# *A consideration of the tree layers in the peat at sites in the Northern Pennines*

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# INTRODUCTION

At certain localities in the Northern Pennines, forest or tree layers composed of small twigs and sometimes larger branches or even parts of tree trunks form well defined layers in the peat (Plate 1). These wood remains are evidence of former woodland which in the early post-glacial, from 8,200 BC onwards was widespread over much of upland Britain. In the Northern Pennines the thickness of the tree layer diminishes towards the 760m contour and so too does the density of twigs per unit volume of peat. This contour seems to have been about the limit of the tree line during the Boreal period, whereas today the tree line lies at about 533m (Johnson and Dunham 1963).

The tree layer is usually seen lying at the base of the peat above a clay layer or occasionally on the bed rock. In the Northern Pennines sections in which tree layers occur may be seen in places where a stream has cut back into a hillside deeply enough to produce a section of the peat down to the underlying clay (Plate 2). In some profiles a second tree layer may be identified higher in the peat.

Tree layers of this type have been described by several workers. One of the earliest accounts in the literature is given by Lewis (1904) who recorded remains of several species of arctic and arctic alpine willow in thin bands of peat on Cross Fell, altitude 715m. The remains he described were mainly leaves but he did record wood of Empetrum. However, Godwin and plate 1

# The tree layer at Quickcleugh

At Quickcleugh, as at the other sites examined, the tree layer is composed predominantly of Betula wood. The clay layer is shown at the base of the section.

plate 2

# Section through the peat at John's Burn

This plate shows a section that has been prepared as a series of "steps" prior to sampling. At some sites a considerable quantity of overlying peat must be removed before a clean profile can be seen.

Clapham (1951) carried out a survey in the same area and could not confirm Lewis's record. After pollen analysis of the peat they considered it to be of Boreal age (zones V and VI) characterised by high Corylus and Ulmus frequencies. They were unable to find any evidence, either palynological or macroscopic of the willows recorded by Lewis. Raistrick and Blackburn (1931) describe the occurrence of tree layers at a number of sites in the Northern Pennines and give a detailed account of one in Seath Beck below Little Dun Fell. They recorded birch wood with Phragmites and a birch wood peat containing Eriophorum and Calluna. Johnson and Dunham (1963) have recorded tree layers from several sites in the Moorhouse area and more recently Turner et al (1973) have recorded wood layers from several localities in Upper Teesdale, e.g., at 150cm at Foolmire Sike moss Betula wood is recorded and a wood Phragmites peat at 154-450cm. There is, also at Weelfoot Moss Betula with Phragmites at 290-322cm.

Tree layers have been described from other areas of the Pennines. Conway (1954) in her account of the stratigraphy and pollen analysis of Southern Pennine peats describes a wood peat with large trunks and roots, probably of Betula, in the Shelf Moss profile. Tinsley (1975) has described tree layers in the peat of the Nidderdale Moors.

Originally it had been intended as part of this investigation to carry out an analysis for geochemicals in the wood samples and to relate the results to levels in the peat matrix and to modern wood. However the idea had to be abandoned as time could not be allocated on the atomic absorption spectrometer.

The present investigation had the following primary objectives:

(a) To discover a number of sites where peat was exposed down to and including the tree layer in order to reconstruct the age and nature of forests they represent.

(b) To carry out pollen analysis and construct short pollen diagrams across the tree layer of each site.

(c) To examine wood from each site and to identify the tree species as far as possible. Also to identify leaves, fruits, seeds etc.

(d) To collect wood fragments from a standard block of peat and to measure the twig diameters. From the data obtained to construct histograms showing class sizes of the twigs, and to relate any differences between the sites to factors such as altitude and soil (substrate) type e.g., as shown by the occurrence of Phragmites peat, on the growth of the principal tree species - Betula.

Whilst following these objectives it became apparent that at every site studied Betula was the most abundant tree species identified from tree remains. Further studies were initiated to see if it was possible to relate the width of growth rings from a sample of twigs with the location of the tree layer within the peat i.e., whether the layer was in contact with the clay layer and therefore in contact with a good supply of nutrient or higher in the peat and therefore out of contact with this mineral supply. Also whether the Phragmites peat indicating Fen conditions had any relationship with the mean growth ring width of the Betula twigs. As a result of this part of the work several interesting features of the growth of Betula in the forest layers came to light. The occurrence of multiple or false growth rings and the incidence of reaction wood are described in detail later on. It was decided to look at these features on an inter site basis.

The sites chosen for Pollen Analysis and collection of wood and peat samples.

Initially valuable guidance was given by Dr. Judith Turner who suggested, by field demonstration, where to look for possible sites. It was then simply a case of consulting the 1" Ordnance Survey map and walking along streams that cut back into the moor exposing the basal clay.

A number of sites, nine in all, were selected, two of which were in the Derwent catchment area in the east, the others being in Upper Weardale or at the extreme western end of the Tees Valley. The area is delimited by a line drawn from Allenheads to Hard Hill in the west then eastwards over the Tees Valley to Smiddy Shaw in the Derwent Valley. A map of the area showing the position of the sites is given in Figure 1. Site names, grid references and Altitude are shown in Table 1.

Table 1

| Name of Site | Nat. Grid Ref. | Altitude (m) |
|---|---|---|
| Foulsike Burn | NY 867438 | 599 |
| Green Combs | NY 799348 | 502 |
| Herdship Fell | NY 803340 | 548 |
| Hise Hope Burn | NY 017459 | 396 |
| John's Burn | NY 774354 | 581 |
| Killhope Law | NY 819444 | 640 |
| Milburn Forest | NY 883468 | 761 |
| Quickcleugh | NY 883468 | 487 |
| Smiddy Shaw | NY 047462 | 344 |

In addition to these sites, living Betula wood samples were collected from Embleton Fen in Northumberland where Betula grows in association with Phragmites communis. It was thought that these birches might serve as a useful comparison when looking at growth rings of Betula twigs found in the Phragmites peat.

It had originally been hoped to use data from at least twenty sites but it soon became apparent that the work was very time consuming so only ten sites were treated adequately. The ten sites chosen provided several contrasting features which may be summarised as follows:

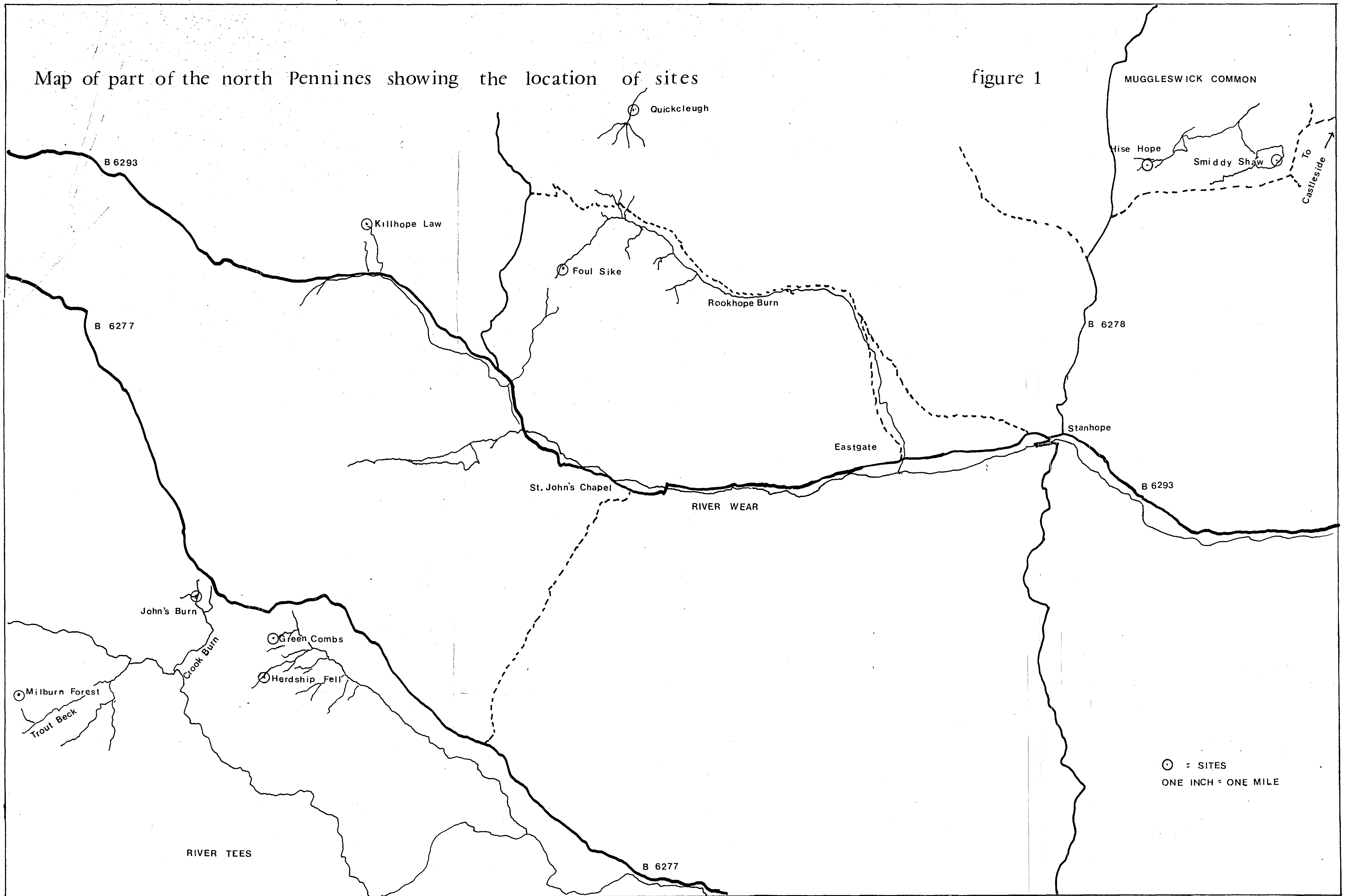
(a) Altitude. Sites above 450m and sites below 450m.

(b) Aspect. Sites situated on a well defined slope or on fairly level ground with impeded drainage.

(c) Age of tree layers. Tree layers in different pollen assemblage zones. Two zones that were identified were late Boreal -

Map of part of the north Pennines showing the location of sites

figure 1



- Zone VIb and early Atlantic - Zone VIIa.

(d) The presence or absence of Phragmites. Tree layers associated with Phragmites suggesting Fen conditions with high nutrients or tree layers with no Phragmites.

Topography and present vegetational cover

All the sites are situated in moorland with virtually no trees in the immediate area. The higher sites lie in dissected peat with streams running off the watershed to form the Tees or Wear. The land is used for sheep grazing and managed as grouse moors, even the lower sites as at Smiddy Shaw and Hise Hope Burn.

The vegetation is dominated by Calluna vulgaris with the grasses Deschampsia flexuosa and Anthoxanthemum odoratum. Nardus stricta occurs in monodominant swards where grazing pressure has been unduly high. In the drier parts such as hummocks, Erica cinerea may be found together with Potentilla erecta and Galium saxatile. These species together with various bryophyte species are more frequent where heather burning has occurred. Wetter hollows contain Sphagnum sp, Erica tetralix and Molinia caerules. Empetrum nigrum forms well defined stands in the vicinity of the Smiddy Shaw reservoir.

Nomenclature of vascular plants follows Clapham, Tutin and Warburg (1962)

# METHODS

## (a) Preparation of profile prior to sampling.

All ten sites were sampled in an identical manner. The peat surface was cut vertically with a spade down to the basal clay layer. Where the peat was too deep for a continuous profile to be cut easily, particularly where there had been subsidence of the overlying peat, the surface was exposed by cutting steps into the peat face. Then the peat face was cut horizontally with a sharp trowel wiping the blade after each horizontal cut to prevent contamination of the peat horizons. The prepared face was then photographed and a diagram of the peat stratigraphy prepared.

## (b) Sampling procedure.

The prepared peat face was sampled by inserting specimen tubes into the peat at 5cm intervals using a tape measure and spirit level. The complete section was not sampled but care was taken to obtain samples to cover the entire tree layer and a few centimetres above. After sampling each tube was fitted with a plastic lid and labelled with self-adhesive labels and marker pen.

The tree layer at each site was sampled by cutting out a peat block 50 x 40 x 40cm with a spade. As far as possible all the twigs in the block were removed and stored in labelled plastic bags. The size of the block used for each site was determined by the shape of the profile obtained at the first site visited. A second wood sample was collected, this time from a wider area along the tree layer. This wood was to be used for the study of growth rings.

