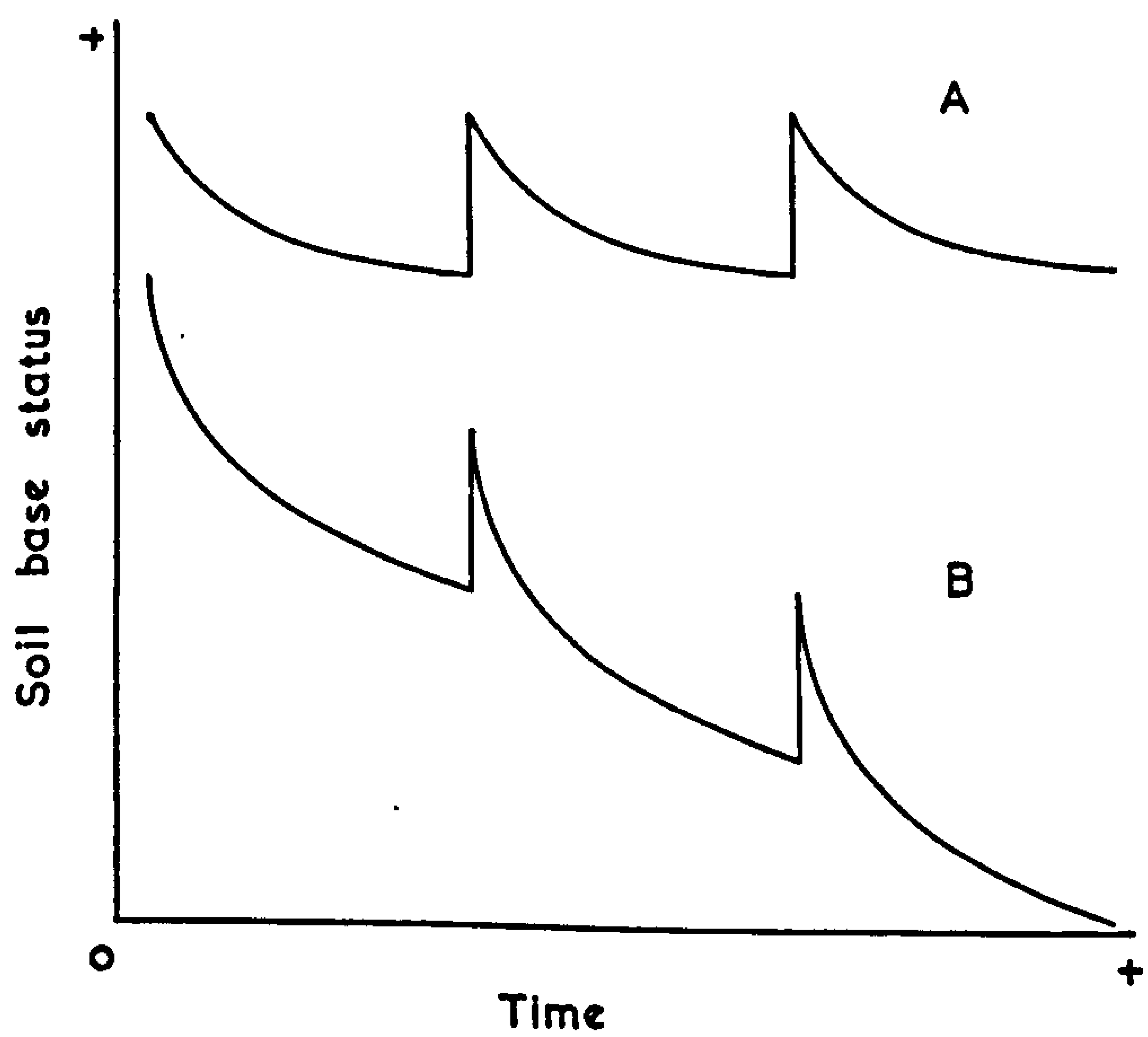
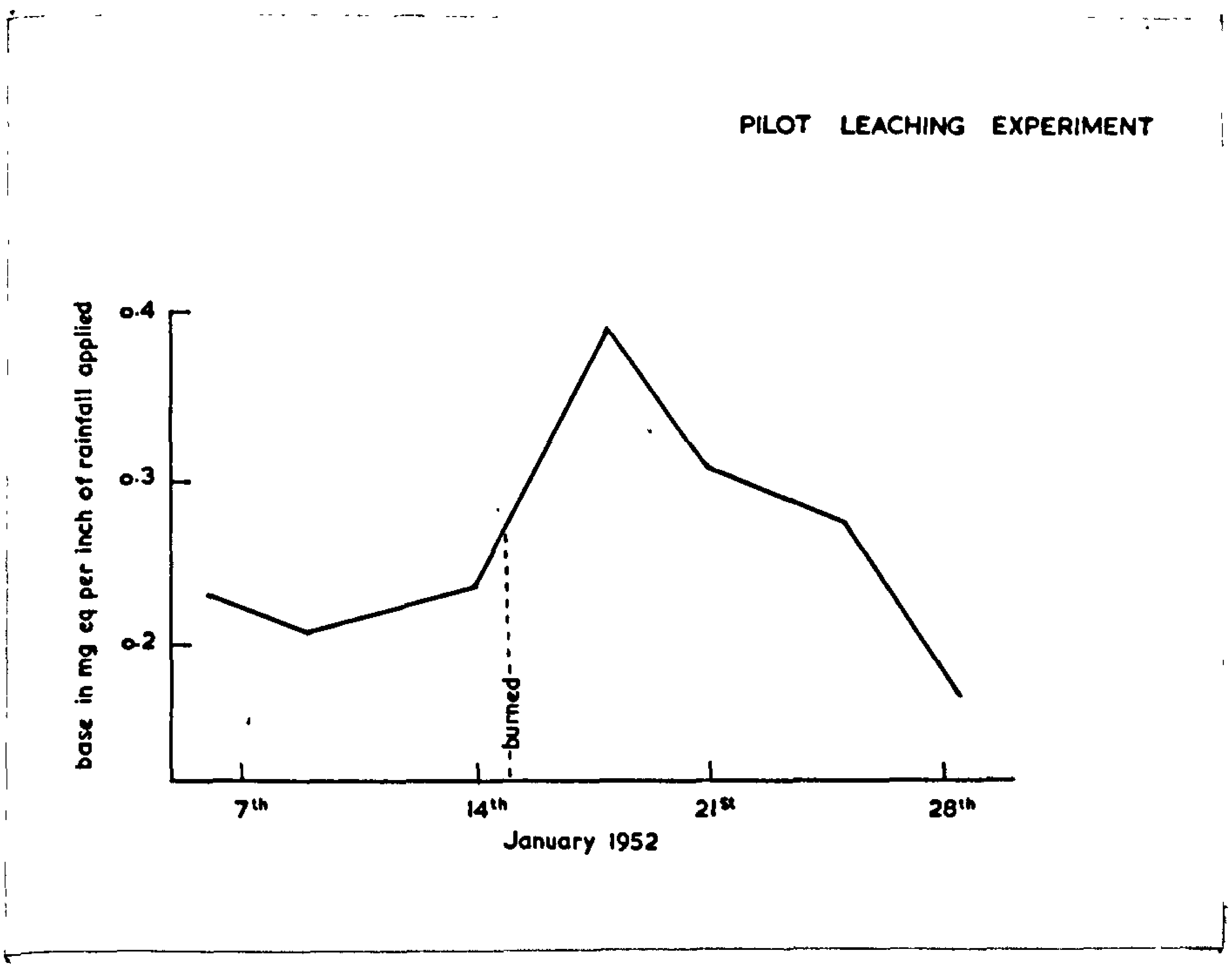


Fig. 18.

Base content (total base) of the leachate from a soil-block before and after the vegetation on it was burned.



soil horizons can therefore be depicted as in diagram 5. The problem then arises as to the sequence of soil base status through a series of cycles i.e. does this follow the pattern of A or B in diagram 6?

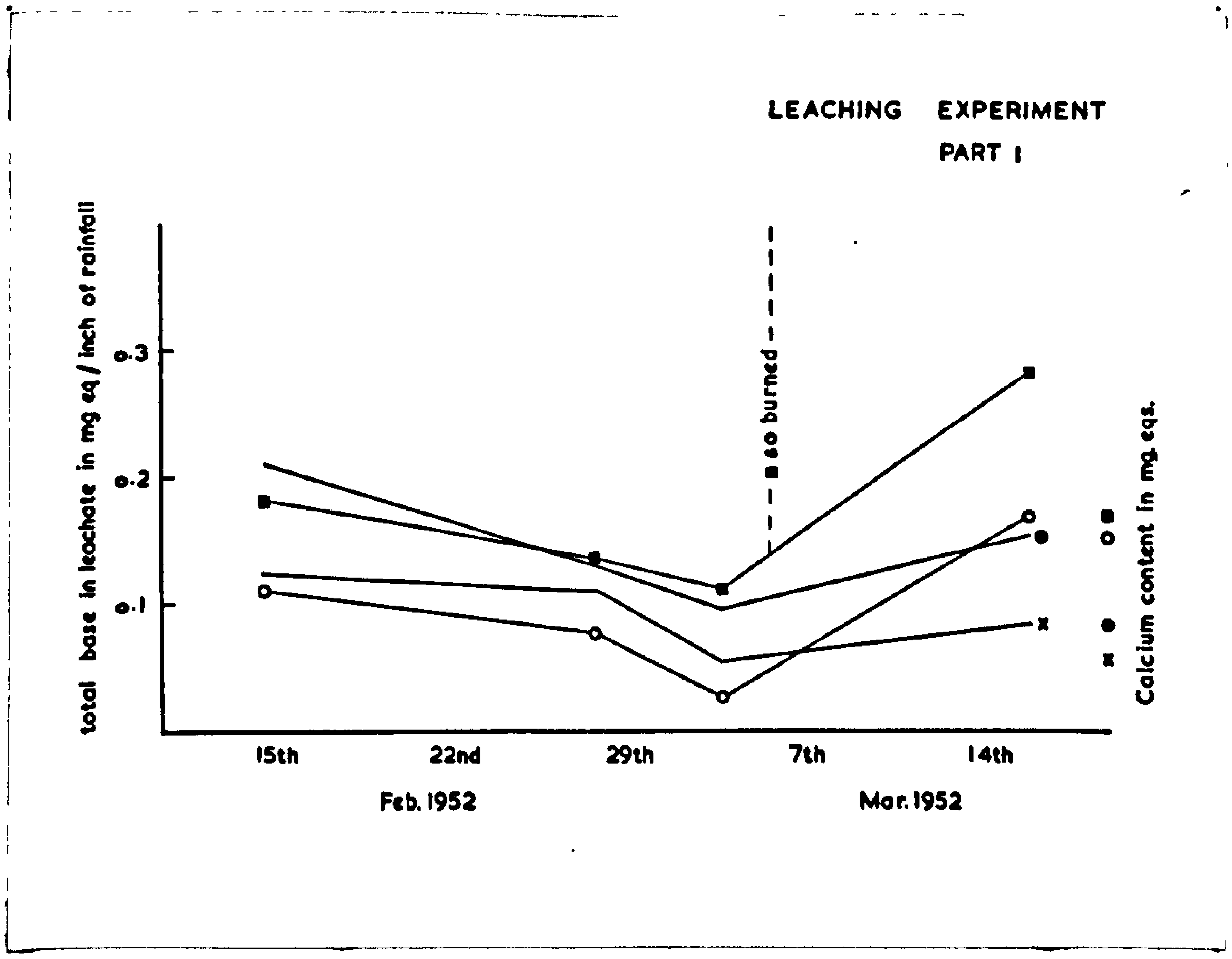
It if can be established that part of the base liberated on the soil surface after burning later appears in the run-off. or drainage water, the evidence would be strongly in favour of the pattern illustrated in 6B. Clearly unless the base supplying power of the soil were sufficient to make good such a loss, the overall base status would decline through a series of cycles. In view of the well-known mineral deficiency of the Millstone Grits, the possibility of weathering effecting enrichment seems most unlikely.

The results of the first pilot experiment on leaching are shown in fig. 18. There is a sudden rise in the base content of the leachate after burning. The loss of base is however of short duration and after 2" - 3" rainfall the amount of base in the leachate is back to 'normal'. This experiment was then repeated using four soil blocks as described on page 41.

The results of burning the vegetation of the first two blocks are shown in fig. 19. The increase of base in the leachate is not so pronounced as in the pilot experiment, although there is no doubt that, compared with the controls, an increase occurs. Fortunately whilst the post-burning leachates

Fig. 19.

Base content (total base) of the leachate from four soil blocks.



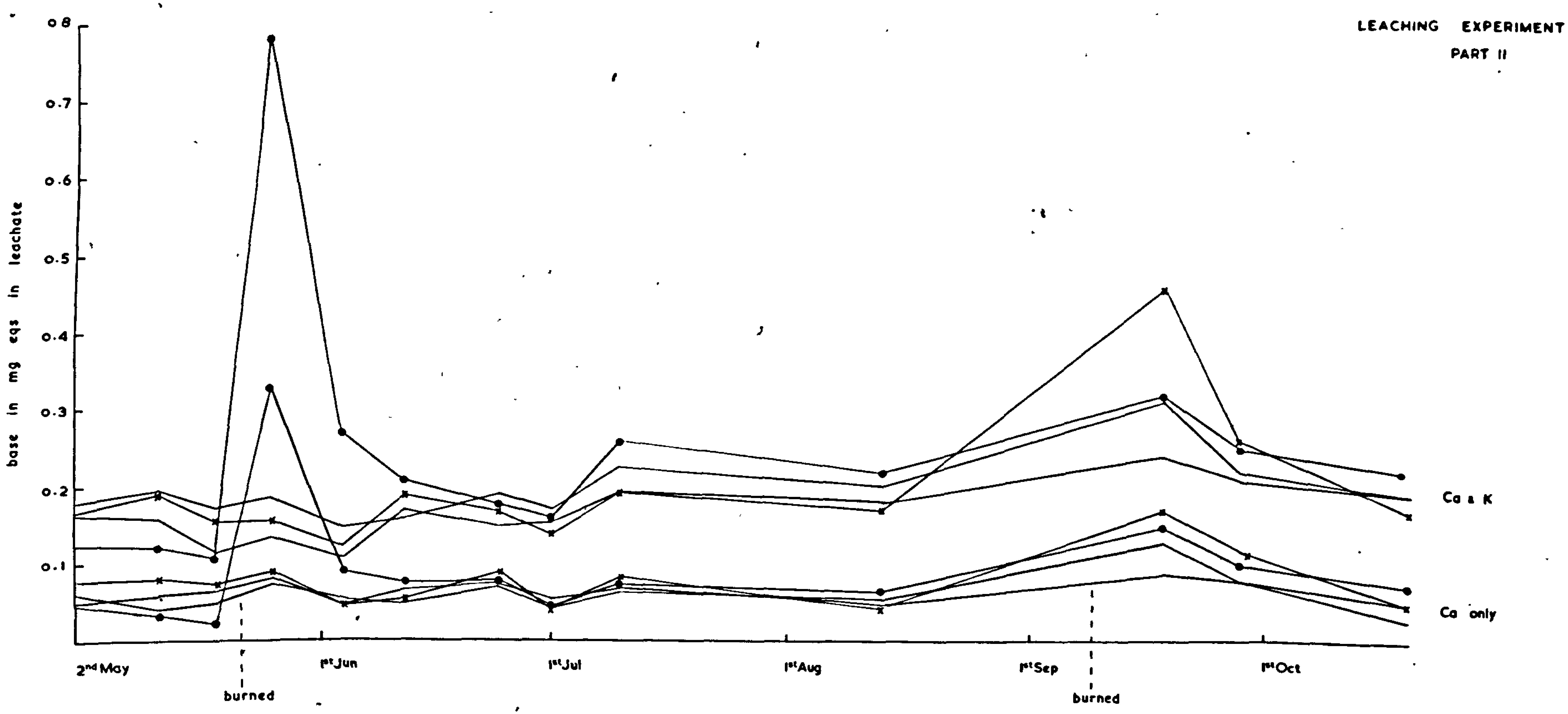
The increased base content of the leachate after the vegetation of two of the soil-blocks had been burned is apparent. The calcium content of the leachates on the 16th March is shown on the extreme right.

were still available, it was possible to analyse these for calcium content and the values on the extreme right of the graph show that this was appreciably higher in the leachates of the two burned blocks than in those of the controls.