Finally, from the tree layer of each site, several large pieces of peat were cut out to be used for the identification of macro-plant remains.

(c) Laboratory Treatment

Preparation of Pollen samples for analysis

0.5cm$^3$ samples were removed from each of the glass tubes used for sampling the peat. All the peat samples were treated in a similar manner. Each sample was first warmed with 10% sodium hydroxide solution in order to break up the peat. The dark brown liquid was then poured through a fine sieve to remove pieces of organic debris. The filtrate was centrifuged and washed in water several times until the supernatant was reasonably clear. The final washing was carried out with glacial acetic acid. The sample was then acetolysed by treating with a mixture of Acetic anhydride and conc. sulphuric acid. After heating the mixture in boiling water in a water bath for one minute the liquid was centrifuged, washed in glacial acetic acid then finally washed in distilled water containing a few drops of 10% sodium hydroxide solution. After removing the supernatant the tube was dried internally with a roll of filter paper before adding glycerine jelly stained with safranin. The method follows that given by Faegri and Iversen (1964).

The bottom samples from all the sites were found to contain a proportion of clay and fine sand grains. These had to be removed before pollen grains could be seen sufficiently clearly for counting. These samples were treated with hot hydrofluoric acid after the initial digestion with sodium hydroxide solution and washing in distilled water. The HF dissolved the insoluble silicates. After this treatment, the sample was mixed with hot 10% hydrochloric acid, centrifuged, washed, then treated with glacial acetic acid before the normal acetolysis treatment. It was found that two slides were sufficient from each sample as there were abundant tree pollen grains, the exceptions being Hise Hope Burn and Smiddy Shaw layers above 60 cm and all the samples from Green Combs. In these cases 500 grains were counted for each slide instead of the 150 tree pollen grains counted from the other slides. There were so few pollen grains in the Green Combs samples that counting was discontinued after 130 tree grains had been counted.

Pollen counts were carried out using a Vickers binocular microscope fitted with x10 eyepieces and using x40 objective. For critical work an oil immersion lens x100 was used. Pollen and spored were identified using the texts of Faegri and Iversen and "An introduction to a Scandinavian Pollen Flora by Erdtman, Berglund and Praglowski (1961). For difficult identifications assistance was given by a palynologist of the department. Pollen diagrams were then constructed in order to cover the forest layer and where time permitted, several samples above the tree layer were counted in order to follow the trends of the vegetation. The samples taken from Green Combs contained very few pollen grains so although a suggested zone is given for the Forest layer, no diagram is presented.

Wood samples - Laboratory treatment.

The twig samples obtained from the peat block were washed in water and identified. Most of the twigs proved to be Betula but where there was some doubt sections were cut, three for each twig - TS, TLS and RLS. The sections were bleached if too dark, using a dilute solution of sodium hypochlorite. The sections were then mounted in water and examined under the x10 objective for the transverse sections and under the x40 objective for the finer details of the medullary rays in the tangential and radial longitudinal sections. Identification of tree genera were made with the aid of keys (Clifford 1956).

(d) Measurement of Twig diameters.

Using vernier calipers, the twig diameters of all the twigs extracted from the peat block obtained at each site, were recorded. The results are set out in the form of Histograms, see Figs. 2 - 10.

(e) Measurement of Growth rings.

Transverse sections of *Betula* wood were cut from ten twigs collected randomly from a wide stretch of the wood layer at each site. Dark sections were treated with dilute sodium hypochlorite solution to improve the transparency of the section. A x3 objective was used for the count and it was found that with the iris diaphragm stopped down the growth rings were reasonably well defined despite the fact that *Betula* has diffuse porous wood and the rings can be difficult to define. The ring widths were measured with a micrometer eyepiece. All ring widths for each twig were recorded so that at the same time the age of each twig was noted. It was during this work that the occurrence of multiple rings was found to complicate the measurement of the true rings in some samples. A discussion of the significance of multiple rings is given later on. In some cases, multiple rings were so frequent that the section was discarded to avoid mis-identification of the normal growth rings. In such cases, a fresh twig was selected and sectioned. Ten twigs from each site were examined for multiple ring formation and their incidence recorded.

Reaction Wood

This is a typical wood that forms along one side of displaced stems. The main samples of wood from each site were examined for this type of formation and its incidence was recorded.

(f) Summary

From the ten selected sites:

(a) Pollen samples were prepared for counting and diagrams constructed.

(b) The stratigraphy of the profile was drawn.

(c) Quantitative sampling of the tree layer from each site was carried out using a standard dimension peat block.

(d) Twigs diameters were measured, the data then arranged in class sizes and shown by histogram.

(e) Transverse sections were made from 10 twigs per site. These sections were used for

  (i) measurement of growth rings

  (ii) identification of multiple rings.

  In addition, twigs showing reaction wood were identified and expressed as % of the total twig count.

(f) Peat samples were collected from the tree layer of each site and macro plant remains were identified, see Table 2.

# RESULTS AND DISCUSSION

A. Zonation of the Pollen Diagrams.

(i) Introduction.

Peat development on the Northern Pennines and elsewhere in Northern Britain is considered to have commenced generally at the time of the Boreal/Atlantic transition c 5,500 BC, when drier more continental climate of the Boreal was replaced by more oceanic conditions. These climatic changes and their significance are discussed by Pennington (1969) (1970) and Conway (1954) for the Southern Pennines.

However, some peat formation did occur in certain localities in the area during the Boreal although the rate of accumulation of the deposit was probably very slow. Sections through the peat in the area under consideration may show up to a metre of Boreal (Zone VI) peat at the base, although such sites are infrequent. More usually the peat is of Zone VII age or later and may reach a depth of several metres.

The tree layers at the sites I have examined were found to occur either in peat of Zone VI age or early Zone VII. In several instances, e.g., at Hise Hope Burn, the tree layer was found to lie across the Zone VI/VII boundary.

Pollen diagrams from the Northern Pennines such as the one for Hard Hill near Moor House, Johnson and Dunham (1963) show large Corylus values for Zone VI with Alnus increasing to c 25% at the transition between Zone VI/VII. Quercus values also rise in Zone VI, whilst Ulmus values show a peak earlier in the zone and then decline towards the zone boundary. Pinus values are extremely variable and reach their maximum later than in diagrams from southern England. At Hard Hill Pinus reaches frequencies of 25% whereas at Cow Green it reaches over 60% before the Boreal/Atlantic transition. Betula frequencies which reach high values in Zone V decrease steadily towards Zone VII.

Early Zone VII is characterised by a dramatic increase in Alnus values. The Hard Hill diagram, for example, shows Alnus exceeding 40% in the early part of Zone VIIa. In contrast to the increase of Alnus, Pinus frequencies decrease considerably, usually to less than 10%. The demise of the Pine is considered by Edlin (1970) to be rather a failure to regenerate on peat rather than the direct effect of the increased rainfall. In early Zone VII Quercus is usually well represented in contrast to Ulmus which steadily declines.

Although these changes are characteristic of many pollen diagrams from the area, there are occasions where unusually high Alnus values have been recorded in Zone VI, e.g., in a diagram from Red Sike Moss, Turner et al (1973), where an isolated "peak" of Alnus, c 17% occurs at the base of the diagram in contrast to Pinus values exceeding 60%. This would appear to indicate a local stand of Alnus where very local conditions favoured its survival.

The Pollen diagrams from the nine sites are now considered.

(ii) Pollen diagrams

Foulsike Burn    Figure 2.

The site is most easily approached from the B 6295 Cowshill to Allenheads road. The burn, one of a number of small streams runs NE from a gently sloping moor which is part of Wolfcleugh Common. The highest regions of these streams contain sections through the peat which in places reach the basal clay exposing the tree layer. There is some peat erosion in the immediate area.

The depth of the tree layer varies between 20 - 38 cm along the section investigated.

The Pollen diagram

Corylus frequencies remain high from 305cm at the base of the tree layer to 250cm. The highest values are in excess of 100% in the lowest levels. Ulmus and Querccus are both well represented with frequencies increasing to the upper limit of the tree layer. Pinus values are c 20% with small peaks at 295 and 185cm. Alnus is represented by only the occasional grain in the lower part of the layer, but the frequency rises significantly at 280cm with a value of 30%. Betula values show a steady decline throughout the tree layer. As coryloid values are high in the tree layer with increasing Querus frequencies and Pinus at around 20% it is suggested that most of the tree layer lies within Zone VI of Godwin's pollen assemblage zones (Godwin 1940) or Chronozone Fl of West (1970). The sudden increase of Alnus at 280cm and decrease of Pinus is indicative of the transition from Boreal Zone VI to Atlantic Zone VIIa.

Most of the Foulsike tree layer would seem therefore to be of late Boreal age with its uppermost limit in early Zone VIIa.

(b) Green Combs. Figure 3.

This site is located to the SW of the B 6277 Middleton to Alston road. The area is composed of eroding peat haggs, is well dissected and gently sloping. Very few of the many sections exposed show the basal clay.

Depth of the tree layer = 20cm.

The pollen diagram

Pollen from this site was in a very poor state of preservation and it was impossible to count sufficient numbers of pollen grains for any statistical accuracy so, therefore, a pollen diagram is not presented for this site. However, three samples were counted and the pollen frequencies are tabulated below.

| Depth (cm) | Betula | Pinus | Ulmus | Quercus | Alnus | Corylus | Salix | Gram. | Cyp. | Calluna. |
|---|---|---|---|---|---|---|---|---|---|---|
| 106 | 13 | 33 | 8 | 23 | 23 | 62 | 7 | 17 | 2 | 5 |
| 121 | 15 | 44 | 3 | 21 | 17 | 32 | 7 | 33 | 7 | 2 |
| 126 | 12 | 33 | 8 | 22 | 25 | 45 | 21 | 34 | 7 | 1 |

Expressed as % total tree pollen.

It is surprisingly difficult to assign these samples to a particular pollen zone. With relatively high Pinus values which are naturally associated with Zone VI and relatively high Alnus values such as are normally associated with Zone VII one could conclude that these few samples lie at the VI/VII transition. On the other hand the Pinus frequency may be over represented because of differential rates of corrosion of the pollen grains of taxa represented (Havinga 1964) or the Alnus values being due to a local "pocket" of the species existing in the late Boreal. I am, therefore, unable on the available information, to assign a zone to this tree layer.

Herbaceous pollen was poorly represented in the samples counted.

(c) Herdship Fell  Figure 4.

The site is on the side of a small stream to the south of Green Combs, but at a slightly higher altitude. The section is shallow and partly covered by an overburden of younger deposit. In places the basal clay is exposed.

The depth of the tree layer is 15cm.

The Pollen Diagram

The *Pinus* frequency is well under 10% through the tree layer and *Alnus* pollen values are high - greater than 20%. *Quercus* pollen is well represented, exceeding 15% at all levels whereas *Ulmus* amounts are low across the layer. The *Pinus*/*Alnus* relationship is indicative of early Zone VIIa. *Betula* values fluctuate between 25/50% and the herbaceous pollen frequency remains low throughout the tree layer with the exception of *Calluna* which maintains high values at all levels.

(d) Hise Hope Burn.  Figure 5.

The site lies in the Derwent catchment area. On both sides of a stream flowing NE into Hise Hope Reservoir is an exposure of peat which in places reaches the underlying clay layer. Easiest access is from the Castle side to B 6278 road where the upper reaches of the stream can be reached by a short walk over the *Calluna* moor.

Depth of the tree layer c 30cm.

The Pollen Diagram

*Pinus* pollen frequencies fluctuate but overall there is an overall trend through the diagram to values of lower than 10% at the upper limit of the tree layer. *Alnus* shows a steady rise from 18% at the base of the layer to values above 20% in the upper part of the diagram. *Corylus* frequencies fluctuate but with a trend to lower values towards the upper limit of the tree layer. *Quercus* is well represented in contrast to *Ulmus*.

This diagram appears to cross the VI/VII boundary which is drawn at 80cm.

Herbaceous pollen is represented by high *Gramineae* and *Calluna* frequencies. Increasing amounts of *Sphagnum* spores above 75cm may indicate increasing rainfall at the onset of Zone VII.

(e) John's Burn Figure 6.

This site is a deep section along the sides of a fast flowing stream of moderate gradient which joins Crook Burn, a tributary of the Tees. The peat section is quite deep for about 90m and the tree layer is exposed on the basal clay for almost the entire length of the section. Several tree stumps are visible in the section and the tree layer generally is very well developed.

The approach is from the Middleton to Alston road with a short walk across a grouse moor from the Cumbria/Co Durham boundary.

The depth of the tree layer is 20cm with a further narrow wood layer 10cm thick at 190cm.

The Pollen Diagram

Corylus pollen frequencies maintain a very high frequency throughout the tree layer, exceeding 100% TTP at several levels. Alnus is scarcely represented in the lower part of the section, reaches 33% at 205cm and then maintains a 15% level. Pinus pollen shows a steady decline from 45% at 225cm to 16% at the uppermost level. Ulmus values fluctuate and have low values compared with Quercus.

The tree layer from 225 - 210cm is clearly in late Zone VI so the boundary is drawn at this point. There is the possibility however that the 33% value for Alnus at 205cm is the reflection of a local isolated Alnus stand referred to in the introduction.

Herbaceous pollen is generally poorly represented.

(f) Killhope Law. Figure 7.

This would seem to be one of the few sections in the vicinity of the summit of Killhope Law where a tree layer is exposed. There are several streams flowing south but only one cuts back into the peat sufficiently to expose the basal clay. The site is most easily approached from Coalcleugh Common.

The depth of the tree layer is 22cm.

The Pollen Diagram.

Alnus frequencies are very low, less than 15% throughout the tree layer whereas Pinus maintains high values at all levels. Ulmus values show a steady decline against rising Quercus frequencies. Corylus values are high at most levels while Betula remains around 30% except for increases at 160 and 150cm. Herbaceous pollen remains at low levels throughout the tree layer.

The entire tree layer is considered to be in Zone VI.

(g) Milburn Forest. Figure 8.

The section is exposed in the side of a stream running SE from Hard Hill. There are several streams in the locality, some with peat exposed to the basal clay. Some peat erosion is evident. Approach to the site is easiest from Dufton via Appleby.

Depth of tree layer = 16cm.

The Pollen Diagram

*Alnus* pollen generally exceeds 20% whilst *Pinus* frequencies are very low, less than 10%. *Quercus* is very well represented and *Corylus* exceeds 75% at all levels. The *Pinus*/*Alnus* ratio is indicative of Zone VII with the caveat that this is a *Phragmites* peat and there is always the slight likelihood that the rather high *Alnus* values may be due to local environmental conditions prevailing in the neighbourhood.

The tree layer lies within Zone VIIa.

(h) Quickcleugh Figure 9.

The site is reached from the Eastgate to Allenheads Road. The area consists of a number of small confluent streams forming Quickcleugh Burn running NE from a *Calluna* moor. There is a good section exposed for some yards along the banks of one stream. The tree layer is prominent with large pieces of wood visible.

Several pieces of tree trunk exceeded 15cm in diameter.

Depth of tree layer = 17 - 20cm.

The Pollen Diagram

Alnus pollen values increase to 41% with Pinus at less than 10% except for the basal sample. Alnus frequencies reach a significant value at 170cm (35%). Betula values only exceed 25% at one level while Ulmus pollen attains low values throughout the tree layer in contrast to Quercus which exceeds 50% at 180cm. Corylus frequencies fluctuate, the highest values being at the tree layer - 90% at 200cm.

Occasional grains of Tilia are found at all levels.

A boundary between Zones VI/VII is drawn above 200cm so that most of the tree layer lies within Zone VIIa.

(i) Smiddy Shaw Figure 10.

The site is an exposed section of peat on the south side of Smiddy Shaw reservoir. The tree layer was the deepest of all the sites examined and large tree trunks are visible along this bank of the reservoir.

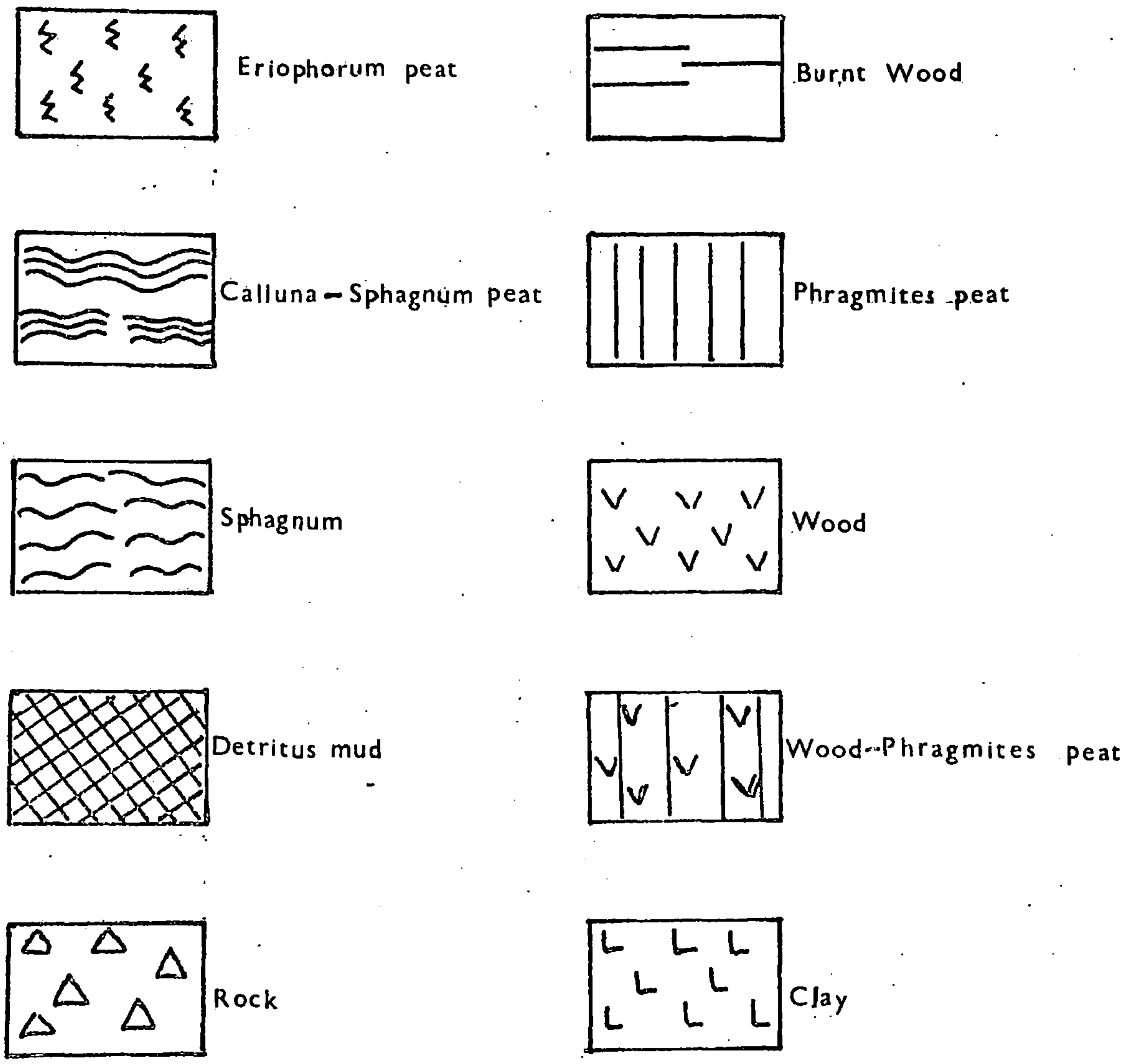
Depth of the tree layer c 80cm but the first 20cm above the clay contains the greatest concentration of wood.

The Pollen Diagram

Alnus maintains a high frequency through the tree layer and between 110-95cm reaches 55%. Pinus values are correspondingly low, rarely exceeding 10% at any horizon. Ulmus values are low whilst those of Quercus fluctuate between 5-20% across the tree layer. Coryloid frequencies also fluctuate. Betula shows an increase of greater than 50% at the upper limit of the layer.

Herbaceous pollen, as at the other sites, is represented by low pollen values.

The large Alnus values compared with the low values of Pinus indicate that the tree layer lies within Zone VII.




Stratigraphic symbols used in the pollen diagrams.

# GREEN COMBS

## figure 3

Histogram showing distribution – diameter of Betula twigs arranged in 5mm classes.

Total number of twigs extracted = 259

GROWTH RING WIDTH

$\bar{x} = 0{\cdot}40 \pm 0{\cdot}02$ mm

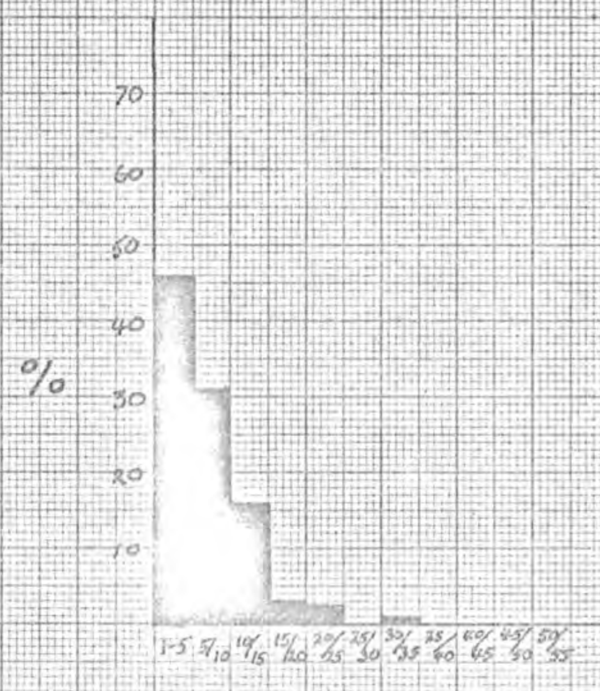
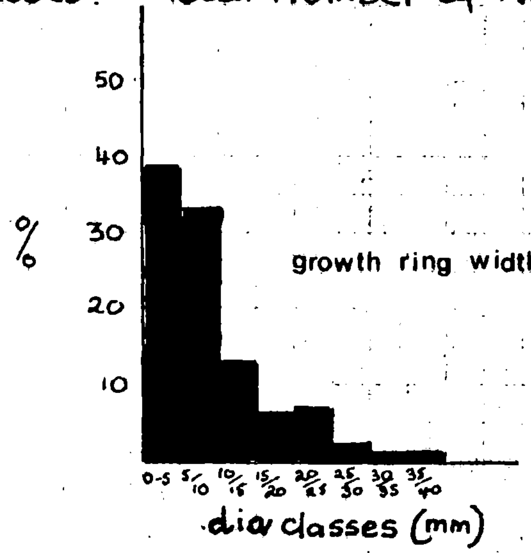


figure 2

# FOULSIKE BURN

Histogram showing distribution - diameter of Betula twigs arranged in 5mm classes. Total number of twigs extracted = 176