Fig. 20 shows the experiment continued using the elements calcium and potassium as representative of the bases in the leachate. The peaks in the curves arising from the burning of the vegetation on the two remaining blocks, leave little doubt that an increased loss of base occurs after burning. It is possible that the high loss of base after the vegetation in the third box was burned, may have been due to run-off between box and soil. However, special care was taken to avoid this in leaching the soil of the fourth box and yet the reflexion of the curve is still considerable. The apparently slow but recognisable increase in base loss towards the end of the season, particularly with regard to calcium (Aug. - Sept.) is probably explained as follows. During the vacation it appears that precautions against splashing the tins with tap-water during the watering of other greenhouse material, were not enforced. This is confirmed in the case of the box furthest removed from the scene of operations which shows comparatively little increase in calcium content over the period in question. The burned block was always kept in the furthest corner of the greenhouse to guard against such an eventuality and therefore can be best compared with the

Fig. 20.

The base content (calcium + potassium and calcium alone) of the leachate from four soil blocks.



Showing the increased base content of the leachate after the vegetation of the third and fourth soil blocks has been burned.

Data on the ash used in the Pilot Leaching Experiment.

Wt. of total ash collected.	21.55	gms.
" " sample A to determine the base content of the ash.	1.73	"
" " " B " " " water-soluble base in ash.	2.09	"
" " ash actually applied to soil surface	17.73	"

Estimation of the base content of the ash applied to the soil surface.

Base in sample A = 8.8 mls. of 0.102 N. NH4OH.

= 0.8976 mgs. eqs.

therefore 17.73 gms. of ash contain 9.20 mg. eqs. base.

The base content of the ash applied to the soil surface

= 9.20 mg. eqs.

Estimation of the water-soluble base in the ash applied to the soil surface.

In the equivalent of the 1st. inch of rainfall.

Base in sample B = 0.95 mls. of 0.102 N.NH4OH.

= 0.0923 mg. eqs.

therefore soluble-base in 17.73 gms. ash

= 0.823 mg. eqs.

In the equivalent of the 2nd. inch of rainfall.

Base in sample B = 0.4 mls. of 0.102 N.NH4OH.

= 0.0408 mg. eqs.

therefore soluble base in 17.73 gms. ash

= 0.340 mg. eqs.

In the equivalent of the 3rd inch of rainfall.

Base in sample B = 0.10 mls. of 0.05 N.NH4OH.

= 0.005 mg. eqs.

therefore the soluble base in 17.73 gms. ash

= 0.05 mg. eqs?

In the 17.73 gms. of ash applied to the soil surface, the amount of base soluble as the result of 3 " of rainfall = 1.21 mg. eqs.

uncontaminated block.

The relatively high proportion of potassium to calcium in the leachate is interesting. Pearsall (57) has shown that the effect of leaching is to lead to an increase in the potassium, sodium: calcium, magnesium ratio of soils, whilst Tansley and Salisbury (77) decided that acid leached soils tended to be those richest in potassium. These observations coupled with those of Stiles and Jørgensen (75) that soluble mineral substances produce a saturated or near saturated solution in soil water must explain the potassium: calcium ratio in the leachate. The ratio of these elements in the first leachates after burning is undoubtedly a reflection of their ratio in the soluble ash.

In the pilot experiment an attempt was also made to measure the proportion of base lost, as the result of leaching, to that liberated on the soil surface. (p. 42). The minimum total base applied to the soil surface was calculated as 9.20 mg. eqs. Before the amount of base in the leachate had returned to 'normal' the equivalent of 2" - 3" 'rain' had been applied and approximately 1.0 mg. eqs. base had appeared in the leachate. (Fig. 18). However, approximately 0.6 mg. eqs. of this could have been expected to appear in the leachate in the absence of burning, so that the base lost as the result of burning must only have amounted to about 0.4 mg. eqs. Of the total base applied to the soil surface, it appears that less than 4.5% appeared in the leachate. This is of course a maximum estimate since it will be recalled that no account of the contribution of the base arising from stem bases, duff, etc. after 'hosing' by Bunsen burner (p. 42), can be made. The loss may also be an overestimate in that some of the base may not have percolated through the soil but passed between the soil and container. In the field however a similar loss could occur as the result of surface run-off.

On the other hand the amount of base soluble in 3" rainfall was determined as about 1.2 mg. eqs. and since only 0.4 mg. eqs. base appeared in the leachate as the result of burning, it can be assumed that not all of the water soluble base readily passes through the soil profile. The proportion of base estimated as water soluble : to total base applied to surface (HCl soluble) is remarkably small, being 1.2 : 9.2.

The rapid return of base in the leachate to 'normal' value is probably explained by the water solubility of the base in the sample of crude ash (p. 76) which fell off in a similar fashion viz.

0.823	mg.	eqs.	base	soluble	in	1st.	inch	of	rainfall
0.340	"	"	"	"	"	2nd.	"	"	"
0.05	"	"	"	"	"	3rd.	"	"	"

The use of the term 'normal' to describe the approximately steady base loss in the absence of burning seems justified in view of data provided by the Sheffield Corporation Water

Works Dept. Analysis of the water running into three of their reservoirs from entirely moorland catchment areas, contain calcium in the following amounts,

Broomhead	0.22 mg. eqs / litre.
Dale Dyke	0.18 " " "
Redmires	0.21 " " "

In the leaching experiments performed above, the 'normal' value for calcium fluctuated about 0.075 mg. eqs. / 1" rainfall (fig. 20). Since the leachate collected was usually about 400 mls., this is equivalent to about 0.19 mg. eqs. of calcium per litre, a figure very similar to the overall values for the reservoir waters.

There are admittedly serious disadvantages in experiments of this kind not the least of which is the change in soil conditions on bringing soil blocks into the artificial conditions of a greenhouse even though this was unheated. Unfortunately observations in the field were not successful. Although streams occur on the moors, none were conveniently situated near burned patches. In lieu of this countless pits were dug, some merely depressions in the Ao horizon, others well down into the sub-soil. By this means it was hoped to measure the base status of surface run-off (shallow pits) and by subtracting this from the values obtained from the water of the deep pits, obtain a measure of the loss of base due to leaching through the soil. Although visited as soon as possible after rain the collection of samples was impossible. Occasionally small amounts of water were found in the shallow pits, but the water table is apparently too low and the soil too porous for water to collect in the deeper pits. Consequently conclusions have had to be drawn from the experimental data presented previously. These may be summarised as follows.

The amount of base in the run-off and leachate increases after burning.

The enhanced loss of base from the soil after burning appears to be of short duration, since after the equivalent of 2 or 3 inches of rainfall have been applied, the amount of base in the leachate returns to normal. However, it is not impossible that a loss, too small to be detected by the analytical method employed, occurs for a longer period.

The base carried off in the leachate and run-off probably does not exceed 4% of the total amount of base deposited on the soil surface at burning.

Only part of the crude ash appears to be readily soluble in water.

Not all of the readily soluble fraction of the ash appears in the run-off and leachate and it seems probable that some of it is retained by the soil. Should any of this become immobilised in the B horizons it would be unavailable to the shallow-rooting heather-moor vegetation thereby constituting a total loss to the 'vegetation- upper soil' system (p. 71). The nett base loss resulting from burning would therefore be greater than the amount actually measured in the run-off and leachate.

Summary of the short-term effects of burning.

On the vegetation.

When heather plants are burned they may be completely destroyed, in which case recovery will be dependent on seedlings, or they may only be damaged in which case if the plants are young enough, new shoots will spring almost immediately from the stem-bases or roots (Beijerinck) and recovery will be more rapid.

When recovery is by seedlings the burned area may remain 'black' for several years, and it is unlikely that complete cover will be achieved before about 10 years after burning.

When recovery is by rootstock regeneration, (i.e. when the heather is burned before it is 15 years old), complete cover may be achieved as early as 5 years after burning.

The direct effect of burning on the individual species of the Callunetum appears to be essentially that described by Frazer (see p. 45). However, there seems little doubt that some suppression of V. vitis-idaea occurs as the direct result of burning whilst if burnings occur in close succession, V. vitis-idaea appears to be eliminated from the vegetation and V. myrtillus shows signs of suppression.

The vegetative composition of moors which have been systematically and irregularly burned differs considerably. Consequently, the burn-subseres on these two types of moors differ, even if a cycle of similar length should be observed on each moor.

Systematically burned moors exhibit a grassy phase in the early stages of recovery. If the cycle length is 15 - 20 years, heather recovery will be primarily dependent on seedlings and its relatively slow rate will permit the associates (principally Deschampsia) more time in which to extend their cover before this is curtailed and eventually reduced by the increasing heather cover. If however on the same moor the heather is burned before it has reached the age of 15 years, the more rapid recovery of the heather reduces the period available for the associates to extend their cover and their representation in the cycle is correspondingly reduced. Moors under such short-cycle treatment exhibit the greatest poverty in associated species and maximum heather-dominance throughout the cycle. Since systematic management entails the burning of heather before the cover disintegrates, no opportunity is afforded the associates to increase their cover at the end of the cycle. If this opportunity does arise, Deschampsia, the only species to be present in any quantity, increases its representation. Since it has been shown that Deschampsia suffers little direct damage as the result of burning, it could be expected, after such a lapse in treatment, to commence the next cycle with better cover than under systematic burning and would undoubtedly exhibit increased representation throughout the cycle.

Irregularly burned moors in view of their better representation of species, exhibit a series of recovery phases which are summarised in the burn subsere described by Adamson (see p. 65). Although suppression of associates occurs at maximum heather cover, the associates are sufficiently well-represented to survive this period until, with the disintegration of the heather cover, the opportunity occurs for them to recover lost ground. Since burning does not appear to be delayed beyond about 30 years the opportunity for the associates to extend their cover indefinitely does not arise. If burning should occur when the heather cover is still continuous, the vitality of the associates will be at its lowest ebb, when this opportunity to extend their cover occurs. This will undoubtedly result in their being less well-represented in the cycle than in the former one. The effects of burning this type of moor on a single short cycle when the recovery of heather is accelerated, has been described and illustrates a still more rapid decline in the representation and variety of species during the cycle.

<u>On the soil.</u>

A decline in soil fertility, measured either as percentage base-saturation or in absolute terms of total exchangeable base, occurs throughout the burning cycle. When estimates of exchangeable calcium and potassium are used as representative of available mineral nutrients in the soil, a similar intra-cyclic trend is observed.

This trend in soil fertility is substantiated by the results of leaf analysis. When the green material per unit area of continuous heather cover is used phytometrically the accumulation of calcium in the green material declines throughout the burning cycle, suggesting that a parallel decline occurs in the supply of base in the soil.

It has been suggested that the vegetation : peat profile constitutes a more or less 'closed' system with a restricted base potential. Since it has been shown that base is lost after burning as the result of leaching or surface run-off and there is little reason to suppose that this is made good by the arrival of base de novo, it must be concluded that the base potential of the vegetation : peat profile decreases with successive burnings.

The inferred trend in soil base status through successive cycles is illustrated in diagram 6B.

PART IV.

The long-term effects of burning.

Effects on the vegetation.

It seems reasonably certain that with the exception of the sub-shrubs, which may be completely destroyed and thereby temporarily excluded from the vegetation, the associates of Calluna suffer relatively little damage as the direct result of burning. Moreover, it seem unlikely that the colonisation of burned areas by seedlings of the associates is responsible for any radical change in the composition of the vegetation after burning. It might therefore be expected that the vegetation would remain relatively constant from cycle to cycle. If a given burning treatment is maintained, this is undoubtedly true and the vegetation appears to establish a state of equilibrium with the particular regime applied. However, it has already been shown that burnings in close succession may considerably alter the composition of the vegetation in a relatively short time (p. 64). Consequently it must be concluded that the factor which governs the composition of the vegetation is the length of the interval between successive burnings (i.e. the frequency of burning) rather than the effects of fire damage.

It is not possible to trace directly the changes in the vegetation from the original unburned heather moor as the result of differences in treatment. However, of the existing moors, the irregularly burned ones have in the past experienced the least interference by burning and will therefore most closely approximate the original condition. On this type of moor the pattern of recovery after burning can be summarised as follows:-

Phase 1.	Recovery phase for all species.
0-10 years.	The vegetative exploitation of the unburned ground by those plants which have survived burning and colonisation by seedlings.
Phase 2.	The phase of heather domination and suppression of associates.
10-20 years.	During this phase the heather is in direct competition with the associates to the disadvantage of these.
Phase 3.	The phase of heather decline and recuperation of associates.
20-30 years.	During this phase the associates exploit the gaps as they appear in the heather cover.

On the irregularly burned moors burning has occurred almost exclusively during phase 3. Consequently the composition of the vegetation at the beginning of each cycle would be fairly diverse (p. 56), and succeeding cycles would tend to repeat the pattern illustrated in diagram 2B (p. 62). It seems probable that in the past this type of treatment has only eliminated those species which are especially sensitive to fire damage e.g. some of the species which are mentioned later (p. 89) but are no longer represented on the Ringinglow type of moor. However, even in the case of some of the species that have proved less sensitive to occasional burning the chances of being eliminated must increase in proportion to the number of times the moor has been burned, i.e. the longer a moor has been established the poorer will be the representation of these species.

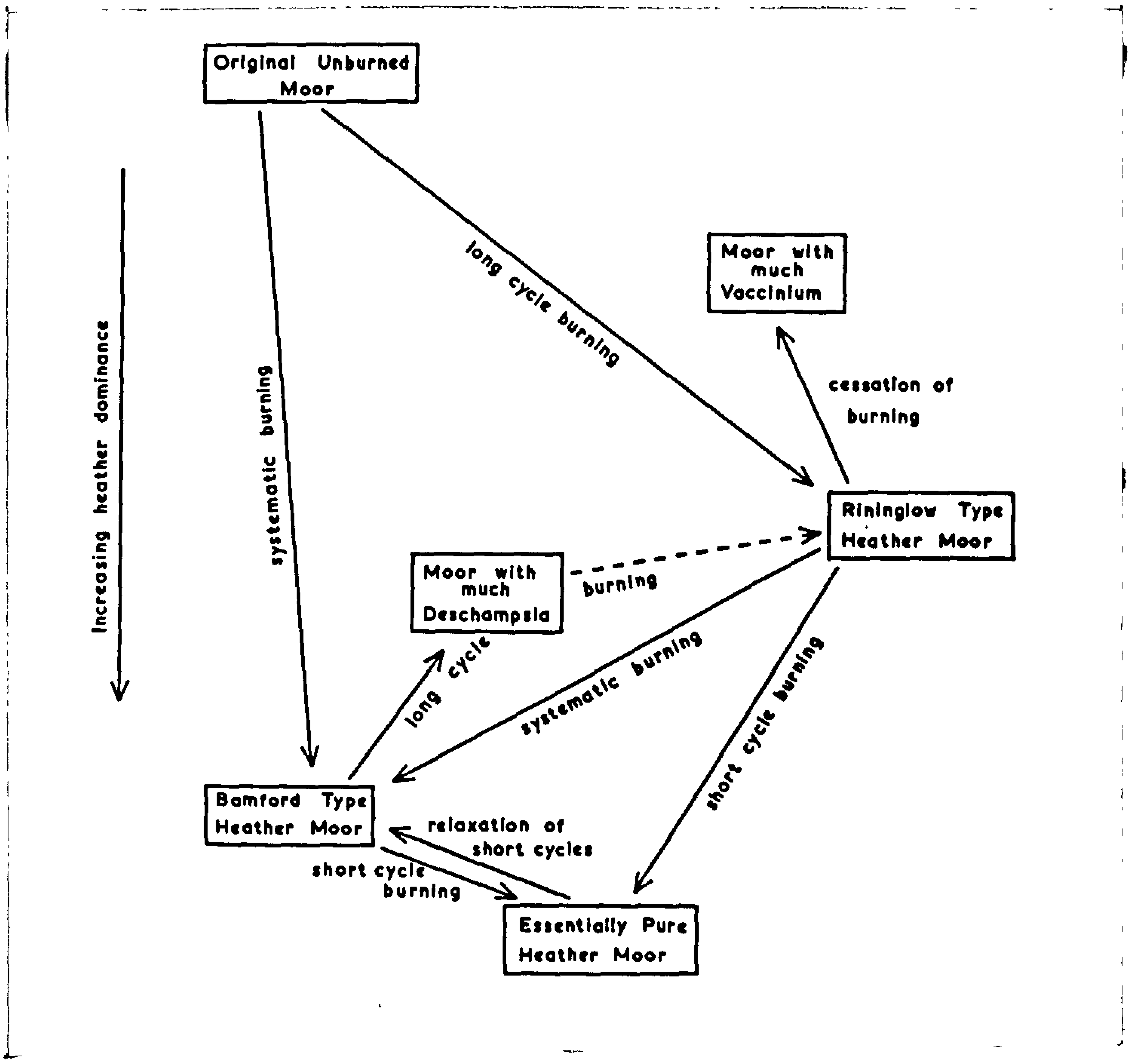
When a moor is systematically managed the vegetation is repeatedly burned before the heather cover disintegrates (i.e. with the elimination of phase 3 of the long cycle) and no recuperative phase for the associates occurs. In addition the vegetation is always burned at a stage when the vigour and representation of the associates is at a low ebb due to their having been in direct competition with heather for several years during phase 2. The cumulative effect of this treatment quite apart from modifications in the habitat due to the more frequent burning, could only lead to a reduction in the variety and representation of the associates in the community. When continued over a period there is no doubt that this treatment has resulted in the development of the Bamford and Toadsmouth type of heather moor.