## POLLEN DIAGRAM FOR TREE LAYER

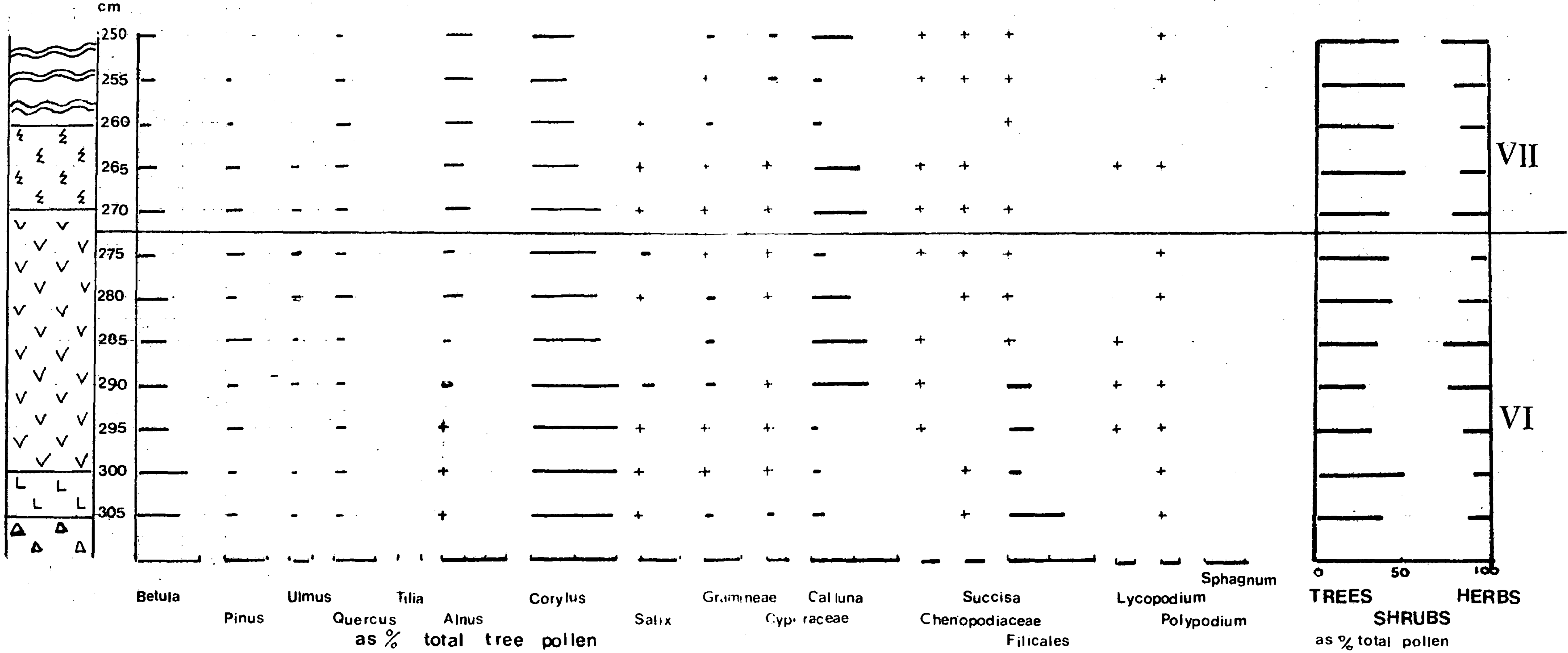
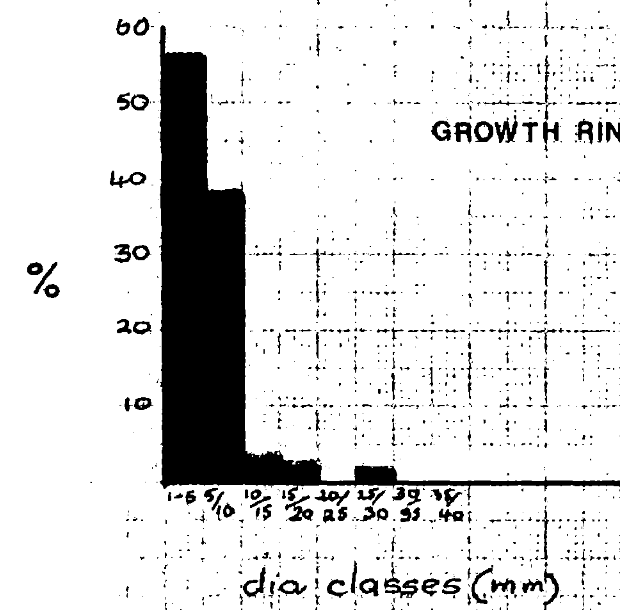


figure 4

# HERDSHIP FELL

Histogram showing distribution – diameter of Betula twigs arranged in 5mm classes. Total number of twigs extracted from a peat block = 291.




# POLLEN DIAGRAM FOR TREE LAYER

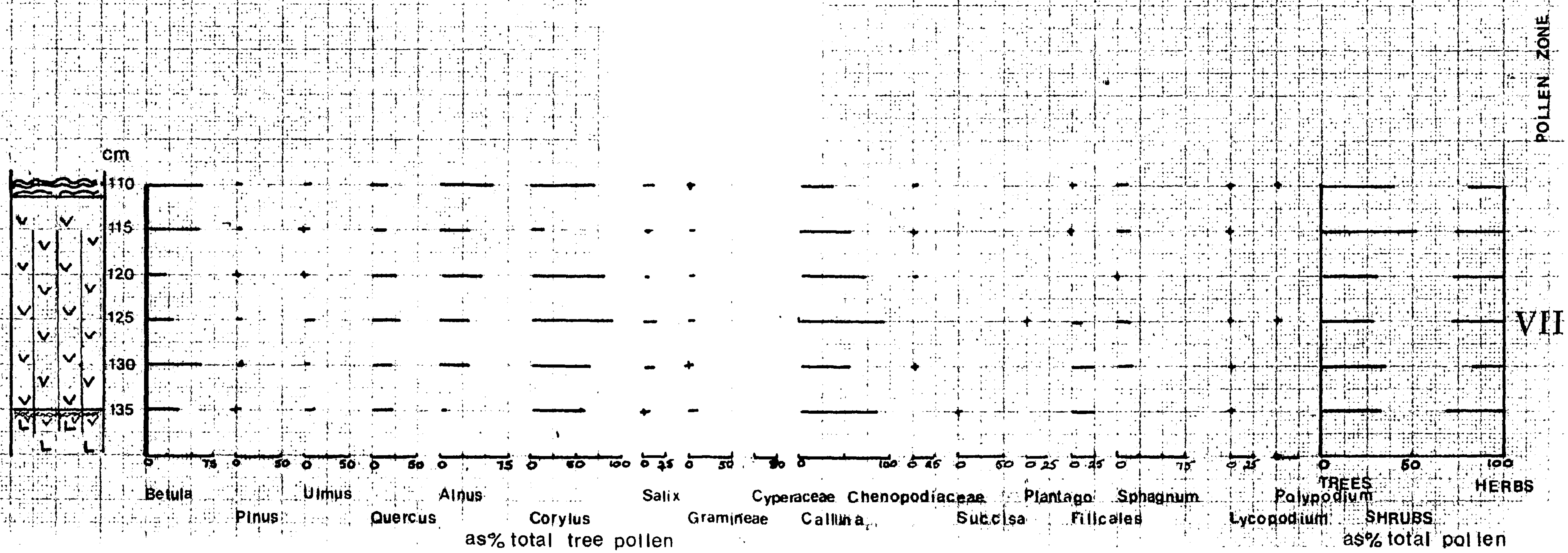
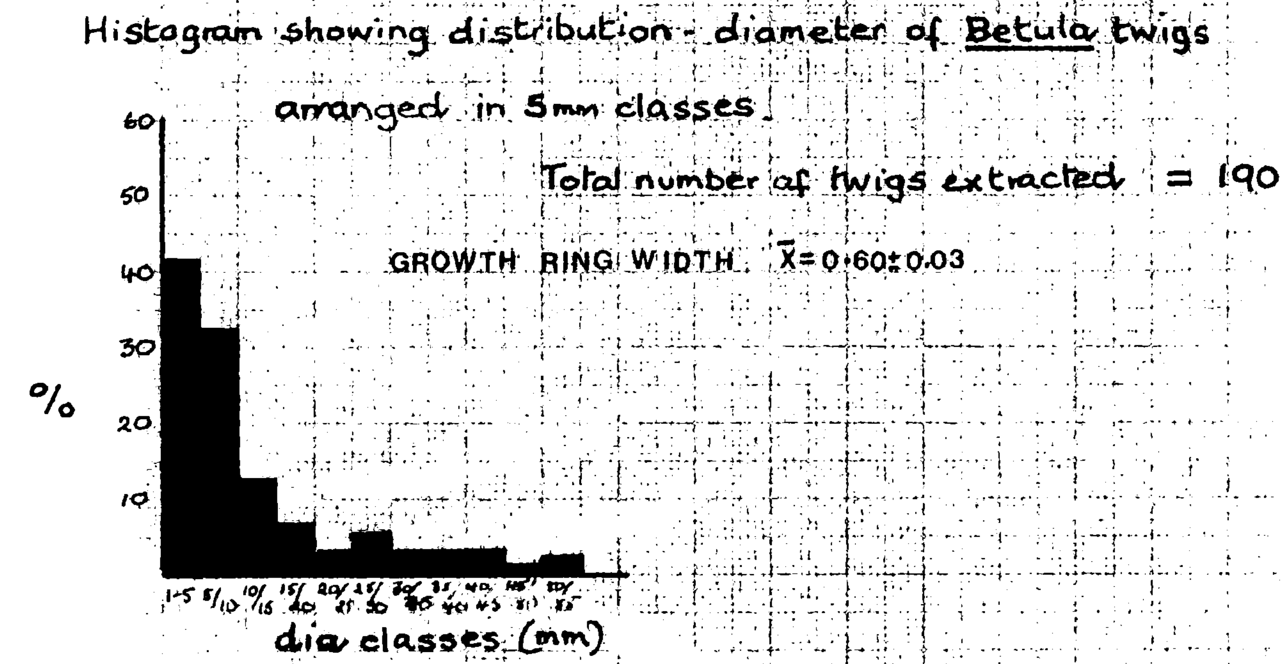
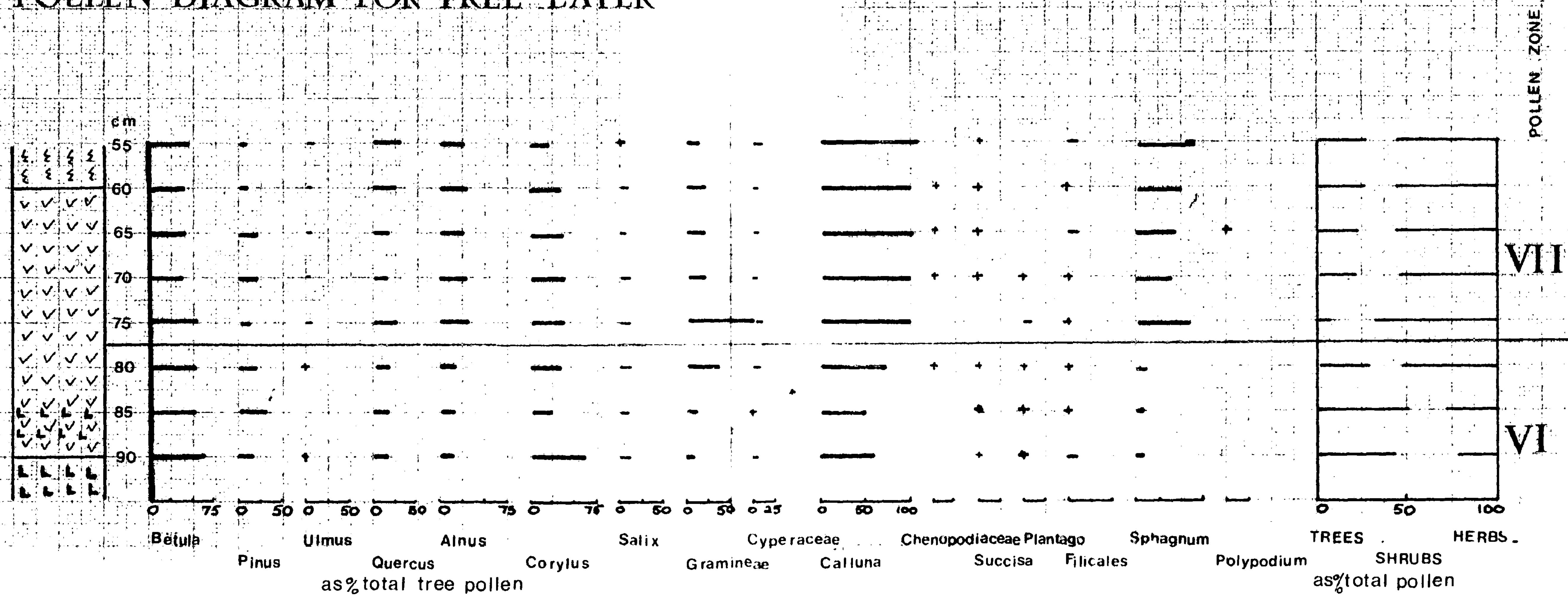


figure 5.

# HISE HOPE BURN




## POLLEN DIAGRAM FOR TREE LAYER



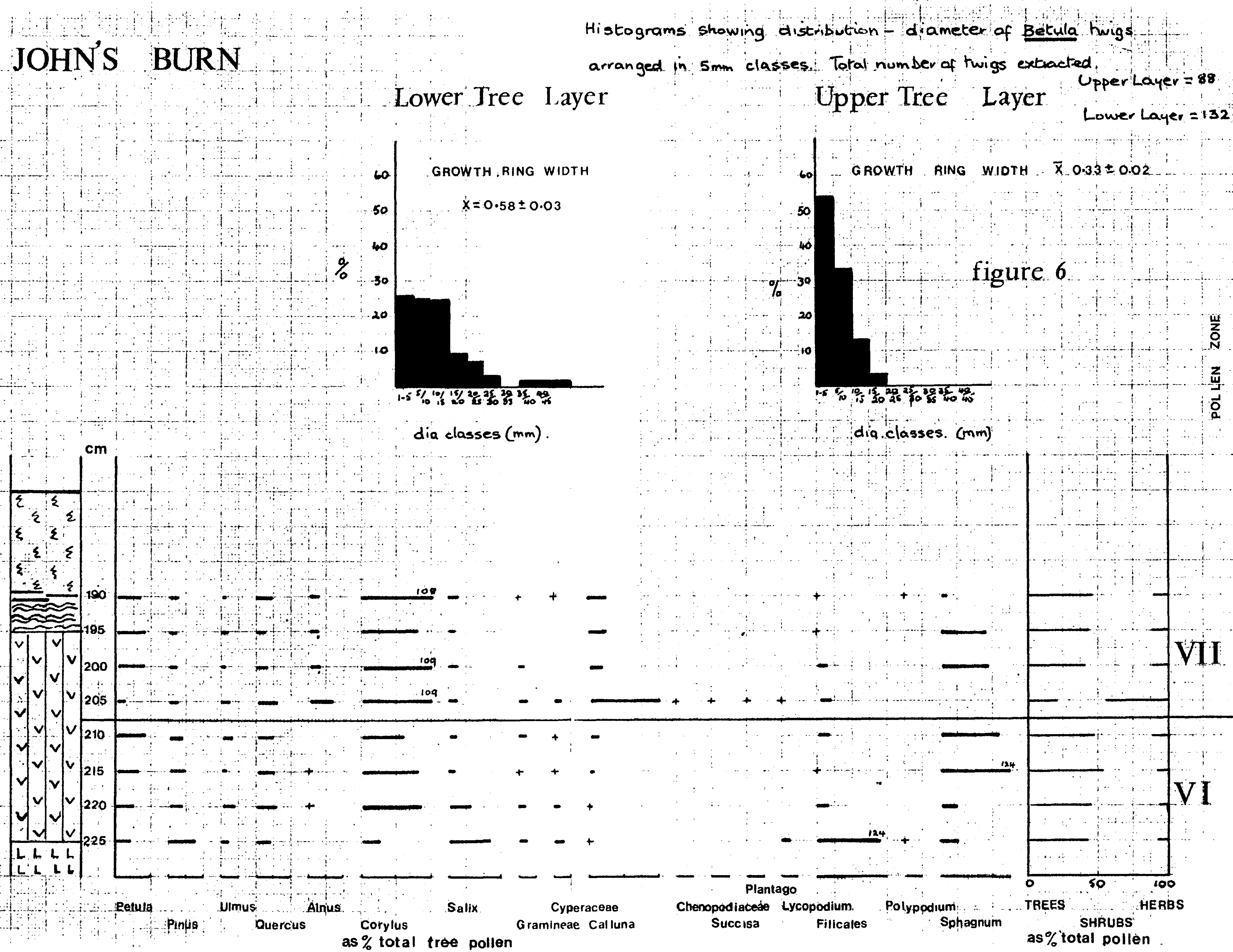
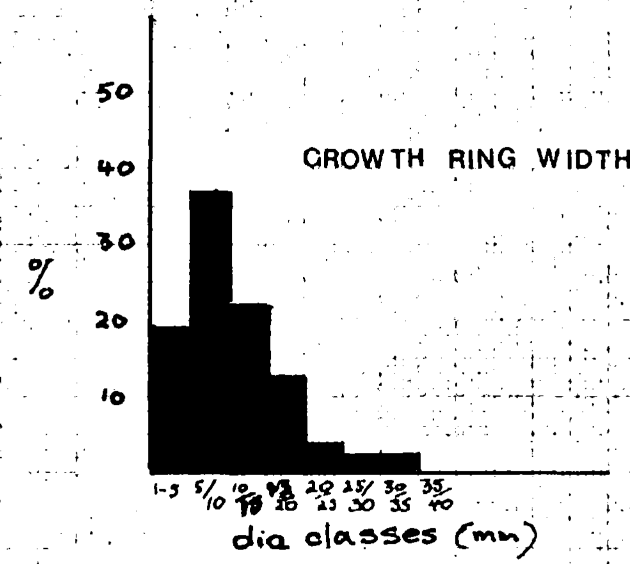

JOHN'S BURN
Histograms showing distribution - diameter of Betula twigs arranged in 5mm classes. Total number of twigs extracted.
Upper Layer = 88
Lower Layer = 132
Lower Tree Layer
GROWTH RING WIDTH
X̄ = 0·58 ± 0·03
%
dia classes (mm).
Upper Tree Layer
GROWTH RING WIDTH X̄ 0·33 ± 0·02
dia.classes. (mm)
POLLEN ZONE
cm
190
195
200
205
210
215
220
225
108
109
109
124
124
VII
VI
Betula
Pinus
Ulmus
Quercus
Alnus
Corylus
Salix
Gramineae
Cyperaceae
Calluna
Chenopodiaceae
Succisa
Plantago
Lycopodium
Filicales
Polypodium
Sphagnum
as % total tree pollen
0
50
100
TREES
SHRUBS
HERBS
as % total pollen

figure 6

figure 7

# KILLHOPE LAW

Histogram showing distribution - diameter of Betula twigs arranged in 5mm classes. Total number of twigs extracted = 264




## POLLEN DIAGRAM FOR TREE LAYER

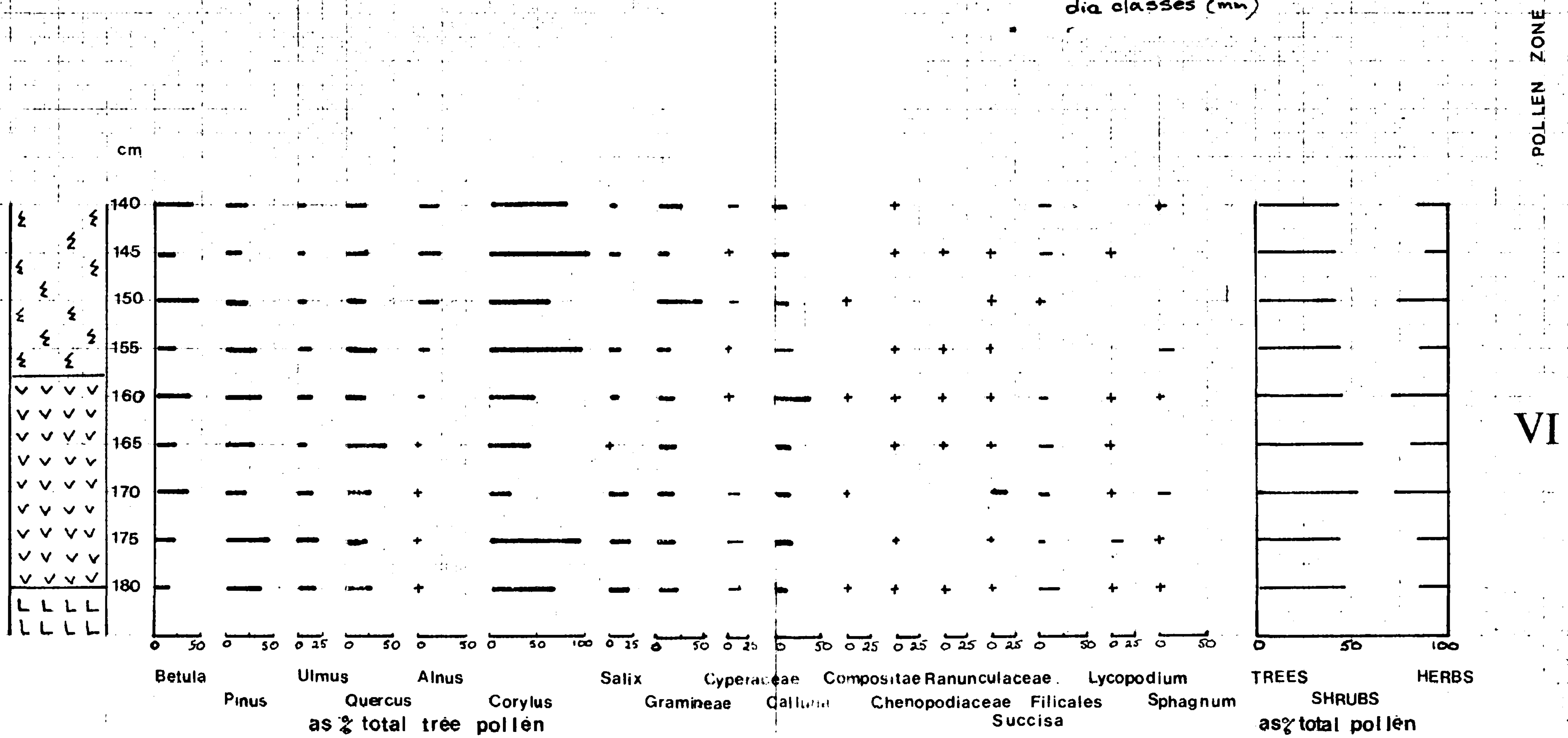
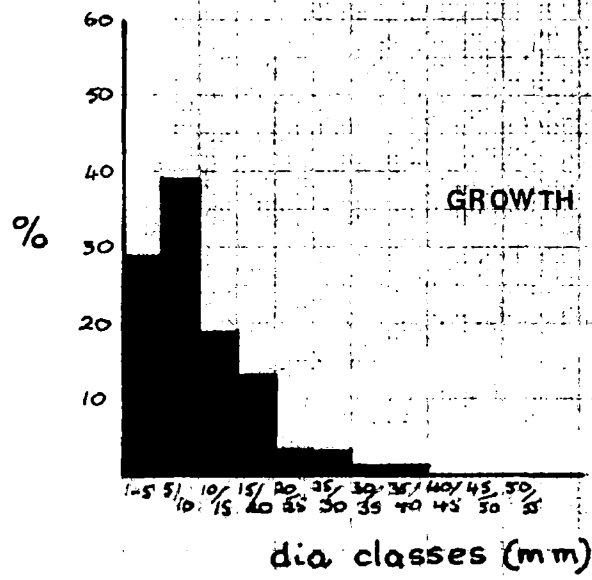


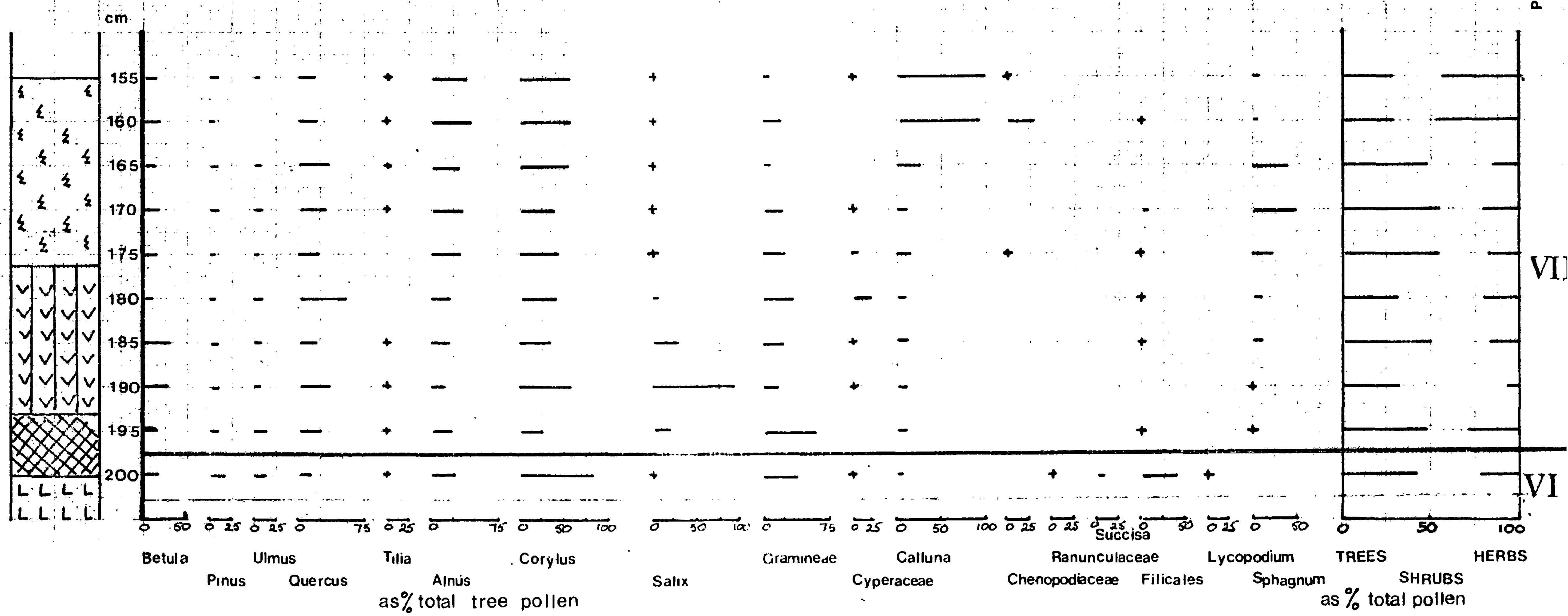
figure 9

# QUICKCLEUGH

Histogram showing distribution – diameter of Betula twigs arranged in 5mm classes. Total number of twigs extracted = 246