It has already been suggested (p. 63) that if the cycle length is further reduced an even more impoverished flora than that of the previous type of moor can be expected, since not only do the above considerations apply equally well, but the accelerated recovery of heather as the result of roostock regeneration considerably shortens the post-burning period of recovery for the associates (phase 1). Moors that have been maintained under such short cycles have not been encountered although there is no doubt that had they been, they would have exhibited almost complete heather domination with negligible amounts of associates. (Diagram 2A. p. 62). Since Deschampsia appears to be the only associate likely to survive such frequent burning it seems probable that relaxation of the treatment would lead to some recovery of this species. The virtual absence of other associates on moors under such treatment would make their re-establishment as a significant part of the vegetation, provided that the soil had not degenerated to such an extent as to prohibit this, dependent on protracted colonisation by seedlings. (N.B. the beginning of the section).

Briefly therefore, it seems that the Bamford type of moor has been developed either directly from the original heather moor or secondarily from the moors of the Ringinglow type, merely by the operation of systematic management. It is not impossible however, that the process has been accelarated by occasional periods of short-cycle treatment. Short-cycle treatment will result in an even more impoverished vegetation than that of the Bamford type of moor, consisting of almost

Diag. 7.

Illustrating the inferred relationship between the subsidiary types of heather moor and burning treatment.



The discontinuous line represents an unsubstantiated and doubtful sequence.

pure heather. Although the change in vegetation from the Bamford type of moor to 'moors under short cycle treatment' may be reversible with the relaxation of burning, it seems doubtful whether even the limited variety in the vegetation of the irregularly burned moor can be regained merely by the relaxation of burning. The inferred relationship between the different 'types' of moors and burning treatment is shown in diagram 7.

Although it was stated earlier that it was not possible to trace directly the changes that have occurred in the vegetation from the original unburned heather moor, it is possible to consider this in a different manner.

Towards the end of the 18th century, Jonathan Salt made a collection of plants to be found in the Sheffield district, including many species from the moors investigated. Those species which are now rare or absent completely from the moors are listed in Appendix 4., and it is suggested that their disappearance is largely due to burning. _Erica cinerea_ and _E. tetralix_ are both described as 'common' and although considerable latitude can be ascribed to this term, neither species could be reasonably thus described today. The fact that the remaining species are mentioned without careful indication of locality, as in the case with the obviously more unusual species from non-moorland habitats, suggests that these were not then uncommon. In the case of the _Lycopodium_ species and Listera cordata, there is evidence of a reasonable supply of material since the former have obviously been selected for their luxuriance and appearance, whilst a number of specimens of the latter species have been arranged to show diversity of form.

That the disappearance of these species can be attributed to burning seems to be well illustrated in the case of Listera. This species is now completely absent from the Hathersage - Houndkirk moors and occurs only on a shaly slope at the margin of the area. This suggests that it has been eliminated from the continuous heather cover such as it occupies in Teesdale and on some of the Scottish moors and survives only on this atypical habitat where burning would be absent or rare. (The effect may be secondary, in that the lowered fertility of the moors can no longer provide adequate base supply whereas the unstable slope does). Smith 72, associates E. cinerea with 'scroggy' heather with a slow recovery. Clearly, once regular burning was introduced the more rapid recovery of heather would produce conditions unfavourable to the wellbeing of this species. In much the same way burning and the associated drainage and drying off the soil would reduce the supply of habitats suitable for E. tetralix. Drying of the habitat would also be detrimental to the Lycopodium species, Pinguicula and Oxycoccus even if the direct effects of burning did not lead to their elimination.

One final comment on the herbarium material concerns the remarkable luxuriance of the heather and the profusion of the flower spikes. This may be the result of selection on the part of the collector, but it might equally well indicate a more prosperous vegetation and generally higher fertility on the moors than occurs now.

The evidence is therefore strongly in favour of there being a more varied flora on these moors in the past than there is today. That systematic burning could account for the disappearance of some of these species is not an unreasonable assumption in view of the effect such treatment can have on species which are relatively immune tothe direct effects of burning but have only managed to survive on the irregularly burned moors e.g. V. myrtillus and V. vitis idaea (table 7). (footnote)

In general therefore it must be concluded that the effect of burning continued over a period is to impoverish the flora. The contrast in floristic variety between moors in other parts of the country(e.g. Northumberland, Durham) where burning has not been so systematic or carried out for so long and the South Pennine moors where there is a long history of routine management, is further evidence of this effect. Finally it must not be forgotten that by adjusting the length of cycles, time and conditions of burning etc., keepers and shepherds have for at least 100 - 150 years been deliberately attempting to swing the balance of conditions in favour of vegetation composed entirely of heather, the only moorland plant which provides all-the-year-round fodder for stock.

Footnote.

It should be emphasised that the Vaccinium species have not been eliminated from the moors in exactly the same sense that some of the species just mentioned may have been. Rather are they being excluded from continuous heather cover and becoming restricted in distribution as large isolated 'blankets' or 'mats' (or to rocky outcrops). These 'blankets' are apparently sufficiently green and extensive to protect the plants from severe fire damage. Indeed several practical observers have expressed the opinion that these are not only maintaining themselves but actually increasing in extent. This certainly seems to be the case at Lodge Moor where the centre of origin was obviously the broken ground of an old cart-track. (N.B. Elgee 23). There are however examples of such mats where no irregularity of surface occurs. It seems probable therefore that the origin and persistance of these societies is related as much to burning treatment as to topographical irregularities per se, or possible flushing effects associated with these. There is undoubtedly a relationship between the prosperity of the Vaccinia and long-cycle burning. Generally keepers are loth to burn steep gradients such as that at Houndkirk Hill (oldest heather encountered), for fear of subsequent peat-erosion and loss of heather cover. Consequently the heather becomes senile whilst the Vaccinia extend their cover into the gaps appearing among the heather by vegetative means. The comparative slight set-back which the Vaccinia experience when burning occurs under these conditions is well illustrated by comparison of the 20 years and 1 year stands at Houndkirk (fig. 12). The end result of such treatment continued over a period is seen on one of the slopes on Howden moor, an otherwise 'well managed' moor, where almost pure Vaccinietum now exists on sites which were formerly heather dominated. This response of the Vaccinia to long-cyclic treatment on 'hard ground' has long been accepted in moor management. Lovat 49, Smith 72.

Effects on soil fertility.

It has already been shown that a certain loss of base occurs soon after burning as the result of leaching or run-off. The cumulative effect of this loss arising from repeated burnings (unless made good by enrichment de novo, e.g. weathering), should result in a recognisably lower base status in the soils of the present day moors than in their predecessors. As this can not be verified directly, use must be made of alternative methods of detecting any deterioration in soil fertility.

Clearly it would be ideal to compare the soil base-status of systematically burned moors and adjacent moors which had never been burned (but had been in existence for a similar period to the former). By this means it would be possible to measure precisely the effects of treatment, other factors having remained substantially the same in the two environments. Unfortunately it seems doubtful that such unburned moors exist and that if they did it is probable that they would not be recognised for what they are, in such a 'natural' condition.

Although differences would not be expected to be so great as in the above comparison, moors known to have been frequently burned can be compared with those known to have experienced relatively less burning. This can be done by inspecting the differences between moors of the Bamford type on the one hand and the Ringinglow type on the other. (Variation arising from mineral soil differences due to spatial separation should be taken into account, table 12). Unfortunately values determined by the Brown method can not be employed here because of their lack of precision (p. 32). However, values of calcium as determined by the method described on page 33, indicate a slightly higher overall base status on the irregularly burned moor (fig. 15). Unfortunately this is not substantiated by the results of leaf analysis (Fig. 17).

Another approach to this problem is to compare the soil base status of areas adjacent to heather moors which have not been subjected to burning e.g. woodland. Using the Brown method several comparisons have been made on these lines (table 11). Before inspecting these however it is necessary to mention the following points. Leeper (48) points out that aluminium and manganese come into solution in important amounts at low pHs, in fact soluble aluminium may increase from 0.2 p.p.m. at pH 5.5, to 15 p.p.m. at pH 4.5. Consequently when woodland and moorland soils are compared by means of the Brown method the tendency will be to over-estimate the 'genuine' bases in the more acid soils relative to those of the less acid. Secondly in view of the differences in density, structure and composition of the surface soils of moorland and woodland, equivalent fresh weights of soil can not be considered to represent approximately equal volumes of soil. Comparisons of absolute values of base per unit weight of fresh soil are therefore unjustified. Legitimate comparisons can however be made of percentage base saturations, particularly as the differences observed between woodland and moorland soils are likely to be less than they really are (above).

It is perfectly clear that the base status of the woodland soils is in every instance appreciably higher than that of its moorland counterpart. Since there is good evidence to believe that the present moorland occupies the sites of former woodland (p.103), it must be concluded that fertility of the moorland soil is not what it would have been had the woodland persisted.

One of the more interesting comparisons using the Brown method is that between Calluna and Vaccinium soils at Lodge Moor and Houndkirk Hill (table 11). In both instances the Vaccinium samples were taken from the centre of extensive V. myrtillus., V. vitis-idaea mats which could not possibly have been seriously burned for many years. Although the soil structure differs considerably beneath heather and Vaccinium it can be seen from the percentage base saturation figures that the soil below the Vaccinia is of appreciably higher fertility. Clearly this is further evidence in favour of the hypothesis that burning leads to a lowering of soil base status. It is fully appreciated that the differences observed above may not be due to the direct influence of burning, but may be a secondary result of local enrichment of the upper soil horizons due to the deposition of more base-rich litter (Thomas 80, 81, 83) combined with the exploitation of deeper soil horizons by the Vaccinia rooting systems (Heath and Luckwill 38). Whatever the cause, the effect of the Vaccinia on soil fertility is conservational. The fact that systematic burning leads to the elimination of the Vaccinia from continuous heather (p.92) means that this type of treatment is detrimental to the maintenance of soil fertility and that any treatment directed towards maintaining or increasing the Vaccinium component of the vegetation (e.g. absence of burning) would be beneficial.

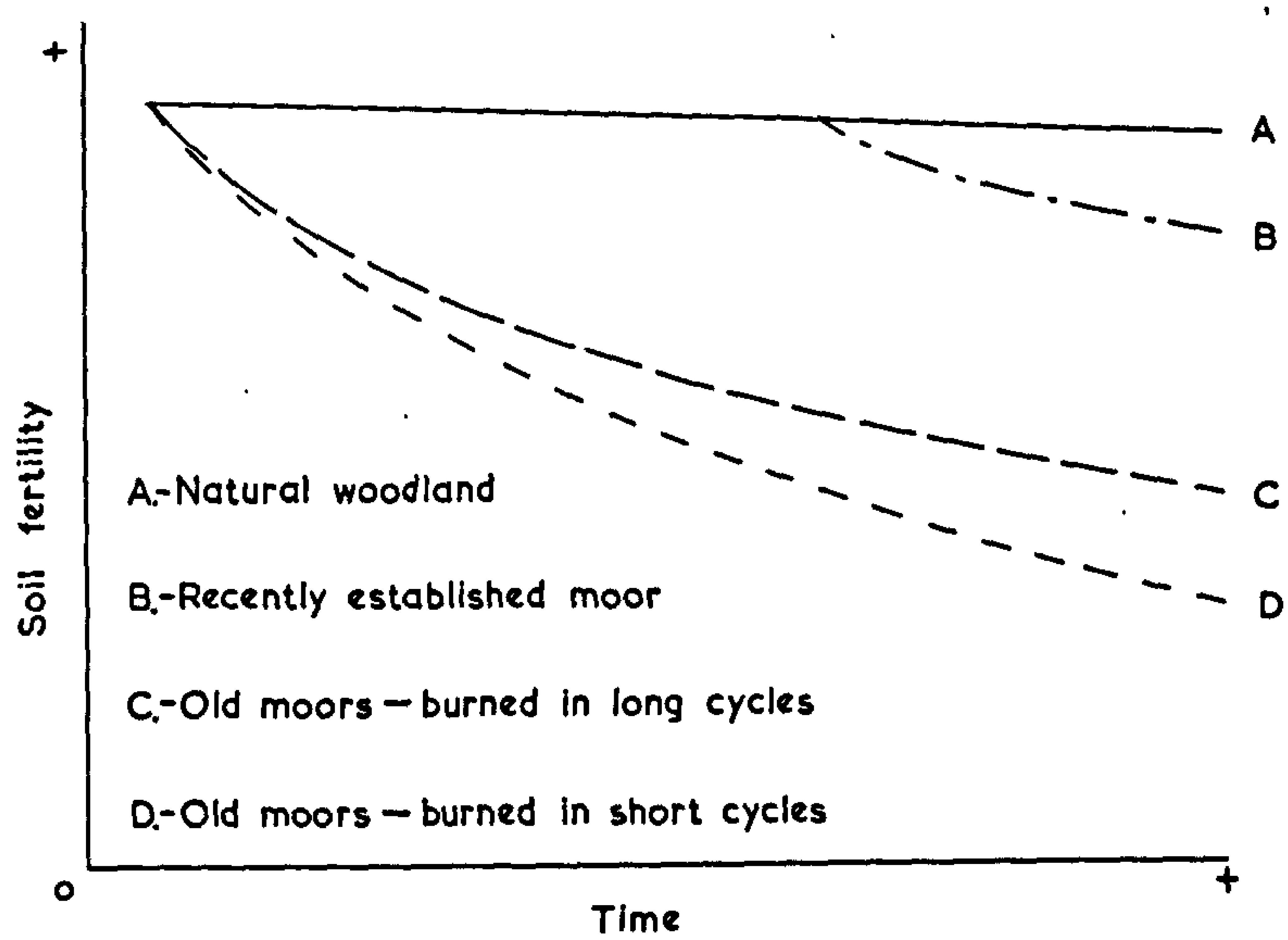
Owing to the difficulties of satisfactorily comparing the fertility of moorland and woodland soils by means of soil analysis (p. 95), it was necessary to achieve this by some other technique. The determination of fertility by means of leaf analysis was an obvious solution in that the sampling material was uniform in the different areas and therefore comparable irrespective of physical differences in the soils.

After diligent search, two woods containing heather in sufficient quantity to sample were discovered. These areas have undoubtedly been immune from burning, (Porter Clough is enclosed by a dry-stone wall and at Blacka the heather is isolated in a woodland clearing). In addition two areas of continuous heather cover, derived from sites which were woodland until between 1875 - 1900, were located reasonably close to both the woodlands. The results of leaf analysis of heather from these areas are shown in table 16 and the calcium uptake per unit area in fig. 17.

The calcium uptake per unit area by the heather in all four sites is considerably higher than that of the heather of comparable age on the long established moors. Moreover, the calcium uptake by the heather of the two woodland sites is appreciably higher than that occurring in the adjacent continuous heather areas - a fact commensurate with the latter areas having been burned several times since the woodland was felled, and the soils being of lower base status due to losses after each burning. (N.B. the estimate of calcium uptake by heather at Porter Clough shown in fig. 17 is based on the sum of [quality per unit weight. × the mean of the 4 highest dry green weights] (table 17.). The reason for doing this is quite straightforward, as it was difficult to obtain as many as six samples from closely growing heather owing to the small amount present in the wood. The rejected samples were collected solely to have three samples for chemical analysis.). Fig. 16, showing the distribution of dry

Diag. 8.