## POLLEN DIAGRAM FOR TREE LAYER



# SMIDDY SHAW

Histograms showing distribution - diameter of Betula twigs arranged in 5mm classes. Total number of twigs extracted from a peat block = 195

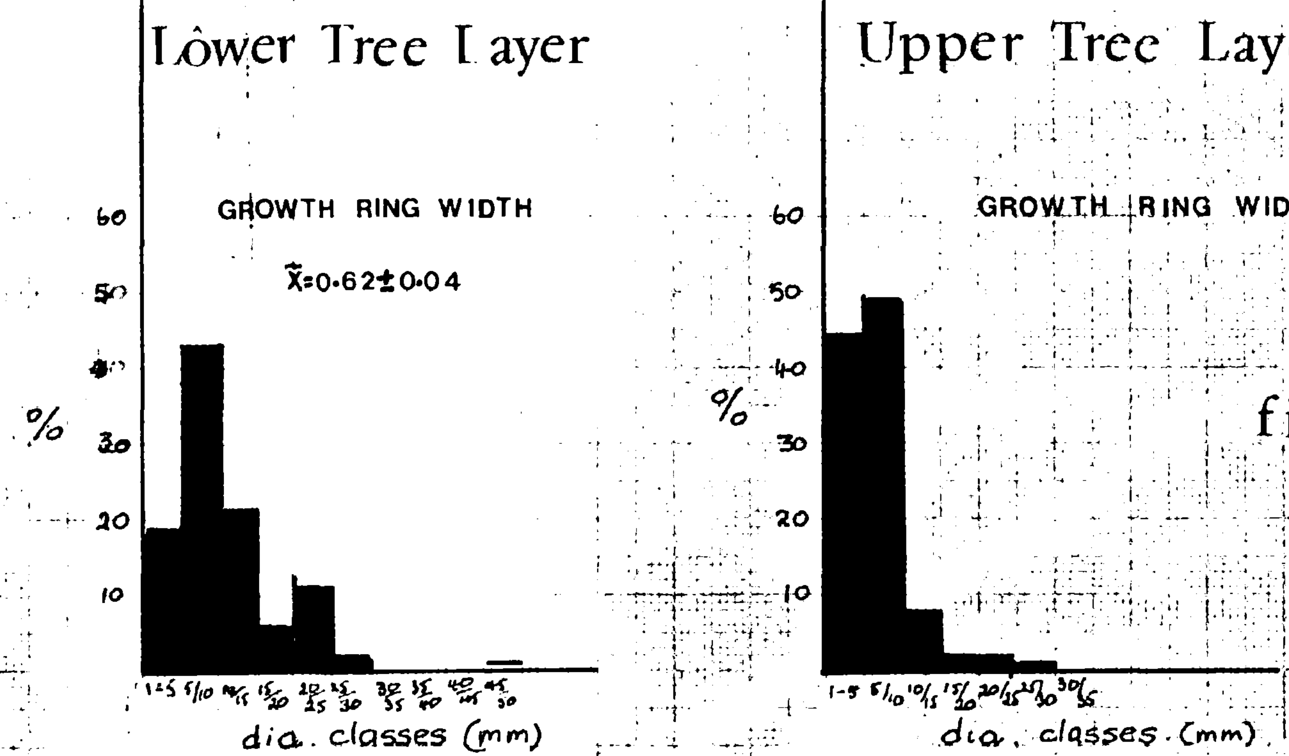
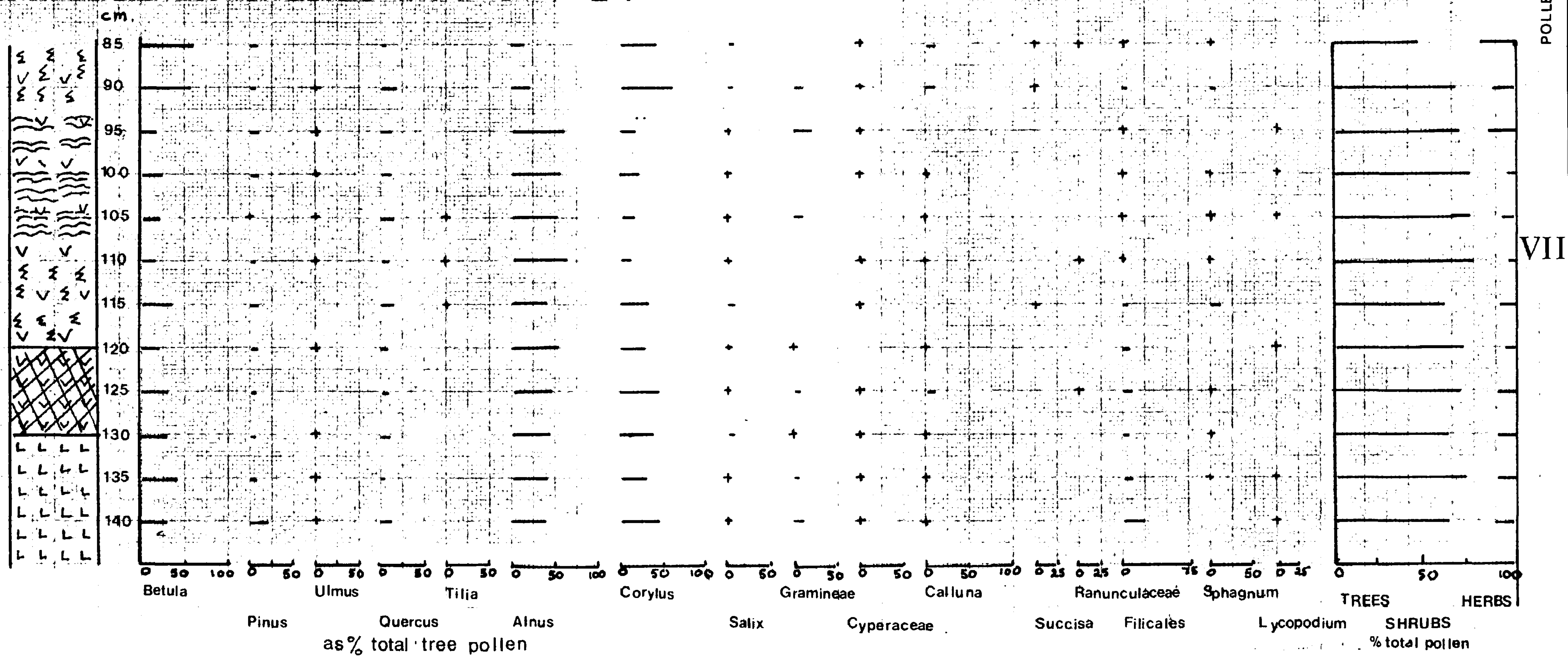



figure 10

## POLLEN DIAGRAM FOR TREE LAYER



(iii) Identification of Plant macro-remains. see Table 2.

All peat samples examined from each site contained Betula wood. The wood layer was found to be associated with Phragmites at five of the sites (see Table 2). At the remaining four sites the wood layer was not associated with Phragmites. Wood from other tree taxa was uncommon but Alnus wood was identified from Smiddy Shaw and Quickcleugh. Surprisingly, only one twig of Pinus wood was identified from the base of the Smiddy Shaw tree layer. Twigs of Pinus have been found on previous visits along this edge of the reservoir. Other sites with the tree layer in Zone VI and high Pinus pollen values e.g., at Killhope Law, did not yield any Pinus wood.

Fruits of Betula were found, often in abundance, at most sites, also the fruits of Carex sp.

From these observations it became apparent that the sites could be classified into at least two types (a) those supporting a Phragmites/Betula community, possibly growing under conditions similar to those found in modern Fen Carr communities and (b) those supporting woodland growing on slightly drier or less flushed soils with probably a lower water table before peat began forming.

Table 2.

Macro-plant remains from peat samples

| Name of site | Plant remains identified |
|---|---|
| Foulsike Burn | Frequent remains of sedge leaves.<br>Fruits of Betula frequent<br>A dark well humified peat. |
| Green Combs | Some large rhizomes of Phragmites.<br>Abundant leaves of Phragmites.<br>Fruits of Betula abundant.<br>A catkin unidentified.<br>A Phragmites peat |
| Herdship Fell | Abundant fine roots.<br>Occasional leaves of Phragmites.<br>Sedge leaves and rhizomes.<br>A "Fen" peat, but with less Phragmites than other sites. |
| Hise Hope Burn | Very few identifiable remains.<br>Abundant sedge remains in lowest layers with Eriophorum higher up at top of tree layer.<br>A dark fibrous peat. |
| John's Burn<br>Lower tree layer | Very small twigs of Betula and masses of fine roots.<br>Several twigs of Salix sp. identified.<br>Phragmites leaves abundant, some c 2cm wide.<br>Female catkin of Betula.<br>(In the same horizon as the sample were several large trunks up to 20cm in diameter.)<br>A Phragmites peat. |
| Upper tree layer | Small twigs of Betula abundant.<br>Small roots of Betula abundant.<br>Pieces of bark, probably of Betula.<br>Rhizomes and leaves of sedge, frequent.<br>Several sedge fruits identified. |

Table 2 (Cont.)

| Name of site | Plant remains identified |
| --- | --- |
| Killhope Law | Small twigs of Betula.<br>Several small twigs of Salix sp.<br>Carex fruits.<br>Bryophyte leaves.<br>Abundant sedge leaves.<br>A dark well humified peat with highly compacted sedge. |
| Milburn Forest | Phragmites leaves and rhizomes, very abundant.<br>Betula twigs, frequent.<br>Salix twigs, occasional.<br>Leaves of Carex sp.<br>A seed of Menyanthes.<br>Fruits of Betula, abundant.<br>A Phragmites peat. |
| Quickcleugh | A dense mat of leaves most of which could be identified as Betula.<br>Many small Betula twigs.<br>Some sedge remains.<br>Two fragments of Alnus wood in upper layer of tree horizon.<br>Phragmites leaves abundant.<br>A "Fen" peat, orange in parts, oxidised. |
| Smiddy Shaw<br>Lower tree layer | Betula bark, often forming lamellae.<br>Matted roots.<br>Sedge leaves and rhizomes.<br>Occasional fruits of Carex sp.<br>Fruits of Betula, abundant.<br>Small Pinus twig identified.<br>Dark humified peat with small quartz grains. |
| Upper tree layer | Betula twigs abundant and generally very small diameter.<br>Eriophorum stems.<br>Several twigs of Alnus identified.<br>Leaves of Carex sp. often making layers in the peat.<br>Occasional twig of Calluna present.<br>A fibrous peat. |

(iv) Discussion.

The nature of the former woodland.

It is difficult to attempt to reconstruct the nature of these late Boreal and early Atlantic woodlands from the evidence supplied by the pollen diagrams. If the area of deposition was small it might be possible to consider that pollen was local in origin being derived from vegetation within short distances of the sampling point. This idea would be in agreement with the work by Tauber (1965) and Andersen (1970). However, the altitude and exposed nature of the western sites may mean that a proportion of the pollen would have come from a more regional source. There is a possibility that the Green Combs site might be defined as a small bog where pollen could have come only short distances.

The problems of interpretation are therefore complex. Processes involving aerial transport of pollen (Tauber 1965, 1967), relative pollen productivity leading to over-representation of some taxa and the use of correction factors (Andersen 1970) would have to be considered before the results expressed by the pollen diagrams can be fully interpreted. Problems of local and regional deposition are considered by Janssen (1972).

In published pollen diagrams for lowland Britain such as that for Hockham Mere, Norfolk (Godwin 1956), the ratio of tree pollen to non-tree pollen is very high in late Boreal times, indicating well developed forest conditions with a closed canopy. Diagrams for areas in the Northern Pennines, such as for Weelhead Moss (Turner et al 1973), give a late Zone VI tree to non-tree pollen ratio as 30:40% and the diagram for Dead Crook Moss

(Turner et al 1973) shows a ratio of 60:20% tree to non-tree pollen. It would seem from these and other diagrams that these upland woodlands were not so closed as those existing in lowland Britain at the time. Certain taxa, particularly Gramineae and Cyperaceae show relatively high values on some upland diagrams. This would seem to indicate open spaces within the woodland. However, the tree to non-tree pollen ratio does show a fluctuation between sites. In another part of the Pennines the diagram for Fountains Earth (Tinsley 1975) with an altitude of 368m, shows a tree to non-tree pollen ratio in late Zone VI of 60:10%.

Results from my pollen diagrams also show fluctuations between sites. In some cases the tree to non-tree pollen ratio bears a greater resemblance to the Fountains Earth diagram than to those from Upper Teesdale. At Smiddy Shaw the tree to non-tree pollen ratio remains high with values around 70:15% indicating a well developed woodland whereas at several of the western sites, e.g., at Foulsike Burn, at some levels the non-tree pollen reaches 25% of the total.

The tree to non-tree pollen ratios may seem a little puzzling in the light of some of the published diagrams but perhaps not so surprising if a localised area of woodland growing along the sides of small streams is envisaged. It is possible that such conditions would favour the growth of woody plants possibly by the presence of a good water supply and nutrients. Extensive growth of Corylus and later Alnus in early Zone VII would locally shade out most of the herbaceous species. Beyond these small wet areas the woodland would be more of an open nature, dominated by Betula.

The macro-plant remains may be used to establish the presence of some of the species present in the former woodland and will confirm the probable presence of the plants represented by pollen. Thus at the Phragmites sites, Betula wood together with Phragmites stems, leaves and rhizomes, Carex fruits and occasional Alnus wood are valuable evidence for the composition of this community. In the context of the nearest modern equivalent the Phragmites/Betula peat represents a community in various stages in a hydrosere, similar to that seen in parts of East Anglia today. Walker (1970) lists twelve stages in hydrosere development, with reedswamp communities containing Phragmites communis and Carex rostrata as the fifth stage.

On several pollen diagrams, such as those for Quickcleugh and Milburn Forest, Phragmites remains, Betula wood and the pollen of Alnus, Corylus and Salix all occur at the same level. Phragmites would have been the first to have appeared (probably represented in the diagrams by the pollen of Gramineae). The nature of Phragmites growth and litter accumulation would have effectively excluded competitor species as Haslam (1971) has shown from studies on present day Phragmites communities in East Anglia. The build-up of the litter mat over a period of time would have caused a decline in vigour of the Phragmites. Should the water table have become lowered, a distinct possibility during the relatively dry conditions of the Boreal period; then other species would appear, probably herbs at first, followed by Betula then Alnus. These incoming species would utilise the more aerobic conditions developing with the decrease in water logging of the substrate. These trees, by shading out the Phragmites, would eventually cause the reed to decline further. A similar situation can be seen taking place at Embleton Fen, Northumberland today. Here the Phragmites is declining but the Betula is not, at present, making really good growth, possibly because of periodic flooding of the ground in winter.

It is possible that Corylus would be able to enter these late Boreal hydroseres under conditions of increasing dryness, but it is difficult to distinguish between Corylus as a member of the Fen Carr community and Corylus producing a regional pollen contribution. It may be significant that no Corylus wood was recovered from the peat samples. The importance of Salix sp. is not clear, for its pollen frequency is very variable between sites.

At the non-Phragmites sites the quantity of Betula wood in the tree layer is indicative that the species was the dominant tree. The shade produced by a Betula woodland may have been augmented by an understorey of Corylus, thus limiting the number of species in the herb layer. Pennington (1970) considers the question of whether Corylus existed as an undershrub or as a forest dominant during Zone VI in her account of vegetation history in north-west England. Where individual trees had senesced in these Betula woodlands, small herb communities may have developed in the clearings. As the regeneration of Betula is poor (Kinnaird 1974), it is likely that small open patches of woodland persisted for considerable periods of time. The occurrence of Ericaceae pollen in quantity at several levels at Fousike Burn and Hise Hope Burn may indicate these open areas within the woodland.

It is, of course, impossible to directly relate this former woodland, on the evidence of pollen alone, to any modern equivalent. McVean and Ratcliffe (1962) assign most present day Highland birch woods to one of two noda. They distinguish between (a) a Betuletum-Oxaleto-Vaccinetum with an associated species total ranging from 18 - 39. _Vaccinium myrtillus_ is an important member of this community, and (b) a _Betula_ - herb nodum (Herb rich nodum) with an average of 33 species.

It is possible that the _Betula_ woodlands as represented at the non-_Phragmites_ sites, growing on the late Boreal soils, would be more akin to McVean and Ratcliffe's _Betula_ - herb nodum. The soils would not yet have been subjected to extensive leaching and would be able to support a herb-rich community. During the increase of oceanicity at the boundary of Zone VI/VII into Atlantic times the woodlands would have changed their species composition. Perhaps the increase of Ericaceae pollen at Quickcleugh indicates such a change taking place.

## Conclusion

The results of pollen analysis and the study of macro-plant remains indicate that at least two types of woodland community existed at the sites studied.

(a) A _Phragmites_/_Betula_ community which was part of a hydrosere.

(b) A Betula woodland, possibly similar to the type of woodland that was more widespread over this part of the Northern Pennines at the time.

However, great caution must be exercised when making an analogy between a modern Highland birchwood and one that existed in late Boreal times.

At sites which show an appreciable value for Quereus pollen in late Zone VI or early Zone VII, it is suggested that the tree must have been present in the neighbourhood, where together with Alnus it had spread at the expense of Pinus.

## (B) Measurements of Betula Twigs

### (i) Introduction

Data on birch twigs from the nine sites was collected in three ways.

(a) The total number of twigs in the peat block were counted and their diameters measured.

(b) A sample of ten twigs was sectioned in order to measure the diameter of the growth rings.

(c) The occurrence of reaction wood was calculated from the total number of twigs from each site.

The data was then used as follows.

(i) To compare the growth of Betula at different altitudes.

(ii) To compare the growth of Betula growing at Phragmites and non-Phragmites sites.

(iii) To compare the growth of Betula where the tree layer is in contact with a clay substrate with the growth of Betula where the layer is situated high in the peat.

(iv) To compare the growth of Betula of different pollen zones.

Difficulties were experienced in measuring the diameter of the twigs and the growth rings. Twigs of the smallest diameters were difficult to extract from the peat, some breaking up completely so this size class must be underestimated. It was also impossible to extract all the twigs from the peat and sometimes I could not be sure that a twig had not broken in places thus being measured twice or more. When measuring growth rings, the repeated occurrence of multiple rings and incomplete growth rings made accurate measurement difficult.

(ii) Measurement of twig diameters. Histograms - Figures 2 - 10

It was thought that the most obvious factor influencing differences between tree growth at the various sites would be altitude. Table 3, therefore, shows sites arranged in decreasing altitude. The number of twigs per sample is shown in brackets and the size classes (mm) expressed as percentages are arranged in vertical columns.

Table 3.

Arrangement of sites according to decreasing altitude, showing twig diameter size classes (%)

| Site | alt. | 1-5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 | 35-40 |
|---|---|---|---|---|---|---|---|---|---|
| Milburn Forest (294) | 761 | 36 | 35 | 15 | 9 | 2 | 0.5 | 0.5 | 1 |
| Killhope Law (264) | 640 | 20 | 36 | 21 | 12 | 4 | 2 | 2 | |
| Foulsike Burn (176) | 599 | 38 | 34 | 12 | 7 | 8 | 2 | 1 | 1 |
| John's Burn (132) | 581 | 32 | 26 | 20 | 8 | 5 | 6 | 0 | 1 |
| Herdship Fell (291) | 548 | 56 | 38 | 3 | 2 | 0 | 1 | 0 | 0 |
| Green Combs (259) | 502 | 46 | 31 | 13 | 4 | 3 | 0 | 1 | 0 |
| Quickcleugh (246) | 487 | 29 | 40 | 18 | 12 | 2 | 1 | 1 | 0 |
| Hise Hope (190) | 396 | 36 | 31 | 12 | 7 | 2 | 4 | 2 | 2 |
| Smiddy Shaw (134) | 344 | 18 | 43 | 21 | 6 | 11 | 2 | 0 | 1 |

Rather unexpectedly, the results shown no correlation of twig diameter and numbers of twigs per peat sample with altitude. Therefore, I can only conclude that altitude is not an important factor in determining the diameter of twigs collected from these sites.

Table 4 shows the sites rearranged according to the presence or absence of Phragmites with the Betula wood. It was thought that the presence of Phragmites might indicate either nutrient-rich substrates which would improve the growth of Betula or waterlogged substrates which would depress the tree growth.

Table 4.

Rearrangement of Sites according to the presence or absence of Phragmites.

Number of twigs per peat sample in brackets.

% Frequency in twig diameter size classes (mm)

| Site | 1-5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 | 35-40 | Pollen Zone |
|---|---|---|---|---|---|---|---|---|---|
| Non-Phragmites sites. | | | | | | | | | |
| Foulsike (176) | 38 | 34 | 12 | 7 | 8 | 2 | 1 | 1 | VI |
| Killhope Law (264) | 20 | 36 | 21 | 12 | 4 | 2 | 2 | 0 | VI |
| Hise Hope (190) | 36 | 31 | 12 | 7 | 2 | 4 | 2 | 2 | VI/VII |
| John's Burn (upper) (88) | 52 | 32 | 12 | 2 | | | | | VII |
| Smiddy Shaw (lower) (134) | 18 | 43 | 21 | 6 | 11 | 2 | 0 | 1 | VII |
| Smiddy Shaw (upper) (195) | 43 | 52 | 11 | 1 | 1 | 0.5 | | | |
| Mean values | 34 | 38 | 15 | 6 | 4.3 | 0.8 | 0.6 | | |

Table 4 (Cont.)

| Site | 1-5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 | 35-40 | Pollen Zone |
|---|---|---|---|---|---|---|---|---|---|
| Sites with Phragmites | | | | | | | | | |
| Green Combs (259) | 46 | 31 | 13 | 4 | 3 | 0 | 1 | 0 | ? |
| Herdship Fell (291) | 56 | 38 | 3 | 2 | 0 | 1 | 0 | 0 | VII |
| John's Burn (lower (132) | 32 | 26 | 20 | 8 | 5 | 6 | 0 | 1 | VI |
| Milburn Forest (294) | 36 | 35 | 15 | 9 | 2 | 0.5 | 0.5 | 1 | VII |
| Quickcleugh (246) | 29 | 40 | 18 | 12 | 2 | 2 | 1 | 1 | VII |
| Mean values | 40 | 34 | 14 | 7 | 2.4 | 2 | 0.5 | 0.3 | |

There appears to be no significant difference between the twig diameters of the two groups of sites. The mean value for the smallest twigs at the Phragmites sites is slightly higher (6%) than the one for the non-Phragmites sites, but for all other classes the differences are too small for any conclusions to be made. The only noticeable inter-site difference is in the total number of twigs extracted from the peat. The number of twigs from the Phragmites sites is greater ($\bar{x}$ = 244) compared with the number of twigs from the non-phragmites sites ($\bar{x}$ = 174). I do not think that very much significance can be attached to this result as the method of extraction of the twigs from the peat can only give a crude estimate.

Another comparison of twig diameters can be made comparing twig diameters from tree layers in contact with the basal clay and tree layers in the peat - at the same site. Table 5 shows such a comparison between upper and lower tree layers at Smiddy Shaw and John's Burn.

Table 5

% frequency in twig diameter size classes (mm)

| Site | 1-5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 | 35-40 |
|---|---|---|---|---|---|---|---|---|
| John's Burn (upper) (88) | 52 | 32 | 12 | 2 | | | | |
| John's Burn (lower) (132) | 32 | 26 | 20 | 8 | 5 | 6 | 0 | |
| Smiddy Shaw (upper) (195) | 43 | 52 | 11 | 1 | 1 | 0.5 | | |
| Smiddy Shaw (lower) (134) | 18 | 43 | 21 | 6 | 11 | 2 | 0 | |

At both sites the upper tree layer yielded a greater number of twigs of the two smallest diameters. At Smiddy Shaw the upper layer also yielded the greatest number of twigs. However, this was not so at John's Burn. There were a few twigs of larger diameters in the lower tree layer at John's Burn and Smiddy Shaw. It is possible that the birches that grew above the clay layer at these sites were of larger dimensions than the trees growing on the peat but a much larger sample would be needed and more sites investigated before any firm conclusions could be made.