Illustrating the inferred relationship between soil fertility and burning treatment.



green weights per unit areas illustrates how far the two rejected samples differed from the remaining four).

The evidence of both soil and leaf analysis indicates a difference in fertility between woodland and moorland soils. Moreover, the results of leaf analysis indicate that the difference is greater in proportion to the length of time (i.e. the number of times) that the moor has been burned. An attempt is made in diagram 8, to illustrate the relationship between fertility and burning history.

Summary of long-term effects of burning.

There seems little doubt that the floristic variety of these moors was considerably greater in the past and that the long history of burning has resulted in the complete elimination of some species.

Other species have proved less sensitive to occasional burning and are still to be found on the heather moors of the Ringinglow type. However even these species appear to be eliminated or reduced to insignificant proportions by the operation of systematic treatment.

It seems possible that a slight difference in soil base status occurs between the systematically and irregularly burned moors. This suggests that more frequent burning leads to lowered fertility. This is supported to some extent by the fact that on the same moor, the percentage base saturation of the soil below the Vaccinia was higher than that of the soil below adjacent heather. Since systematic burning results in the elimination of the Vaccinia from the Callunetum, those moors with the greater Vaccinium cover (the irregularly burned ones) could be expected to be more fertile than those in which the Vaccinia were poorly represented or absent. (i.e. the systematically burned moors.)

Comparison of woodland and moorland soils by means of both soil and heather-leaf analysis, leaves little doubt that a considerable difference is present in soil fertility. Since it is almost certain that the present moors occupy the sites of former woodlands (p. 103) it must be concluded that the fertility of the moors is lower than what it could and would be, had the woodland survived. In view of the detectable loss in base as the result of leaching after burning, it is suggested that the cumulative effect of this, arising from long-continued burning, is a contributory factor to the degeneration in fertility that has occurred in the moorland soils.

PART V.

General Discussion.

It is not unusual to hear shepherds and other practical men assert that the fertility of the moorland grazings is declining. This opinion is not confined to general observers, agricultural scientists have also expressed it (Thomas 84, Thomas 85, Cameron 6).

Quite often there is little enough evidence to confirm the opinion of the shepherd, since his criterion of this reduced fertility is that where his father or grandfather could graze 5 sheep, he can now only manage to graze 2 or 3. Whilst his deduction may be correct the fundamental reasoning is unsound. In comparatively recent times the demands for mutton have altered considerably and consequently so have the breeds of sheep (Fenton 29 and 30, Thomas 85). Clearly if a better quality animal is to be raised on the same vegetation as an inferior animal, some compensation by way of increased grazing area per sheep (or increased selectivity in grazing) in necessarily involved.

Moreover since the middle of the last century a change in grazing practice has occurred. Formerly it was the custom to graze only wethers on the moors, and these largely in the spring and summer, returning them to fold or pasture to maintain condition during the winter. In any event the system involved comparatively little demand on the base-supply of the moor since the animals were mature (or almost) before being dispatched to the moorland. More recently ewes of the hardier native breeds have been introduced as permanent inhabitants of the moors. Consequently the period spent on the moor is no longer considered as affording temporary relief to lowland pasture, rather are the periods spent away from the moor e.g. in severe weather, flushing before lambing etc., considered exceptional.

In addition from the beginning of the century there has been a marked increase in the sheep population of the higher grazing land. (Thomas 84).

The result of these changes in grazing practice must be a greatly increased demand on the mineral reserves of the moor, since an annual population (to all intents equivalent to the mean winter population) of young animals has to find all the calcium, phosphorus etc., required for bone and body development from moorland pasture. Since the moorland could not possibly support the annual crop of young animals throughout the year, the surplus to the winter population (and the bases assimilated) is removed at the end of each season.

In the same fashion the tendency during the past 100 years has been to force up the grouse population to fantastic levels and each season witnesses the removal of anything up to 80% of the population at the beginning of August. Although individually of small size the cumulative effect of removing annually such a large number of birds, can only be to accelerate the impoverishment of mineral reserves caused by sheep grazing. The remarkable fact is that moorland owners apparently think that this process can continue indefinitely, yet any farmer who continued to exploit his land in a similar manner and did not attempt to replace some of the loss by fertiliser would be considered very stupid.

The question of whether the fertility of the moorland is declining can hardly therefore be in doubt, even in the absence of the evidence presented in the previous section.

It would therefore seem that three main causes contribute to the deficit in base status of the moors compared with what it might have been had they remained woodland; viz.

a-. The removal of the forest cover of itself - which has facilitated leaching of the soil and resulted in the loss of deep-rooting plants capable of returning bases from the lower soil horizons to the surface soil.

b-. The effect of burning which - by favouring excessively shallow-rooting heather-dominated vegetation, has accelerated the above process - and directly occasioned the loss of base as the result of run-off or leaching at each burning.

c-. The removal of animal bodies and the bases they have assimilated from the vegetation.

In the absence of further data it is clearly impossible to justly apportion the loss occasioned individually by each of these factors.

Clearly two solutions for regaining fertility are available. The first which may not be possible if degeneration has proceeded too far (Jenny 43), or may not be desirable if the demand for home-reared mutton continues and is to receive preference, necessitates reforestation with suitable trees (Jacks 40). Dimbleby (20,21) and others have shown that the change, podsol with mor humus, to brown earth with mull, is possible by reforestation with birch even in the absence of the application of fertilisers. Whilst birch timber may not be of much economic importance, the improvement in soil conditions would ultimately permit the culture of more remunerative hardwood trees. Moss 55, Adamson 1, Woodhead 95 accept as fact, the presence in former times of forest on the sites of many of the present South Pennine heather moors at least up to 1500'. Conway 17, working in the immediate vicinity of one of the higher sites investigated (Ringinglow) encountered abundant fragments of birch and alder during peat boring, whilst exposed tree butts are common on Hallam moor and have been seen on the highest parts of the district (Stanage Edge). The presence of scrub below many of the edges suggests that this is the residue of formerly more extensive woodland, now restricted in distribution to those places where burning and grazing are least effective. Since the evidence suggests that deforestation occurred comparatively recently and almost certainly as the result of human activities (Conway 17) there seems no reason to suppose that climatic factors are such as to prevent the reforestation of much of this area. The presence of prospering timber at about 1300' and the remains of recent plantations of sizeable timber at 1400'+ on Stanage Edge, shows that woodland can be developed if it is desired.

The alternative solution involves the expenditure of capital on soil improvement in a more direct way. Dressings with fertiliser could clearly be expected to improve the soil base status at least for limited periods. It has already been shown that base uptake by heather declines as the cycle progresses and it has been suggested that this is due to the parallel decline in available base in the soil. If this deduction is correct there seems no reason why the application of e.g. lime during the later part of the cycle should not improve the mineral content of the vegetation. Provided that the liming was not so severe as to interfere with the metabolism of the moorland plants (Hinchcliffe and Priestley 39) and did not raise the pH above 5.0 - 6.0 (p.11), there seems every possibility of retaining heather cover. Owing to the broken nature of the terrain, orthodox methods of treatment would not be possible. However, the use of aircraft to shower areas with fertiliser might be considered / Campbell (9)
Unfortunately the possibility does exist of losing the heather

cover if liming is too heavy (Farey 25, Stapledon 74), and although this would undoubtedly lead to a more nutritious grassy vegetation with a higher mineral content it is certain that the change would be unacceptable to the shepherd in view of the loss of the all-the-year-round pasturage of the heather (Thomas 84, Wallace 89). Moreover, it is difficult to see how the regeneration of the heather could be achieved without burning so that the post-burning loss of base due to leaching would have to be accepted. On face value therefore it seems that capital would be more profitably employed in improving the present cultivatable marginal land on which the response to fertiliser application has been thoroughly studied. The economic utilisation of the present heather moors would therefore seem to be by reforestation. This would in time result in the improvement of soil fertility and the timber crop might ultimately be more profitable than sheep in terms of cash returns.

Considered from the very short-term point of view there is no doubt that rigid systematic management is the only effective method of cropping the moors whilst moorland owners maintain their present attitude towards the land. It has already been shown that systematic burning in short cycles results in almost pure heather stands. Since maximum heather cover means highest stock carrying capacity, short cycle burning is obviously the way in which to achieve this. The observations of Thomas (82) on the mineral and protein content of heather show that the productivity of a given area increases up to a maximum at about 7 years after burning after which it begins to decline. Consequently the fodder value of an area of heather will be at its maximum between 5 and 10 years after burning so that burning in cycles of not more than 10 years is probably necessary to extract continually the 'maximum' from the moor.

It is not however, suggested that such management is efficient even less is it advisable. The point at issue is essentially between short-term exploitation of the moors and long-term economic utilisation of the land. It has been noted that the fertility of the heather moor is progressively declining and it seems reasonable to conclude that there is a limit to the extent to which this can continue before the moor becomes entirely unproductive. It must be clear that ultimately the management of these moors will have to be revised and it would obviously be better to do this before fertility falls to danger-level. Re-establishment of fertility is likely to be a long and costly business, but there is little doubt that the longer it is delayed the heavier will be the final cost. The present forms of management must therefore be branded as inefficient since maximum productivity is not being achieved and short-sighted since they amount to 'living on capital'. However unpalatable this may be, the fact remains that the moors are not being utilised in the best interests of national economy.

Notes on tables 1 - 5.

a) Each stand is identified by

1. an estimation of the number of growing seasons that have elapsed since it was burned and
2. the modal age of the heather.

b) In each table, the individual stands are arranged in sequence according to the age of the heather.

Notes on tables 6 - 8.

c) These are constructed from data contained in tables 1 - 5. Individual columns are identified by the initials of the moor concerned.

viz. B - Bamford
T - Toadsmouth
R - Ringinglow
L - Lodge Moor
H - Hallam
H.H - Houndkirk Hill

and the age (or ages, where the means of more than one year's observations are used) of the heather.

d) To eliminate insignificant differences, the values are expressed to the nearest unit as the frequency to be expected in 10 quadrats.

TABLE 1.

FREQUENCY OF SPECIES IN 50 QUADRATS.

BAMFORD

Date.	8.52	7.51	8.52	3.51	7.51	8.52	3.51	7.51	8.52	3.51	7.51	Mean values.				
Seasons since burned	1	2	3	4	5	6	11	12	13	20	20	1	2-3	4-6	11-13	20
Age of heather (yrs)	1	1	1-2	2	3	4	9	10	11	16-17	17-18	1	1-2	2-4	9-11	16-18
Calluna	25	18	49	47	47	50	50	50	50	50	50	25	34	48	50	50
Deschampsia	3	12	11	12	18	16	12	14	13	2	4	3	12	15	13	3
Empetrum				1		2	6	5	3	4	2			1	5	3
Vacc. myrtillus							2								1	
Eriophorum ang.				3	2	5		1	1					3	1	
" vag.	1							1			1	1			+	+
Juncus squar.				2	2	1			1					2	+	
Carex. goodenovii					2	2		1						1	+	
Agrostis tenuis	1			4	2	3						1		3		
Nardus			1	2	1	2							+	2		
Bare Ground	50	50	50	43	43	38	2		1			50	50	41	1	

Successive seasons of the same stand are shown in brackets.

Table 2.

FREQUENCY OF SPECIES IN 50 QUADRATS.

TOADSMOUTH

Date.	8.52	10.51	8.52	10.51	8.52	10.51	8.52	Mean values.			
Seasons since burned	3	2	3	8	9	20	20	3	2-3	8-9	20
Age of heather (yrs)	1	2	3	7	8	20	20	1	2-3	7-8	19-20
Calluna	45	50	50	50	50	48	42	45	50	50	45
Deschampsia	8	10	16	16	24	10	14	8	13	20	12
Erica tetralix			1						+		
Vacc. myrtillus					4	3	4			2	4
Eriophorum ang.				4			2			2	1
Juncus squar.											
Agrostis		2	1						2		
Bare Ground	50	50	48		4	24	17	50	49	2	21

Successive seasons of the same stand are shown in brackets.

Table 3.

FREQUENCY OF SPECIES IN 50 QUADRATS.

RINGINGLOW

Date.	3.51	7.51	8.52	7.51	8.52	3.51	7.51	8.52	3.51	7.51	8.52	Mean values.			
Seasons since burned	3	4	5	4	5	10	11	12	20	20	20				
Age of heather	1	2	3	4	5	9	10	11	20	20	20	1-3	4-5	9-11	20
Calluna	50	46	48	50	50	50	50	50	43	48	36	48	50	50	42
Deschampsia	43	45	47	46	46	30	32	18	43	45	41	45	47	27	43
Empetrum						2	2		13	15	17			1	15
Erica											1				+
V. myrtillus	11	23	18	11	16	9	4		8	10	12	17	14	4	10
V. vitis-idaea	6	8	4	2					22	16	19	6	1		19
E. angustifolium	6	5	3	8	6	2			8	2	2	5	7	1	4
E. vaginatum	1		1			2		2	1	1		1		1	1
Juncus			1		1							+	+		
Agrostis		1										+			
Nardus	4				2				3		4	1	2		2
Bare Ground	37	30	32	20	7					1	7	33	14		3

Successive seasons of the same stand are shown in brackets.

Table 4.

FREQUENCY OF SPECIES IN 50 QUADRATS.

LODGEMOOR.

Date.	10.51	8.52	3.51	10.51	8.52	3.51	10.51	Mean values.		
Seasons since burned	3	4	2	3	4	12	13	3-4	2-4	12-13
Age of heather (yrs)	1	2	2	3	4	10	11	1-2	2-4	10-11
Calluna	47	49	50	50	50	50	50	48	50	50
Deschampsia	2			2	9	9	8	1	4	9
Empetrum							3			2
Erica tetralix	2		2		1			1	1	
Vacc. myrtillus	5	3	32	36	33	25	30	4	34	28
Vacc. vitis-idaea	4					15	16	2		16
Eriophorum ang.		1		2		2		+	+	1
" vag.	2	2	6	4	2		3	2	3	2
Nardus	1							+		
Bare Ground	50	50	?	42	36		2	50	39	1

Successive seasons of the same stand are shown in brackets.

Table 5. FREQUENCY OF SPECIES PER 50 QUADRATS.

	HALLAM.		HOUND KIRK.	HOUNDKIRK HILL.		
Date	8.52	8.52	6.51	8.52	8.52	7.51
Seasons since burned	1	9	20	2	2	20
Age of heather (yrs)	1	9	20	1	2	20
Calluna	50	50	50	25	48	38
Deschampsia	18	32	2	27	8	26
Erica tetralix			22			
Vacc. myrtillus	2	3		21	4	28
Vacc. vitis-idaea				15		24
Erioph. angust.			13	1		
" vag.		1	3			
Juncus squar.		1	1			
Bare Ground.	50	1		43	50	

Table 6. Showing the effect of introducing short-cycle burning on the frequency of species on moors which have been irregulary burned at long intervals.

	Shortened cycle.									
	Long Cycle									
	Old Stands			Derived directly from former.			Derived from stands of intermediate age to the previous groups			
Reference	R.	H.H.	✠	R.	H.H.	L.	R.	H.H.	L.	R.
Age of heather	20	20	20	1-3	1	1-2	4-5	2	2-4	9-11
Orginal number of quadrats.	150	50	-	150	50	100	100	50	150	150
Calluna	8	8	10-	10	5	10	10	10	10	10
Deschampsia	9	5	2+	9	5	+	9	2	1	5
Empetrum	3		+							+
Erica	+					+			+	
V. myrtillus	2	6	6+	3	4	1	3	1	7	1
V. vitis-idaea	4	5	3+	1	3	+	+			
E. angustifolium	+		+	1	+	+	1		+	+
E. vaginatum			+	+		+			+	+
Juncus				+			+			
Agrostis				+						
Nardus	+			+		+	+			
Bare Ground	1		+	7	10	10	3	10	8	

✠ Estimate based on L. 10-11 (table 4).

Table 7. A comparison of the frequency of species under sustained systematic burning (cycles of 10-20 years) and irregular burning at long intervals (20-30 years)

Reference	Stands arising as the result of sustained systematic burning.										Stands arising as the result of burning only at long intervals.					
	Young Stands				Medium aged Stands			Old Stands			Young Stands			Medium aged Stands	Old Stands	
	Hal.	B.	T.	B.	T.	Hal.	B.	B.	T.	H.	H.H.	L.	R.	L.	H.H.	R.
Relative age of heather	1	1-2	2-3	2-4	7-8	9	9-11	16-18	20	20	1	2-3	1-3	10-11	20	20c
Original number of quadrats.	50	100	100	150	100	50	150	100	100	50	50	100	150	100	50	150
Calluna	10	7	10	10	10	10	10	10	9	10	5	10	10	10	8	8
Deschampsia	4	2	3	3	4	6	3	1	2	+	5	+	9	2	5	9
Empetrum				+			1	1						+		3
Erica			+							4		+				+
V. myrtillus	+				+	1	+		1		4	1	3	6	6	2
V. vitis-idaea											3	+	1	3	5	4
E. angustifol				1	+		+		+	3		+	1	+		1
E. vaginatum						+	+	+		1		+	+	+		+
J. squar.				+		+	+			+		+	+			
Agrostis			+	+									+			
Nardus		+		+									+			
Bare Ground	10	10	10	8	+	+			4		9	10	7	+		+

<u>Table 8.</u> A comparison of the overall frequency of species on systematically and irregularly burned moors, illustrating the difference in the number of the associates of Calluna under the different treatments.

	Systematically burned moors								Irregularly burned moors							
	Bamford			Overall mean per 10 quads.	Toadsmouth			Overall mean / 10 quadrats	Ringinglow			Overall mean / 10 quadrats	Lodge Moor		Overall means / 10 quadrats.
Reference.	2-4	9-11	16-18		2-3	8-9	20		1-3	9-11	20		2-4	10-11	
Original no. of quadrats.	150	150	100		100	100	100		150	150	150		150	100	
Calluna	48	50	50	10	50	50	45	10	48	50	42	9	50	50	10
Deschampsia	15	13	3	2	13	20	12	4	45	27	43	8	4	9	1.5
Empetrum	1	5	3	0.5						1	15			2	+
Erica					+			+			+	+	1		+
V. myrtillus		1		+		2	4	+	17	7	10	2	34	28	6
V. vitis-idaea									5		19	1.5		16	1.5
E. angustifolium	3	1		+		2	1	+	5	1	4	0.5	+	1	+
E. vaginatum		+	+	+					1		1	+	3	2	0.5
Juncus squar.	2	+		+					+	1		+			
Agrostis	3			+	2			+	+			+			
Nardus	2			+					1		2	+			
Bare Ground	41	1		3	49	2	21	5	33		3	2	39	1	4.0
Number of Associates of Calluna represented by frequency of 0.5 or more				<u>2</u>				<u>1</u>				<u>5</u>			<u>4</u>

Table 9. Percentage Cover of the individual species on an irregularly burned moor (Ringinglow) and a systematically burned one (Bamford) (1950 September)

	Ringinglow				Overall mean R1,R9 &R20.	Bamford			Overall mean.
Reference & Age of heather	1	3	9	20		2	9	17-18	
Number quadrats	20	20	20	35		20	20	20	
Calluna	26	84	99	62.5	62.5	39.5	99	100	79.5
Deschampsia	24	11	1	7.5	11.0	1	1	+	0.5
Empetrum				12	4.0	+	+	+	+
Erica							+		+
V. myrtillus	3	1	+	2	1.5				
V. vitis-idaea	2			8	3.5				
E. angustifolium	0.5	1		4	1.5				
E. vaginatum	+			1	0.5				
Juncus squar.	+				+	+			+
Agrostis	+								
Nardus	+				+				
Bare Ground	43.5	3		3	15.5	59.5	+		20
Totals (percentages)	99+	100	100	100	100	100	100	100	100

Notes on tables 10 - 12.

a) Estimates shown in the first two columns are the means of duplicate samples of bulked fresh soil. When the duplicates differed considerably from each other, estimations were repeated and if the repeats did not show improved agreement the mean of the 2 sets of duplicates was accepted.

b) Bulked samples usually consisted of about 20 random samples collected in the field.

c) The soil : replacing solution ratio is shown in the final column. This was not identical throughout, as some results were collected during an exploratory phase in which an effort was being made to determine the most convenient and effective ratio. Since no attempt is made to compare series with series, variations in this proportion do not detract from the value of the results.

Note on table 13.

a) The estimates, and duplicates, of exchangeable calcium and potassium are shown in columns 2 and 3. Estimates and duplicated of exchangeable hydrogen generally agreed closely and the mean of the results is shown in column 1.

b) Bulked soil material was used as in note (b) above.

Note on table 14.

Values shown are single estimates on the bulked soil used in table 13.

Table 10.

Soil Analysis (Using the Brown Method).

Showing the base-status of amorphous peat (Ao horizon) relative to the age of the heather stand.

Reference and Age of heather stand.	/100 gms. fresh soil. Exchangeable Hydrogen in mg. eqs.	/100 gms. fresh soil. Exchangeable Base in mg. eqs.	/100 gms. dry soil. Exchangeable Hydrogen in mg. eqs.	/100 gms. dry soil. Exchangeable Base in mg. eqs.	Soil pH.	Dry soil /100gms. fresh weight.	% base Sat.	Soil: Solution ratios.
Bamford 3yrs.	28.75	2.30	64.2	5.13	3.5	44.8	7.4	Exchangeable hydrogen 4 gms.:100 mls. Exchangeable base 20gms.:100 mls.
" 10 "	33.25	1.95	75.2	4.42	3.575	44.2	5.6	
" 17 "	26.25	1.15	85.5	3.75	3.6	30.7	4.2	
Toadsmouth								
1 yr.	28.75	2.2	108.5	8.33	3.48	26.5	7.14	
" 2 "	37.5	2.25	85.2	5.62	3.43	44.05	5.66	
" 7 "	40.6	1.85	78.0	3.56	3.47	52.05	4.36	
" 20 "	30.0	1.13	84.2	3.16	3.23	35.6	3.62	
Ringinglow								
2yrs.	27.5	1.44	79.2	4.14	3.4	34.75	4.97	Exchangeable hydrogen 4 gms.:100 mls. Exchangeable base 25gms.:100 mls.
" 4 "	24.5	1.16	75.8	3.58	3.6	32.3	4.52	
" 10 "	28.75	0.88	88.2	2.71	3.3	32.55	2.98	
" 20 "	23.5	0.88	91.3	3.41	3.4	25.85	3.61	
Lodgemoor								
2 "	27.0	1.3	103.9	5.0	3.6	26.0	4.6	Exchangeable hydrogen 4 gms.:100 mls. Exhangeable base 50 gms.:100 ml.
" 3 "	31.5	1.1	75.5	2.63	3.5	41.8	3.38	
" 10 "	29.4	0.96	74.8	2.45	3.3	39.3	3.15	
" 20 "	26.75	0.90	85.5	2.88	3.3	31.25	3.26	

Table 11. **Soil Analysis** (Using Brown Method).

Comparisons of base status of A horizons (generally from depth 0-2 inches) in adjacent communities.

Reference.	/100 gms. fresh soil. Exchangeable hydrogen in mg. eqs.	/100 gms. fresh soil. Exchangeable base in mg. eqs.	/100 gms. dry soil. Exchangeable hydrogen in mg. eqs.	/100 gms. dry soil. Exchangeable base in mg. eqs.	Soil pH.	Soil/ 100 gms. fresh weight.	% base Sat.	Soil:Solution ratios.
Bamford								
Calluna(10yrs)	32.8	3.25	73.5	7.38	3.55	44.2	9.14	
Pasture	25.0	3.5	36.2	4.98	3.8	69.0	12.05	
Pinewood	28.13	3.75	67.7	9.05	3.82	41.55	13.40	Exchangeable hydrogen 4 gms.:100 mls.
Bretton								
Calluna(10-15	31.68	1.38	71.25	3.09	3.38	44.4	4.17	Exchangeable base
Pasture yrs)	3.75	15.28	4.36	19.75	6.9	77.25	84.4x limed.	20gms.:100 mls.
Larchwood	25.75	2.15	56.6	4.73	3.85	45.5	7.72	
Blacka								
Calluna (20yrs)	27.38	1.45	106.3	5.63	3.25	25.78	5.03	
Pasture	11.75	6.85	19.1	11.3	5.15	61.5	36.7x flushed	
Alder-Birchwood	27.38	2.05	83.1	6.22	3.55	32.95	6.97	
Lady Cannings								
Calluna (15yrs)	33.25	0.925			3.15		2.71	Exchangeable hydrogen
Pinewood	31.9	1.05			3.13		3.19	2 gms.:50 mls.
Rowanwood	38.0	1.325			3.3		3.38	Exchangeable base
Derelict Pinewood (wet)	29.0	1.325			3.3		4.37	10gms.:50 mls.
Strines								
Calluna (10-15 yrs)	50	1.5	149.0	4.46	3.5	33.6	2.91	Exchangeable hydrogen
Pinewood (some larch)	50	2.0	151.2	6.02	3.8	33.2	3.85	2 gms:50 mls.

continued..........

Table 11 (Continued)

Reference.	Exchangeable hydrogen in mg. eqs.	Exchangeable base in mg. eqs.	Exchangeable hydrogen in mg. eqs.	Exchangeable base in mg. eqs.	Soil pH.	Soil/ 100gms. fresh soil.	% base Sat.	Soil : Solution ratios.
Strines (Cont'd)								
Young pine & spruce plantat.	37.5	3.7	66.6	6.58	4.1	56.3	8.98	Exchangeable base 10gms.:50mls
Derwent Valley								
Calluna (10yrs)	56.0	1.5	163.0	4.37	3.53	34.3	2.61	
Pinewood	47.0	2.3	107.5	5.26	3.75	43.75	5.23	
Sycamore plantation	26.5	2.8	43.9	4.63	3.88	60.4	9.55	
Lodgemoor.								
Calluna (20yrs)	31.63	1.75	85.3	4.73	3.25	37.0	5.24	Exchangeable hydrogen 4gms.:100mls.
Vac.myrtillus stand	27.25	1.88	77.8	5.36	3.5	35.0	6.44	
Houndkirk Hill.								
Calluna (20yrs)	25.94	1.13	48.25	2.09	3.31	53.8	4.16	Exchangeable base 20gms.:100mls
Vacc.myrtillus stand	17.5	1.31	31.20	2.35	3.43	56.0	6.98	

Table 12.

Soil Analysis

Comparisons of the base status of soil of the C horizon from some of the sites detailed in tables 10 and 11.

Reference	/100 gms. fresh soil. Exchangeable Hydrogen in mg. eqs.	/100 gms. fresh soil. Exchangeable Base in mg. eqs.	/100 gms. dry soil. Exchangeable Hydrogen in mg. eqs.	/100 gms. dry soil. Exchangeable Base in mg. eqs.	Soil pH.	Dry soil /100 gms fresh soil.	% Sat.	Soil:Solution ratio
Ringinglow 2 yrs	10.75	4.25	14.2	5.62	4.0	75.7	28.3	
" 4 "	11.25	4.35	14.75	5.70	3.9	76.3	27.9	
" 10 "	10.75	4.25	14.25	5.63	3.9	75.5	28.3	Exchangeable hydrogen 4 gms:100 mls.
" 20 "	11.25	4.25	15.3	5.76	3.7	73.7	27.4	
Bamford 3 "	8.0	5.15	9.67	6.22	4.1	82.8	39.2	Exchangeable base 20 gms:100 mls.
" 10 "	10.0	5.5	12.67	6.96	3.9	79.0	35.5	
" 17 "	8.0	4.75	9.97	5.92	4.0	80.3	37.2	
Pinewood	11.0	4.75	13.75	5.95	3.9	80.4	30.3	
Strines.								
Calluna (10-15)	11.0	2.1	15.0	2.86	3.95	73.25	16.1	
Pine-Larixwood	10.0	2.5	12.15	3.04	3.80	82.20	20.0	Exchangeable hydrogen 2 gms.:50 mls.
Open Pine Spuce plant.	9.0	3.4	11.35	4.29	5.63	79.25	27.4	Exchangeable base 10gms.:50 mls.
Derwent Valley								
Calluna (10yrs)	8.5	2.2	11.75	3.2	3.72	72.8	20.28	
Pinewood	9.0	3.0	11.95	3.98	3.73	75.4	25.0	
Sycamore	6.0	3.1	7.75	3.89	4.15	77.4	33.2	
Lodge moor								
Calluna (old)	10.0	2.75	13.5	3.71	3.75	74.0	21.6	
Vacc. (old)	7.0	2.75	8.86	3.48	3.88	79.0	28.2	

Table 13. **Calcium - Potassium status of soils relative to the age of the heather stand**

Bamford

/100 gms. fresh soil

Soil	horizon	Exchangeable Hydrogen in mg. eqs.	Exchangeable Calcium in mg. eqs.	Exchangeable potassium in mg. eqs.	Base/100 gms fresh soil in mg. eqs.	(Ca+K)/100 gms dry soil in mg. eqs.	% Saturation Ca/Ca+H.	% Saturation Ca+K/Ca+K+H.
1 yr	A^o	20.0	.602	.161	.772	2.18	2.92	3.72
			.613	.167				
4 yrs	"	21.875	.546	.148	.692	1.86	2.43	3.07
			.541	.147				
11 "	"	24.0	.510	.179	.676	1.94	2.07	2.74
			.505	.157				
1 "	A_2	12.0	.232	.130	.336	.393	1.83	2.72
			.214	.135				
4 "	"	12.0	.210	.108	.308	.342	1.72	2.59
			.208	.089				
11 "	"	18.0	.163	.074	.242	.275	0.9	1.33
			.163	.090				
1 "	B	14.25	.143	.097	.252	.320	1.02	1.75
			.148	.115				
4 "	"	16.25	.113	.083	.198	.243	.69	1.20
			.113	.087				
11 "	"	16.5	.130	.071	.210	.236	.78	1.26
			.130	.088				
1 "	C	7.75	.123	.071	.210	.258	1.56	2.64
			.123	.072				
4 "	"	5.25	.092	.109	.163	.196	1.71	3.01
			.091	.078				
11 "	"	8.75	.128	.087	.216	.260	1.39	2.41
			.117					

Table 13 (Cont'd) /100 gms. fresh soil **Toadsmouth**

Soil	horizon	Exchangeable hydrogen in mg. eqs.	Exchangeable Calcium in mg. eqs.	Exchangeable potassium in mg. eqs.	Base/ 100 gms fresh soil in mg. eqs.	(Ca+K)/ 100 gms dry soil in mg. eqs.	% Saturation. Ca/Ca+H.	% Saturation. Ca+K/Ca+K+H
1 yr.	A^o	24.5	.695 .705	.155 .155	.855	2.34	2.77	3.36
3 yrs	"	24.75	.575 .570	.180 .140	.733	2.16	2.26	2.88
8 "	"	25.75	.575 .535	.180 .195	.743	1.88	2.11	2.81
20 "	"	24.0	.470 .435	.155 .140	.601	1.77	1.85	2.44
1 "	B	Not represented in profile			-	-	-	-
3 "	"	9.05	.160 .130	.130 .110	.265	.388	1.58	2.86
8 "	"	9.3	.175 .165	.080 .090	.255	.360	1.80	2.67
20 "	"	8.7	.140 .125	.060 .075	.201	.264	1.51	2.26
1 "	C	-	No Subsoil - bedrock immediately below A_2					
3 "	"	-						
8 "	"	6.0	.120 .125	.095 .080	.211	-	2.01	3.40
20 "	"	7.45	.145 .130	.140 .150	.283	-	1.83	3.66

Table 13 (Cont'd) Ringinglow.

Soil	Horizon	/100 gms. fresh soil Exchange-able hydrogen in mg. eqs.	Exchange-able Calcium in mg. eqs.	Exchange-able potassium in mg. eqs.	Base/100 gms fresh soil in mg. eqs.	(Ca+K)/100 gms dry soil in mg. eqs.	% Saturation Ca/Ca+H	Ca+K/Ca+K+H
3 yrs.	A^o	23.75	.775 –	.0995 –	.875	2.80	3.16	3.55
5 "	"	21.25	.685 .700	.142 .121	.825	2.18	3.16	3.74
11 "	"	24.375	.613 .613	.141 .113	.740	2.43	2.46	2.95
20 "	"	20.75	.540 .537	.165 .188	.715	2.78	2.53	3.33
3 "	A_2	11.0	.194 .195	.078 .078	.273	.322	1.61	2.39
5 "	"	13.75	.184 .176	.074 .104	.269	.329	1.40	1.95
11 "	"	15.0	.160 .157	.115 .103	.268	.311	1.05	1.76
20 "	"	11.0	.177 .172	.09 .09	.265	.310	1.57	2.35
3 "	B	17.75	.087 .082	.094 .114	.189	.258	.473	1.05
5 "	"	21.75	.133 .128	.120 .130	.255	.359	.594	1.16
11 "	"	17.25	.117 .102	.102 .102	.212	.288	.634	1.22
26 "	"	17.75	.082 .082	.087 .085	.173	.250	.486	0.96
3 "	C	5.0	.061 .072	.084 .100	.159	.197	1.32	3.08
5 "	"	5.75	.072 .082	.093 .074	.161	.202	1.32	2.72

Table 13 (Cont'd) Ringinglow (Cont'd)

Soil	Horizon	/100 gms. fresh soil Exchangeable hydrogen in mg. eqs.	Exchangeable Calcium in mg. eqs.	Exchangeable potassium in mg. eqs.	Base/100 gms fresh soil in mg. eqs.	(Ca+K)/100 gms in mg. eqs.	% Saturation Ca/Ca+H	Ca+K/Ca+K+H
11 yrs.	C	4.25	.082	.096	.173	.194	1.89	3.91
			.082	.086				
20 "	"	5.0	.082	.109	.180	.229	1.52	3.48
			.072	.097				

Table 14. Physical data on Soils.

Bamford.

Soil horizon	Moisture/ 100 gms. fresh soil (in gms.)	Organic matter/ 100 gms. fresh soil (in gms.)	Residual matter/ 100 gms. fresh soil (in gms.)	Dry matter/100 gms. fresh soil (in gms.)
1 yr. A^o	62.8	23.5	13.7	37.2
4 yrs. "	64.6	25.2	10.2	35.4
11 " "	65.2	22.1	12.7	34.8
1 yr. A_2	9.93	5.55	84.52	90.07
4 yrs. "	11.90	7.98	80.12	88.10
11 " "	14.55	7.70	77.75	85.45
1 yr. B_2	18.4	8.2	73.4	81.6
4 yrs. "	10.9	6.8	82.3	89.1
11 " "	21.3	7.3	71.4	88.7
1 yr. C	16.4	3.6	80.0	83.6
4 yrs. "	16.8	5.3	77.9	83.2
11 " "	18.6	4.3	76.1	80.4

Table 14 Cont'd.

Toadsmouth.

Soil horizon.		Moisture/ 100 gms. fresh soil (in gms.)	Organic matter/ 100 gms. fresh soil (in gms.)	Residual matter/ 100 gms. fresh soil (in gms.)	Dry material /100 gms. fresh soil (in gms.)
1 yr.	A^o	66.0	19.8	14.2	34.0
3 yrs.	"	63.4	20.2	16.4	36.6
8 "	"	60.5	22.0	17.5	39.5
20 "	"	66.1	21.2	12.7	33.9
	A_2	NOT INVESTIGATED.			
1 yr.	B_2	NOT PRESENT IN PROFILE.			
3 yrs.	"	31.4	7.2	61.4	68.6
8 "	"	29.0	6.2	64.8	71.0
20 "	"	24.0	6.6	69.4	76.0
	C	Little sub-soil above bed-rock.			

Table 14 Cont'd.

Ringinglow.

Soil horizon	Moisture/ 100 gms. fresh soil (in gms.)	Organic matter/ 100 gms. fresh soil (in gms.)	Residue/ 100 gms. fresh soil (in gms.)	Dry matter/ 100 gms. fresh soil (in gms.)
3 yrs. A^o	68.8	25.5	5.7	31.2
5 " "	62.0	23.6	14.4	38.0
11 " "	69.5	25.8	4.7	30.5
20 " "	74.2	20.7	5.1	25.8
3 yrs. A_2	18.4	76.3	5.3	81.6
5 " "	15.4	62.9	21.7	84.6
11 " "	13.9	64.2	21.9	86.1
20 " "	14.6	67.6	17.8	85.4
3 yrs. B_2	29.0	7.8	63.2	71.0
5 " "	28.9	8.4	62.7	71.1
11 " "	26.4	6.3	67.3	73.6
20 " "	31.0	6.9	62.1	69.0
3 yrs. C	19.2	3.9	76.9	80.8
5 " "	20.5	4.1	75.4	79.5
11 " "	10.9	3.7	85.4	89.1
20 " "	21.4	3.6	75.0	78.6

Table 15. Analysis of green material (Total base content)

Place.	Seasons since the stand was burned	Modal age of heather in years	mg. eq. of base in sample	Weight of sample.	Weight of crude ash	ash/100 gms. green material	carbon: ash ratio	base in mg. eqs./100 gms. green material	
Ringinglow	4	2	1.030	3.100	0.162	5.2	18.0	33.2	*
	4	4	0.986	2.980	0.162	5.2	17.5	33.1	*
	11	c10	1.275	3.990	0.209	5.4	18.5	31.9	*
	20+	c20	0.907	3.170	0.136	4.3	22.3	28.6	*
Ringinglow	4	2	1.18	2.86	0.144	5.1	19.0	41.4	
	4	4	1.14	2.68	0.142	5.3	18.0	42.5	
	11	c10	0.979	2.38	0.108	4.5	21.0	41.2	
	20+	c20	0.877	2.645	0.107	4.0	23.0	33.2	
Toadsmouth	2	2	0.996	2.720	0.156	5.7	16.5	36.6	
	8	c7	1.060	2.980	0.157	5.3	18.0	35.6	
	20+	c20	0.882	2.90	0.127	4.4	22.0	30.4	
Toadsmouth	2	2	0.893	2.39	0.137	5.7	16.5	37.4	
	8	c7	1.105	3.02	0.159	5.3	18.0	36.6	
	20+	c20	0.771	2.59	0.108	4.2	23.0	29.8	
Bamford	5	3	1.14	2.91	0.146	5.0	19.0	39.2	
	12	10	1.05	2.80	0.148	5.3	18.0	37.5	
	c20	18	0.921	2.78	0.140	5.0	19.0	33.2	
Bamford	5	3	1.040	2.670	0.136	5.1	18.5	38.9	
	12	10							
	c20	18	0.970	2.880	0.149	5.2	18.5	33.7	
Lodge moor	3	2	1.29	3.160	0.152	4.8	20.0	41.2	
	3	3	1.00	2.52	0.124	4.9	19.8	39.7	
	12	11	1.06	2.76	0.130	4.7	20.0	38.4	

*Titration of excess acid by sodium hydroxide using phenolpthalein as indicator.

Table 16.

Heather-Leaf Analysis
(Ca content of green material per 5 gms. sample and duplicate)

Reference.	Wt. of Sample in gms	Wt. of crude Ash in gms.	Wt. of silica in gms	Equiv. of ¼ extract in mls. Versene (to nearest 0.25 mls.)	Calcium in mg. eqs./ 5 gm. sample.
Ringinglow.					
	5.03	0.250	0.080	14.0,14.0	1.12
3 yrs. S1-3	5.03	0.250	0.080	14.0,14.0	
	5.02	0.275	0.095	18.0,18.0	1.44
5 " S1-3	5.00	0.275	0.090	17.75,18.0	
	5.02	0.245	0.070	16.0,16.0	1.26
11 " S1-3	5.03	0.245	0.070	15.5,15.5	
	5.03	0.250	0.070	12.25,12.0	0.96
20 " S3+5	5.01	0.250	0.070	12.0,12.0	
3 " S4-6	4.99	0.290	0.100	15.75,15.75	1.26
	4.98	0.285	0.100	- -	
	4.99	0.265	0.095	15.5, 15.5	(1.25) x 1
5 " S4-6	4.99	0.265	0.095	15.75,15.75	
	4.99	0.255	0.075	15.0, 15.0	1.20
11 " S4-6	4.98	0.260	0.080	14.5, 14.5	
	4.98	0.215	0.060	10.0, 10.0	0.80
20 " S1-2	4.99	0.215	0.060	10.0, 10.0	
	5.02	0.280	0.085	17.0, 17.0	1.36
3 " S7-9	5.02	0.280	0.080	16.75,17.0	
	5.02	0.295	0.110	17.75,18.0	1.42
5 " S7-9	5.02	0.295	0.105	17.75,17.75	
	5.03	0.260	0.080	14.5, 14.5	1.15
11 " S7-9	5.02	0.260	0.080	14.25,14.25	
	5.03	0.190	0.050	8.25, 8.25	0.66
20 " S4-6	5.03	0.185	0.050	8.25, 8.25	
Bamford.					
	5.01	0.235	0.080	18.0, 18.0	1.45
4 yrs. S1-3	5.01	0.245	0.080	18.25,18.25	
	5.03	0.265	0.090	16.0, 16.0	1.28
11 " S1-3	5.02	0.255	0.090	16.0, 16.0	
	5.03	0.255	0.085	15.25,15.25	1.21
18 " S1-3	5.02	0.250	0.085	15.0, 15.0	
	5.01	0.250	0.080	18.0, 18.0	1.44
4 " S4-6	5.00	0.255	0.080	18.0, 18.0	

Table 16 (Cont'd)

Reference.		Wt. of Sample in gms.	Wt. of Crude Ash in gms.	Wt. of Silica in gms.	Equiv. of ¼ extract in mls. Versene (to nearest 0.25 mls.)		Calcium in mg. eqs./ 5 gm. sample.
		5.01	0.245	0.080	17.0	17.0	
11 yrs.	S4-6	5.01	0.245	0.080	16.75	16.75	1.35
		5.00	0.255	0.075	15.25	15.25	
18 "	S4-6	5.01	0.255	0.070	15.00	15.00	1.22
4 "	S.7-9	5.03	0.275	0.095	17.75	17.75	1.42
		5.03	0.265	0.095	17.75	17.75	
		5.01	0.285	0.110	17.25	17.25	
11 "	S7-9	5.02	0.285	0.115	17.25	17.25	1.38
		5.02	0.275	0.100	17.75	18.0	
18 "	S7-9	5.03	0.275	0.100	18.0	18.0	(1.44) x 2
Repeats of previous analysis							
		5.01	0.270	0.090	16.0	16.0	
R. 5yrs.	S4-6	5.02	0.265	0.090	16.0	16.0	1.28 x 1
		5.00	0.275	0.100	16.75	16.75	
B. 18 "	S7-9	5.00	0.275	0.100	16.75	16.75	1.34 x 2
Toadsmouth							
		5.00	0.275	0.100	17.0	17.0	
3 yrs.	S1-3	5.00	0.275	0.100	17.0	17.0	1.36
		4.99	0.230	0.075	15.25	15.25	
8 "	S1-3	5.00	0.230	0.075	15.0	15.0	1.21
		5.01	0.245	0.075	13.75	13.75	
20 "	S2&4	5.00	0.245	0.075	13.75	13.75	1.10
3 "	S4-6	5.00	0.275	0.105	16.75	17.0	1.34
		5.00	0.275	0.105	16.75	16.75	
		5.01	0.245	0.085	15.0	15.0	
8 "	S4-6	5.01	0.250	0.085	15.0	15.0	1.20
		5.00	0.200	0.070	10.75	10.75	
20 "	S3&5	5.00	0.200	0.065	10.75	10.75	0.86
		5.00	0.245	0.085	15.0	15.0	
3 "	S7-9	5.00	0.245	0.080	15.0	15.0	1.20
		5.00	0.235	0.070	14.0	14.0	
8 "	S7-9	5.00	0.235	0.070	14.0	14.0	1.12
		5.00	0.220	0.075	12.5	12.5	
20 "	S1&6	5.00	0.220	0.080	12.25	12.25	0.99
Lady Cannings.							
		5.02	0.255	0.085	16.0	16.25	
	S1-3	5.02	0.255	0.085	16.25	16.25	1.30

Table 16 (Cont'd)

Reference	Wt. of Sample in gms.	Wt. of Crude Ash in gms.	Wt. of Silica in gms.	Equiv. of ½ extract in mls. Versene (to nearest 0.25 mls.)		Calcium in mg. eqs./5gms. sample.
Lady Cannings (Cont'd)						
S.4-6	5.02	0.260	0.075	14.5	14.5	1.16
	5.03	0.260	0.075	14.25	14.5	
S.7-9	5.00	0.285	0.105	15.0	15.0	1.20
	4.99	0.285	0.105	14.75	15.0	
Blacka (heather)						
S.1-3	5.02	0.260	0.085	14.25	14.25	1.13
	5.01	0.260	0.085	14.0	14.0	
S.4-6	5.00	0.275	0.095	15.25	15.25	1.22
	5.00	0.275	0.095	15.25	15.25	
S.7-9	5.01	0.265	0.080	15.0	15.0	1.19
	5.01	0.265	0.080	14.75	14.75	
Porter Clough						
S.1-2	5.00	0.255	0.070	12.5	12.5	1.00
	5.00	0.250	0.075	12.5	12.5	
S.3-4	5.00	0.255	0.055	12.5	12.5	1.00
	5.01	0.250	0.055	12.5	12.5	
S.5-6	5.00	0.255	0.065	16.75	16.75	1.34
	5.00	0.255	0.065	16.75	16.75	
Blacka (woodland)						
S.2&6	5.01	0.245	0.080	14.75	14.75	1.17
	5.00	0.240	0.080	14.5	14.5	
S.1&3	5.0	0.240	0.070	12.75	12.75	1.02
	4.99	0.240	0.070	13.00	12.75	
S.4&5	5.00	0.215	0.060	13.0	13.0	1.04
	5.00	0.215	0.060	13.0	13.0	

Table 17. Dry wts. of green material from unit areas of continuous heather cover.

(results expressed to the nearest 0.05 gms.)

Bamford

Age of heather stand	Sample number	Dry wt. of green mat. in gms.		Total wt. of dry green material/ stand.	Mean wt. of samples.
	1	12.60			
	2	14.70	38.10		
	3	10.80			
	4	11.95			
4 yrs.	5	12.55	38.00	114.20	12.69
	6	13.50			
	7	12.60			
	8	13.55	38.10		
	9	11.95			
	1	11.75			
	2	8.55	31.00		
	3	10.70			
	4	11.70			
11 yrs.	5	12.50	39.80	103.10	11.46
	6	15.60			
	7	11.15			
	8	12.05	32.30		
	9	9.10			
	1	13.45			
	2	10.35	32.85		
	3	9.05			
	4	9.05			
18 yrs.	5	10.95	30.40	95.55	10.62
	6	10.40			
	7	10.20			
	8	11.15	32.30		
	9	10.95			

Table 17 (Cont'd)

Ringinglow.

Age of heather stand	Sample number	Dry wt. of green mat. in gms.		Total wt. of dry green material/ stand.	Mean wt. of samples.
	*1	10.15			
	*2	8.85	25.30		
	*3	6.30			
3 yrs.	4	13.15			
	5	12.60	37.35		
	6	11.60		76.00	12.67
	7	13.75			
	8	13.75	38.65		
	9	11.15			
	*1	11.25			
	*2	8.65	29.20		
	*3	9.30			
5 yrs	4	12.00			
	5	10.90	33.75		
	6	10.85		69.60	11.60
	7	12.60			
	8	11.80			
	9	11.45			
	1	8.25			
	2	12.30	31.10		
	3	10.55			
11 yrs.	4	9.60			
	5	9.85	29.85	93.20	10.36
	6	10.40		(62.10)	(10.34)
	7	12.30			
	8	9.45	32.25		
	9	10.45			
20 yrs.	1	10.00			
	2	8.50			
	3	10.35		54.45	9.08
	4	7.75			
	5	10.90			
	6	6.95			

Table 17 (Cont'd)

Toadsmouth

Age of heather stand	Sample number	Dry wt. of green mat. in gms.		Total wt. of dry green material/ stand.	Mean wt. of sampleß.
	1	13.75			
	2	15.80	43.50		
	3	13.95			
3 yrs.	4	13.25			
	5	13.05	39.10	124.75	13.86
	6	12.80			
	7	12.55			
	8	15.80	42.15		
	9	13.80			
	1	13.30			
	2	14.85	39.85		
	3	11.70			
8 yrs.	4	15.50			
	5	12.45	40.15	126.70	14.08
	6	12.20			
	7	16.30			
	8	13.95	46.70		
	9	16.45			
	1	10.60			
	2	11.80			
20 yrs.	3	11.10		68.45	11.41
	4	13.90			
	5	11.30			
	6	9.75			

* Discarded. In these samples the method of stripping was not comparable with the remainder.

Table 17 (Cont'd)

Age of heather stand	Sample number	Dry wt. of green mat. in gms.		Total wt. of dry green material/ stand.	Mean wt. of samples.
Blacka (woodland)	1	16.40			
	2	19.65			
	3	16.80		101.35	16.89
	4	15.60			
	5	13.65			
	6	19.25			
Blacka (heather moor)	1	14.15			
	2	14.85	42.30		
	3	13.30			
	4	15.45			
	5	15.85	46.05	131.15	14.57
	6	14.75			
	7	13.65			
	8	15.35	42.80		
	9	13.80			
Porter Clough (Woodland)					
	1	18.60			
	2	16.95		63.10	15.78
	3	13.55			
	4	14.00			
	*5	11.30			
	*6	11.20			
Lady Cannings.					
	1	17.40			
	2	14.60	46.75		
	3	14.75			
(Heather moor)	4	14.00			
	5	13.05	40.05	120.25	13.36
	6	13.00			
	7	11.90			
	8	9.25	33.45		
	9	12.30			

* Discarded for reasons mentioned on p.97

Table 18. Leaf Analysis.

Age of stand in years.	Calcium per sample of 5 gms. (in mg. eqs.)	Mean of 3 samples in previous column.	Mean dry wt. of green material/ unit area in gms.	Calcium uptake per unit area of vegetation. (in mg. eqs.)
Ringinglow.				
3	1.12 1.26 1.36	1.25	12.67	3.16
5	1.44 1.25 (1.28) 1.42	1.37	11.60	3.18 (3.25)
11	1.26 1.20 1.15	1.20	10.36	2.49
20	0.96 0.80 0.66	0.87	9.08	1.58
Bamford				
4	1.45 1.44 1.42	1.44	12.69	3.65
11	1.28 1.35 1.38	1.34	11.46	3.07
18	1.21 1.22 1.44 (1.34)	1.29 (1.26)	10.62	2.74 (2.68)
Toadsmouth				
3	1.36 1.34 1.20	1.30	13.86	3.60
8	1.21 1.20 1.12	1.17	14.08	3.29
20	1.10 0.86 0.99	0.98	11.41	2.24

Table 18. (Cont'd)

	Calcium per sample of 5 gms. (in mg. eqs.)	Mean of 3 samples in previous column.	Mean dry wt. of green material/ unit area in gms.	Calcium uptake per unit area of vegetation. (in mg. eqs.)
Blacka. (woodland)	1.17 1.02 1.04	1.08	16.89	3.64
Blacka (heather moor)	1.13 1.22 1.19	1.18	14.57	3.44
Porter Clough (woodland)	1.00 1.00 1.34	1.11	15.78	3.52
Lady Canning (heather moor)	1.30 1.16 1.20	1.22	13.36	3.26

Appendix 1.

Rainfall data for the main area investigated.

(provided by Sheffield Water Works Dept.)

Annual rainfall in inches for the years 1941 - 51.

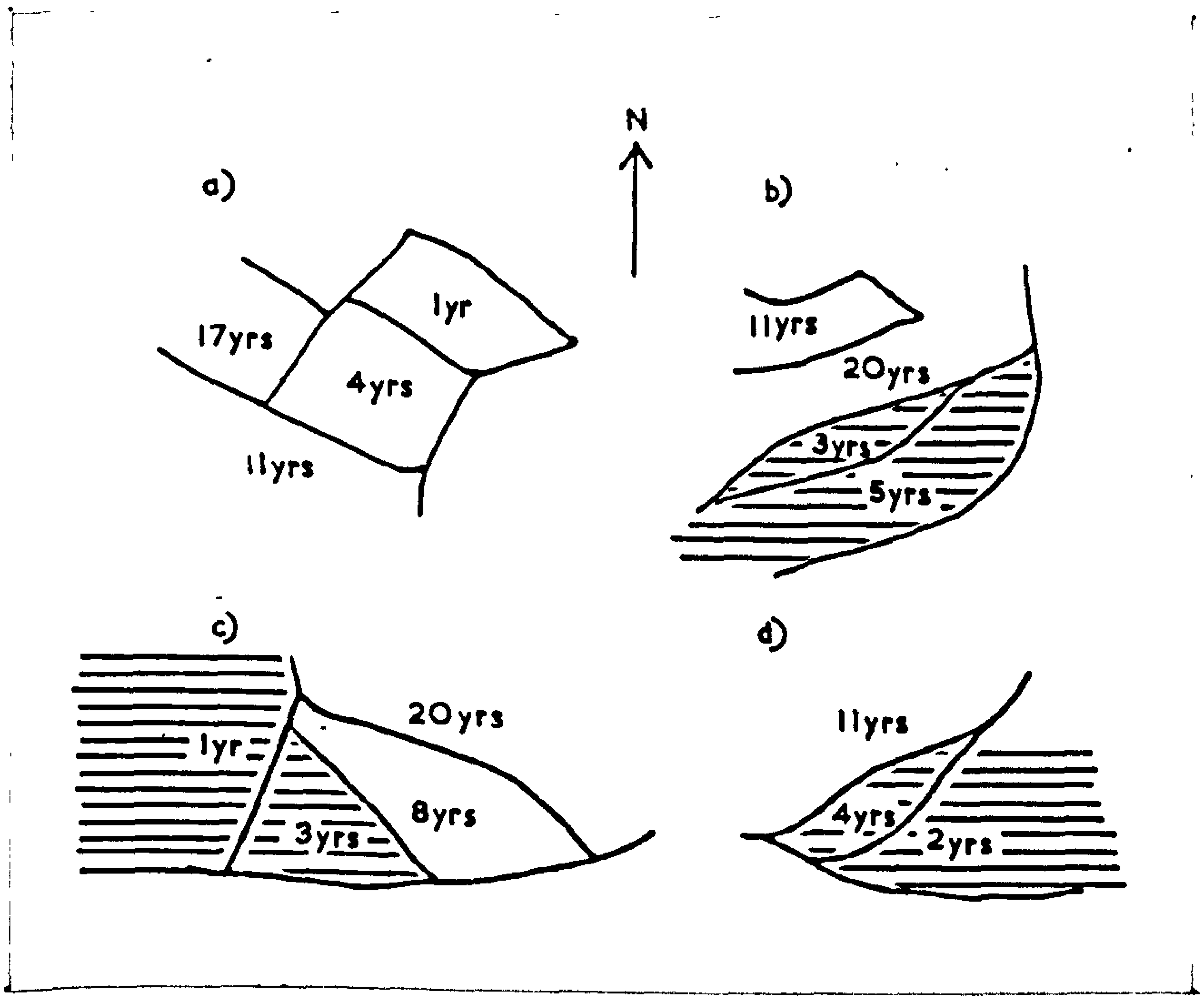
	1. Lower Burbage	2. Badger House	3. White Edge.	4. Higger Lodge	5. Parson's House	6. Upper Burbage	7. Stanage
	924ft.	1138ft.	1209ft.	1225ft.	1309ft.	1364ft.	1395ft.
1941	41.91	43.45	38.35	42.10	41.28	46.04	42.66
42	31.96	33.96	30.91	33.00	30.89	34.75	36.77
43	33.14	34.82	32.44	44.17	32.85	35.51	35.41
44	41.10	43.35	40.67	42.38	41.26	44.93	46.78
45	32.18	33.22	33.83	34.22	33.03	36.71	38.55
46	44.60	48.23	47.69	49.36	50.86	52.90	56.21
47	33.66	36.39	34.30	35.20	36.38	37.59	44.23
48	33.27	37.05	33.72	36.11	36.57	37.56	38.29
49	29.39	30.84	30.34	31.24	32.28	32.50	36.23
50	32.74	35.42	34.01	35.81	34.34	37.86	38.14
51	41.35	41.92	41.48	41.17	42.98	44.12	46.69
Estimated long averages.	37.50	38.90	36.40	38.00	36.80	40.10	46.30
Stations established in,	1926	1930	1926	1926	1926	1926	1936

Monthly rainfall in inches in 1951.

	1.	2.	3.	4.	5.	6.	7.
J.	3.15	3.18	3.25	3.38	3.19	3.33	3.79
F.	3.64	3.94	4.03	3.84	4.07	3.97	3.90
M.	4.78	4.71	4.73	4.66	5.03	4.92	5.54
A.	1.65	1.70	1.63	1.82	1.70	2.06	1.71
M.	4.11	4.06	4.09	4.68	4.44	4.67	4.70
J.	1.20	1.30	1.15	1.35	1.40	1.37	1.40
J.	1.45	1.76	1.62	1.72	1.71	1.68	1.59
A.	4.80	4.77	4.49	4.71	4.82	5.05	4.85
S.	2.09	2.25	2.16	2.05	2.14	2.07	2.14
O.	1.43	1.43	1.31	1.23	1.36	1.42	1.37
N.	8.87	9.64	9.76	8.33	9.25	10.02	10.32
D.	4.18	2.18	3.26	3.40	3.87	3.56	4.38

Diag. 9.

Showing the inter-relationship of the heather stands on four of the moors investigated.



The shaded areas mark the extent of the last burning.
(The individual areas are not to scale).

Appendix 2.

Notes on the individual areas investigated.

All map references apply to O.S. 1/25000, Sheet 43/28 (1947).

Bamford

The area investigated in detail is situated at about 1,250 ft. (M.R. 21.9,84.9), in the midst of heather-moor which is systematically burned in blocks of about 100 x 100 yards. Observed from Stanage Edge, the moor is seen as a patch-work of heather stands of different ages which under suitable illumination appear to show traces of the boundaries of former burnings, although these can not be detected at close range.

The ground slopes gently to SSE and also towards the east into Moscar stream where drainage becomes impeded and a grass-sedge community occurs. Whilst grazing does not seem to be heavy, the area may be slightly overgrazed in wet weather owing to the sheep refusing to cross the stream in their diurnal perambulations from Bamford Edge to Stanage Edge.

The four burned areas investigated are arranged as illustrated (diag. 9 a), and are uncomplicated by "overburning". All 4 areas seem to have developed as the result of seedling regeneration (Appendix 3,&p. 50) so that the previous stands must have been 15 or more years old at the time of burning. Burning on the moor as a whole, at least in recent years, appears to have been in cycles of about 20 years.

Ringinglow

The area investigated is situated at about 1400 ft. (M.R. 25.6,82.7), and is isolated from adjacent heather by roads on the south and west, and by White Path Moss to the north. Ownership ties the area with White Path Moss and moorland to the north and it is unlikely to have received the attention that other parts of the property have done because of its isolation. In any event, burning is not systematically practised on the more extensive heather-dominated areas of the property. It is almost certain that the burned areas investigated arose from accidental firing.

The ground slopes gradually to the east and slightly more to the north. Part of the old stand and all of the medium aged one are located on the more noticeable slope, the remainder of the stands are on the gradual slope.

Grazing pressure may be heavier than the extent of the area would suggest and it is rare for sheep to be absent from it. This is probably due to the shortage of young heather in the immediate vicinity.

The four heather stands investigated are arranged as in diag. 9 b. The last burning (shaded) destroyed a young stand of heather (predecessor of present 5 years old stand) and that part of the oldest stand labelled 3 years. Consequently regeneration in the area labelled 5 years has been by rootstock whilst recovery of the 3 year old area is much slower, being dependent on seedling regeneration. The 11 years old stand was derived directly from the present 20 years old one, when the latter was young enough for the burned part to regenerate from rootstock. Briefly the 5 years old and 11 years old heather stands have arisen as the result of rootstock regeneration, whilst the 3 year old and almost certainly the 20 year old stands are the result of seedling regeneration in normal long-cycle burning.

Toadsmouth.

The area investigated in detail is situated at about 1,100 ft. (M.R. 25.7,81.1), in the midst of moor that was systematically burned until taken over by Sheffield Corporation in 1939. Burning was previously done in narrow strips of 10 - 30 yards width, and variable lengths.

The ground slopes slightly to the south west.

Grazing is not likely to be heavy as the sheep 'walks' are long, from Higger Tor to Padley Wood.

The four burned areas investigated are shown in diag. 9 c. The last burning (shaded) destroyed the western part of the oldest stand in the area labelled 1 year and encroached into a younger one (the present 8 years old), in that part labelled 3 years. Consequently although the areas labelled 1 and 3 years were burned at the same time, the rates of heather recovery in the two areas are very different, that of the 1 year being the result of seedling and that of the 3 year old the result of rootstock regeneration. The area labelled 8 years (and that of the present 3 years old stand) was previously derived directly from the oldest stand and there is no doubt that regeneration was by rootstock. The heather of the oldest stand is certainly more than 20 years old and is interesting as it suffered a heavy infestation of heather beetle in 1952 and was almost completely defoliated. Younger heather in the vicinity was not attacked to any extent which is contrary to the observations of Cameron (6) and Leslie (49).

Lodge Moor.

The small area investigated is situated at 1300 ft., (M.R. 24.6, 88.5). The moor is reserved for grouse-shooting and no grazing by sheep occurs. Although deliberately burned, the acreage burned is very small and quite inadequate to maintain a rigid cycle. There seems little doubt that burning in the past has been equally irregular.

The moor is almost level but the area investigated slopes imperceptibly to the south east.

The last burning completely destroyed an old stand (the area labelled 2 years) and encroached into a small area of the present 11 years old stand in the part labelled 4 years (diag. 9d). Regeneration of heather in the 4 years old area has clearly been by rootstock and contrasts markedly with the 2 years old area where regeneration is by seedlings. For some reason the recovery of the latter area is more than usually slow (fig. 11 a - b).

Hallam.

The two areas investigated are situated at 1,100 ft., (M.R. 25.5, 87.2). The moor has a long history of systematic burning and these two areas in particular will have been heavily burned in view of their proximity to shooting butts.

The ground slopes slightly to the north. Grazing is normal. Only two adjacent stands have been investigated in detail; these are referred to as the 9 years old and 1 year old stands. The 1 year old stand was derived directly from the present 9 years old one. Heather regeneration in both stands has been rootstock.

Houndkirk Hill.

The area investigated is situated at 1,200 ft. (M.R. 28.6, 81.9), on the top of a pyramidal hill rising abruptly from the surrounding moor. The Hill has obviously not been frequently burned, although the surrounding moor has no doubt been systematically managed in the past. The ground of the burned areas slopes to the north-east, and the last burn was probably accidental. Grazing is normal.

Only 3 stands were investigated, referred to as the 20+ years, 2 years and 1 year old stands.

The last burning destroyed part of the oldest stand and also a small patch of younger heather of unknown age within it. The latter must have been less than about 15 years old since regeneration has been by rootstock. Consequently, as burning only occurred two seasons previously, the contrasted rates of heather recovery as the result of rootstock regeneration (2 yrs) and seedling regeneration (1 year) can be seen at an early stage after burning (fig. 12). The heather on this site was the oldest encountered, several stems showing 24 annual rings.

Porter Clough.

Situated at about 1,050 ft., (M.R. 28.7, 84.1), this plantation was probably established in the early part of the last century. It is located on soil derived from the Millstone Grits. Further details of its history, vegetation etc., are given by Ovington (56).

Only a small amount of heather occurs within the enclosure, in the form of large isolated bushes where shading is absent.

Lady Cannings Plantation.

Situated at approximately 1,150 ft., (M.R. 28.6, 83.4) this site is very near to Porter Clough. Formerly an extensive plantation, much of it has been felled in the lifetime of some of the local inhabitants i.e. since 1875 - 1900. The felled parts have been replaced by continuous heather cover, at present consisting of oldish but vigorous plants. The last burning must have been extensive as the heather is of uniform age over a large area. The vegetation of the wooded area is described by Scurfield (69).

Blacka Plantation.

This area is situated on Millstone Grit, at approximately 1,000 ft., (M.R. 28.5, 80.8). The ground slopes towards the east.

Part of the original plantation was felled prior to 1900 and is now occupied by continuous heather cover (with extensive patches of Vaccinium dominated vegetation). The remaining part of the plantation is probably a complex of natural regeneration (birches) and planting. The heather collected for leaf analysis, from an area unlikely to have been burned, was taken from a small clearing in part of the remaining woodland.

Other areas will be described when and if required.

Appendix 3.

The estimation of the time of burning in heather stands.

Although records are maintained by some keepers of 'vermin' destroyed, 'bags' etc., it does not appear to be the practice to record information on burning. Consequently in order to determine the time that has elapsed since a particular stand was burned a considerable amount of research and enquiry may be involved. It is possible to set about this in several ways but the following have proved most fruitful.

Although it would seem that the most reliable method is to consult the persons who own the property or actually conducted the burning, the confidence that can be placed in this information largely depends on the individual supplying it. Moreover even in the case of the more reliable observers, accuracy falls off rapidly with the passage of time. Occasionally 'disinterested' bodies have been able to provide accurate information, e.g. road-menders local inhabitants etc., although this is likely to be even less reliable than that of the shepherd or keeper unless the burning happened to coincide with some incident in which they were particularly interested.

In the absence of such information and even when this has been available it has been the practice to estimate the time of burning by means of ring counts. In view of the relatively small size of the stems this can not be done in the field and material must be sectioned and inspected under the microscope. Unfortunately the differentiation of woody material according to the season is not so clearly defined in heather as in trees whilst aberrations other than those due to defoliation, drought etc. are apparently common. Smith (72) quotes an example of this in heather known to be 55 years old which on sectioning showed only 30 annual rings. The fact that heather has not been encountered of greater age than 24 years despite the fact that in many areas burning may not have occurred for at least 30 years, may be the result of this phenomenon. Experience has shown that aberrations in the number of annual rings occur in heather of all ages, although in young and medium stands these are usually conspicuous by their divergence from the general age-distribution range. These will obviously not be so easy to detect in older stands with a wider distribution range and it has been found advisable to give the time of burning as 20+ years where the modal age of a stand was estimated as more than 20 years.

With regard to the details of technique these are as follows. Stems for sectioning were collected as near ground level as possible without 'burrowing' into the peat. In more mature stands this was done more or less at random, but in the younger stands the larger stems only were collected. (i.e. young seedlings were neglected). It should however, in fairness, be stated that the diameter of the stem is of little guide to age and frequently the younger stems are several times thicker than the older ones. In practice it has been found that 25 stems are usually sufficient to obtain a fair estimate of the age distribution of a particular stand.

For each stem a number of serial sections were taken from the oldest part and the annual rings counted in as many sections as were necessary to reach a decision as to the age of the stem. This is necessary since the rings are extremely difficult to detect unless the cut face is exactly at right angles to the axis of the stem. Owing to torsion, bending and the excentric arrangement of the rings a considerable number of sections may be necessary before an estimate can be made. Fortunately the sections can be fairly thick (indeed they should not be too thin) and may be inspected without staining although a light wash with saffranin may assist if difficulty is experienced.

In sectioning very stout and hard old stems it is often advisable to pare down the cut face in order to enable a clean and continuous cut to be made. Care must of course be taken to arrange the paring so that sections can be made where the annual rings are widest. If stems are taken too near the peat they are likely to appear as an undifferentiated mass of tissue whilst stems which are 'laid' on or in peat tend to exhibit a similar confusion of structure. Whether this is due to genuine anatomical change in the rootstock region or to growth under moist conditions has not been decided. In considering the age distribution of the various stands it will be convenient to commence with the medium aged stand at Bamford where in view of the large blocks burned uniform results may be expected. The distribution in this stand was as follows.

Age.	Frequency.	
13	xx	
12	xxxx	
11	xxxxxxxx	(One estimate of 17 years
10	xxxxxx	was discarded).
9	xxxx	
8	xx	

This distribution range was one of the more spectacular encountered and shows a very regular curve. In view of the form of this (and of others), individual stands have been identified throughout the thesis according to the modal age of the heather plants e.g. 11 years in this instance. Fortunately it was possible on this occasion to date the time of burning, a shepherd recalling that the stand was burned at the outbreak of war (autumn 1939). Since the counts were made in autumn 1952 it is clear that the 2 oldest plants in the distribution curve (13 years) were established in the first growing season. The date of burning is therefore equivalent to the modal age of the stand plus two years. This fact is of considerable interest when related to the sequence of recovery after burning illustrated in fig. 13. It will be recalled that it is not until the 3rd year after burning that 100% frequency is achieved by heather. Although data has not been accumulated on the proportion of 1:2:3 year old seedlings, it is clear from fig. 13 that a 50% increase in frequency, due to the establishment of seedlings of the current season, has occurred between the second and third years after burning. It would therefore appear reasonable to expect a 50:50 chance of encountering 1 year-old seedlings in the third year after burning. Alternatively the chances of encountering 1 year old seedlings in the third season after burning would be greater than those of either 2 or 3 years old plants - a fact which is borne out by the age distribution. Hence it appears that the third year after burning represents the period of greatest colonisation since inspection of the age distributions suggests that the frequency of new arrivals into the stand declines in succeeding years. The latter is no doubt related to the decrease in colonisable ground due to the vegetative expansion of plants already established, particularly where grazing occurs (Gimingham 34) and where the bare ground is not uniformally open to colonisation due to litter accumulation (p. 51).

The oldest stand at Bamford shows essentially the same type of distribution viz.

Age.	Frequency.
19	x
18	xxx
17	xxxxxxxx
16	xxxxx
15	xx
14	xxx
13	xx
12	x

The modal age of the stand is clearly 17 and the evidence is in favour of burning having occurred 19 (possibly 20) years previously.

A younger stand at Bamford had the following distribution.

Age.	Frequency.
6	xx
5	xxxxxxxx
4	xxxxxxxxxxx
3	xxxx

Here owing to the conscious selection of older stems the curve has been curtailed and over-weighted in the older region. The time of burning would still however be estimated as 6 years previously which was in fact confirmed by enquiry.

The youngest stand shows the effect of selection in an even more pronounced manner.

Age.	Frequency.
5	x
4	x
3	xxxxxxxxxxxxx
2	xxxxxxxxxx

There is clearly little pattern evident in this distribution and the modal age could be either 2 or 3 years (a larger sample might easily alter the 13:10 ratio). Actually 3 seasons had elapsed since burning when the count was made. If sampling had been random it would have been expected that the frequency of 1 year old seedlings would have exceeded that of the 2 and 3 years old.

Another type of distribution needs to be mentioned and this is the one arising from the burning of young heather stands. The 5 year old stand at Ringinglow falls into this category and the distribution is as follows.

Age.	Frequency.
6	xx
5	xxxxxxxxxxxxxxxx
4	xxxxxx
3	x

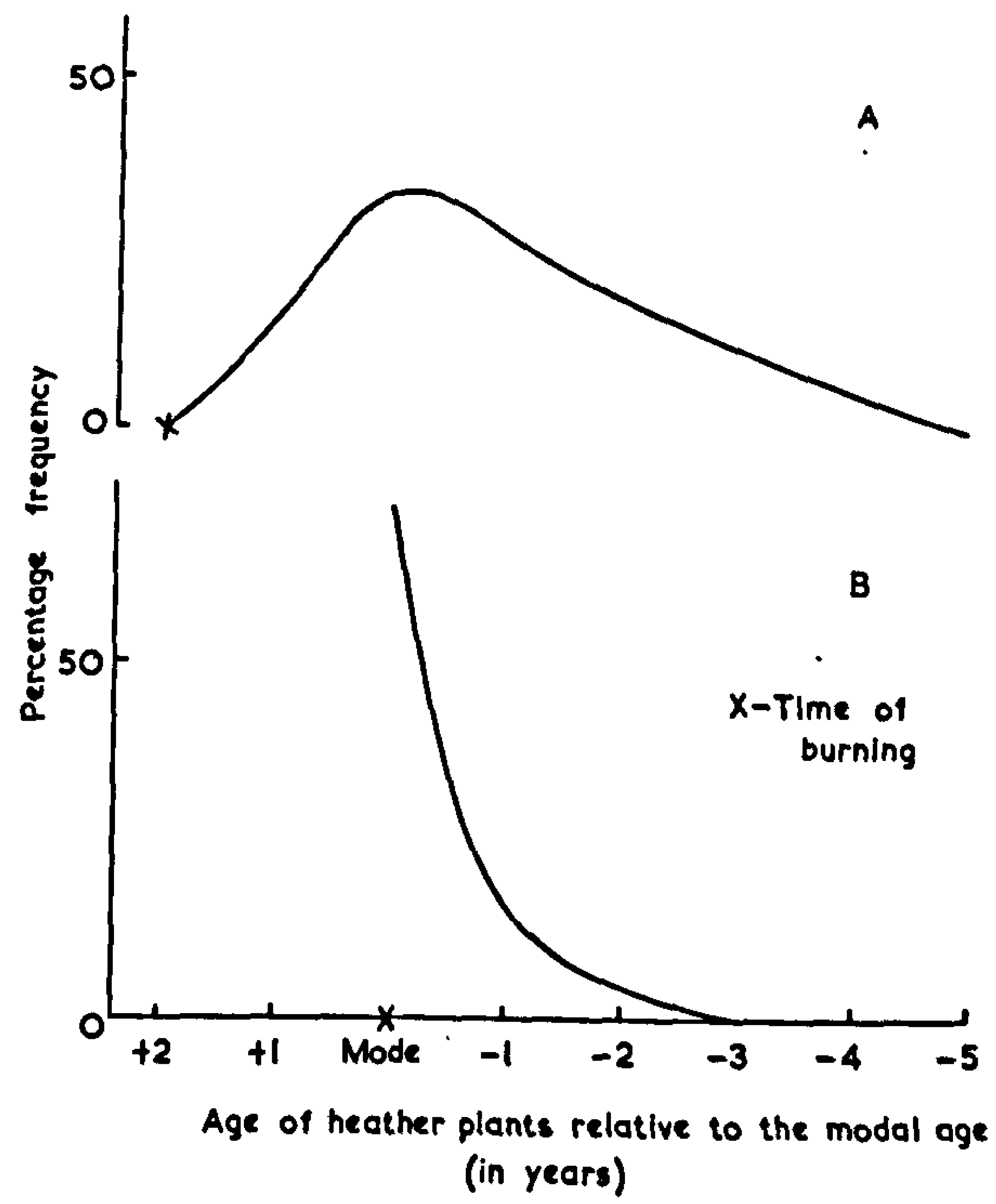
The corresponding stand derived from old heather and burned at the same time has the normal distribution.

Age.	Frequency.
5	xx
4	xxxxxx
3	xxxxxxxxxxxx
2	xxxxx

Both stands were burned at 5 growing seasons previous to ring counting a fact substantiated by the normal distribution (3 years modal age + 2 years). When young heather is burned it is clear that the modal age of the stand coincides with the time of burning. This is not unexpected when the high coverage, due to regeneration from rootstock, in the first year after burning is considered (fig. 14). It is clear that the two 6 years old stems recorded were due to causes mentioned

Diag. 10.

Illustrating the age-distribution of heather plants where regeneration has resulted from A. seeding and B. rootstock.



The relationship of the time of burning to the modal age of the population is indicated.

earlier (p. II) or more probably to inclusion of parent material which survived the burning.

That this type of distribution is a regular feature of stands regenerating from rootstock is confirmed in the following examples. The 11 years old stand at Ringinglow originated in this manner and has the following distribution.

Age.	Frequency.
12	xxx
11	xxxxxxxxxxxxxxx
10	xxxx
9	x
8	
7	x
6	x

The time of burning is therefore very probably 11 growing seasons previously. (The 3 counts of 12 yrs. can be discarded for reasons stated above). The value of appreciating this type of distribution is illustrated by the fact that this stand was not at first recognised as one due to regeneration from rootstock until ring counts were made. Thereafter inspection of the bush form of growth (p. 50) and calculation of the probable age of the parent stand at the time of burning (p. left no doubt as to its origin.

Two further stands taken from Toadsmouth will be sufficient to conclude the illustration of this type of distribution. The youngest was burned in the spring of the year previous to that in which sampling was done (autumn).

Age.	Frequency.
5	x
2	xxxxxxxxxxxxxxxxxxxx
1	xxxx

The form of this curve should be contrasted with that of the youngest stand at Bamford (p.VI) when it will be obvious that no possibility of confusing the two can arise. In this particular stand the burning had been comparatively light and some of the parent stems still remained. When these were examined they frequently showed burning scars on the rings laid down two seasons previously.

The parent stand itself (Appendix 2) showed the same form of distribution.

Age.	Frequency.
8	xxxx
7	xxxxxxxxxxxxxxxxxx
6	xx
5	x

--- clearly dating the time of burning as 7 years previously.

Briefly therefore it seems possible to determine the date of burning with a fair degree of accuracy and also the origin of the stand, by inspecting the age distribution of the plants. (In any event the use of the modal value alone to compare stands of different ages is not likely to be more than 2 years out from the time of burning). If the age distribution curve is as in diagram 10A. the evidence suggests that the stand arose as the result of regeneration by seedlings and the number of seasons that have elapsed since burning is 2 more than the modal age of the heather plants. If on the other hand the curve follows the pattern in diag. 10B, with appreciably more than 50% of the stems showing the same age, there is every possibility that the stand arose as the result of rootstock regeneration and that the time of burning coincides with the modal age of the stand.

Before concluding it is necessary to mention the difficulty of dating the oldest stands. All those investigated apparently follow the age-distribution depicted in diag. 10A. (no examples of old stands showing the pattern of diag. 10B, i.e. arising originally by rootstock regeneration, have been recognised). It is virtually impossible to determine whether this is because no old stands arising originally from rootstock regeneration have been encountered or whether old stands ultimately conform to the general pattern of 10A.

The following points should be noted in dealing with the age-distributions of old stands. Apart from theoretical considerations involving changes in the composition of the population owing to the death of individual plants, the technical difficulties of handling old materialsare considerable. The rate of growth as the plant ages and the resulting proximity of the more recent annual rings makes the accurate determination of the age of individual stems very difficult. Because of the toughness of the material, the toppling-over of stems in the field, leading to mechanical damage, burying under peat etc., a larger proportion of each stem is necessarily discarded than in the case of younger stems, before a sufficient number of satisfactory sections can be obtained. The nett result is probably an estimation of age at as much as 2 or 3" above the original stem base giving an overall underestimation of age by possibly 1 or more years.

To illustrate this, the distribution of old stands at Toadsmouth and Ringinglow are given, both of which are certainly older than they appear to be.

Toadsmouth

Age.	Frequency.
21	xx
20	x
19	xxxxxxxxx
18	xxxxxx
17	xxx
16	x
15	xxx

Ringinglow (Autumn 1950).

Age.	Frequency.
20	x
19	x
18	xxxxxxxx
17	xxxxx
16	xx
15	xx
14	xxxx
13	xx

In conclusion, although this technique may not be entirely satisfactory to the statistician, it can be said that it works tolerably well in practice and that in those instances where it has been possible to date the time of burning by other means, the estimate based on this method has agreed in the case of the younger stands and not differed by more than a year (or at most two) in the case of the older stands, from this date.

Appendix 4.

Jonathan Salt Herbarium. (Collected 1775-1800 and now at Western Park Museum, Sheffield 10.)

The following is a list of some of the moorland species in the collection which are now uncommon on, or absent from, the heather moors. Information on the distribution of species is taken from the herbarium sheets or the accompanying index.

Arctostaphylos uva-ursi	Occurring	on	high	moors	S.	W.	of	Sheffield	
Listera cordata	"	"	"	"	"	"	"	"	
Lycopodium alpinum	"	"	"	"	"	"	"	"	
" clavatum	"	"	"	"	"	"	"	"	
" selago	"	"	"	"	"	"	"	"	
Oxycoccus palustris	"	"	"	"	"	"	"	"	
Pedicularis palustris	"	"	"	"	"	"	"	"	(boggy places)
" sylvatica	"	"	"	"	"	"	"	"	(boggy places)
Pinguicula vulgaris	"	"	"	"	"	"	"	"	(boggy places)
Potentilla erecta	"	"	"	"	"	"	"	"	
Erica cinerea	Common	"	"	"	"	"	"	"	
" tetralix	"	"	"	"	"	"	"	"	

The Calluna specimens were very luxuriant with flowering spikes of considerable length.

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