The only other comparison that could be carried out on twig diameters would be to compare inter-site tree layers on an age basis i.e., whether the layer is in Zone VI or VII. It will be seen on consulting Table 4 that little difference exists.

## (iii) The Measurement of Growth Rings.

### Introduction.

Observations on annual growth rings of trees goes back four centuries to Leonardo da Vinci who made the fundamental contribution to the subject by suggesting that the age of a tree may be determined by counting its rings. He also observed that water was of great importance to tree growth and that ring thickness revealed the nature of the seasons. There is now an extensive literature on the subject, perhaps the most comprehensive being by Glock (1937, 1940, 1941a, 1941b) and Douglass (1919, 1928, 1936).

The development of tree ring studies was pioneered by Douglass on *Pinus ponderosa* which proved to be one of the most suitable and sensitive of trees with regard to its ring widths in response to varying amounts of rainfall. He also produced an empirical formula for calculating mean rainfall from mean tree growth on the Arizona plateau, including correction for reduction of ring widths with increasing age of the tree.

Climatologists have used growth rings as reasonable indications of climatic conditions, especially rainfall. Kramer and Kozlowski (1960) state that the sensitivity of diameter growth to soil moisture forms the basis for the science of dendrochronology. Salisbury and Jane (1940) compared annual ring widths in modern hazel (*Corylus avellana*) and oak (*Quercus* sp.) with those shown in charcoal of the same species from Maiden Castle, at Neolithic and early Iron Age levels. They measured large numbers of specimens - nearly 2000 rings from prehistoric charcoal; 568 rings being from *Corylus*. The ring widths of modern hazel from Dorset were found to correlate strikingly with rainfall over a period of four years. Mean ring widths were found to increase slightly but consistently from Neolithic times to recent, but the difference was not considered to be statistically significant. This result and others discussed in the paper illustrates the difficulty of drawing conclusions about climate from tree ring data. As Dobbs (1951) states "the assumption always has to be other things being equal" and this reservation is reiterated by Morey (1973) who considers the whole array of environmental factors that indirectly affect the formation of annual rings. In his account of Hayley Wood, Rackham (1975) considers factors such as the proximity of other trees in the early stages of a tree's growth, the effect of faster growing neighbours, their removal and defoliation by insect pests.

If, as Morey (1973) suggests that the most important aspect of tree ring chronology is to provide a record of past regional climate, then the study of growth rings of Betula in the tree layers might be of some relevance.

Betula is not an ideal subject for growth ring study mainly because it possesses diffuse porous wood. This means that the growth rings are not so well defined. Also, as occurs in other temperate trees, a late seasonal flush of growth can occur, particularly after a dry summer, leading to the formation of false or multiple rings. These must be examined under the high power of the microscope in order to avoid inaccurate measurements of the true ring. In addition to these problems, many of the twigs used for the study, crumbled on sectioning.

Measurement of Growth Rings - Results.

Measurements of annual growth rings of Betula, 10 samples from each site, are shown in Table 6 together with standard errors.

Table 6

Mean ring widths of Betula twigs from the tree layers

| Site | Pollen Zone | Alt. (m) | Mean ring width (mm) |
|---|---|---|---|
| Embleton Fen | Present | 55 | 0.63 ± 0.07 * |
| Foulsike Burn | VI | 599 | 0.56 ± 0.03 |
| Hise Hope Burn | VI/VII | 396 | 0.60 ± 0.03 |
| Herdship Fell | VII | 548 | 0.32 ± 0.01 |
| John's Burn (Lower) | VI | 581 | 0.58 ± 0.03 |
| John's Burn (Upper) | VII | 581 | 0.33 ± 0.02 |
| Green Combs | ? | 502 | 0.40 ± 0.02 |
| Milburn Forest | VII | 761 | 0.56 ± 0.02 |
| Killhope Law | VI | 640 | 0.58 ± 0.03 |
| Quickcleugh | VII | 487 | 0.34 ± 0.02 |
| Smiddy Shaw (Upper) | VII | 344 | 0.39 ± 0.02 |
| Smiddy Shaw (Lower) | VII | 344 | 0.62 ± 0.04 |

*Omitted in regression analysis.

Correlation coefficient = 0.079.

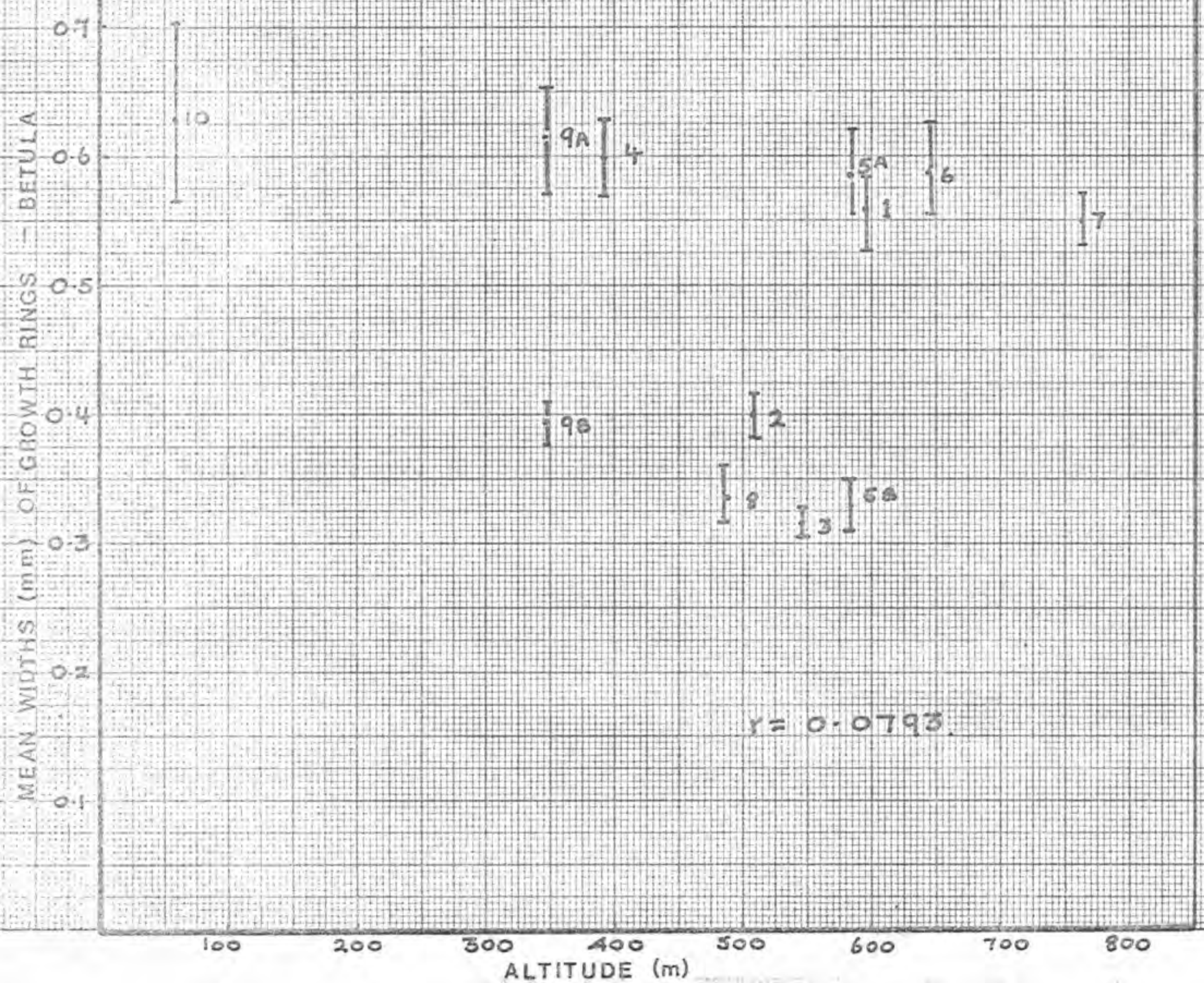
It was again considered that correlation between mean growth ring widths and altitude, presence or absence of Phragmites, the age of the peat, and contact with clay or peat might be possible.

The data is expressed as follows:

(a) Mean widths of growth rings are plotted against altitude - Figure 11. Results of Regression analysis give a correlation

FIGURE 11

The mean growth ring widths (mm) of *Betula* from the tree layers at sites of varying altitudes in the Northern Pennines.




Key for Site Names.

1. - Foulsike Burn.
2. - Green Combs
3 - Herdship Fell.
4. - Hise Hope Burn.
5A John's Burn. Lower tree layer.
5B John's Burn. Upper tree layer.
6. Killhope Law
7. Milburn Forest.
8. Quickcleugh.
9A. Smiddy Shaw. Lower tree layer.
9B Smiddy Shaw. Upper tree layer
10. Embleton Fen.

I = standard error

coefficient of 0.0793 indicating little correlation between altitude and annual growth ring width. This result is not what I would have expected, but is in agreement with the results obtained when comparing twig diameters with altitude.

(b) The sites are arranged according to the presence or absence of Phragmites.

Meangrowth ring widths -

Table 7

| | Mean growth ring widths |
|---|---|
| Phragmites sites | |
| Green Combs | $0.40 \pm 0.02$ |
| Herdship Fell | $0.32 \pm 0.01$ |
| John's Burn | $0.58 \pm 0.03$ |
| Quickcleugh | $0.34 \pm 0.02$ |
| Milburn Forest | $0.56 \pm 0.02$ |
| Non-Phragmites sites | |
| Foulsike | $0.56 \pm 0.03$ |
| Hise Hope Burn | $0.60 \pm 0.03$ |
| Smiddy Shaw | $0.62 \pm 0.04$ |
| Killhope Law | $0.58 \pm 0.03$ |

There appears to be some difference between four non-Phragmites sites which give ring widths greater than 0.5mm when compared with three of the *Phragmites* sites - Green Combs, Quickcleugh and Herdship Fell which give lower values. John's Burn and Milburn Forest, however, give measurements similar to the non-*Phragmites* sites. It is possible that some unidentified environmental factor is operating against tree growth in the case of these three *Phragmites* sites, two of which are related geographically. Possibly, a high water table might have been responsible for the lower growth rate.

(c) The comparison of mean growth ring widths from twigs from the upper and lower tree layers.

Table 8

| Site | Mean growth ring width |
|---|---|
| John's Burn - lower tree layer | $0.58 \pm 0.03$ |
| John's Burn - upper tree layer | $0.47 \pm 0.02$ |
| Smiddy Shaw - lower tree layer | $0.62 \pm 0.04$ |
| Smiddy Shaw - upper tree layer | $0.39 \pm 0.02$ |

The most interesting difference lies in an intra site comparison of mean growth ring widths. Two wood layers have been identified at Smiddy Shaw and at John's Burn. The latter has more distinct separate layers whereas at Smiddy Shaw the great depth of the tree layer makes an upper and lower horizon a possible comparison. At both sites the basal tree layer is resting on clay, in fact some twig fragments actually occur in the clay. Mean ring diameters obtained from the layer for both sites exceeds 0.55mm whereas the ring diameters from the upper tree layers are significantly narrower, especially at Smiddy Shaw.

Using Analysis of Variance (a) the mean growth ring values of both tree layers are compared on an inter-site basis.

John's Burn $0.53 \pm 0.02$

Smiddy Shaw $0.48 \pm 0.02$

When the ring widths (mm) of the 2 sites were compared, an "F" value of 3.71 (df = 1,507) was obtained indicating that there is not a significant difference between the ring widths of the two sites.

However, when the upper tree layer is compared with the lower tree layer of both sites a significant difference is obtained.

Mean growth ring widths from upper tree layers = $0.42 \pm 0.01$

Mean growth ring widths from lower tree layers = $0.72 \pm 0.11$

When the ring widths of twig samples from upper and lower tree layers were compared, an "F" value of 10.35 was obtained (df = 1,506). This value indicates a significant difference between the ring widths of twig samples from the two layers. ($p = 0.01$)

It is possible that the difference in mean growth ring diameter of twigs from these layers is related to a greater availability of nutrients for the trees growing on the clay layer. Presumably, trees growing with their roots in the peat would have access to a much lower nutrient supply.

Conclusions.

The mean growth ring widths show considerable variation between sites i.e., from 0.32mm to 0.62mm so this method is better than the measurement of twig diameters for estimating growth. It is difficult, however, to isolate any one factor, of overriding importance, affecting growth ring width.

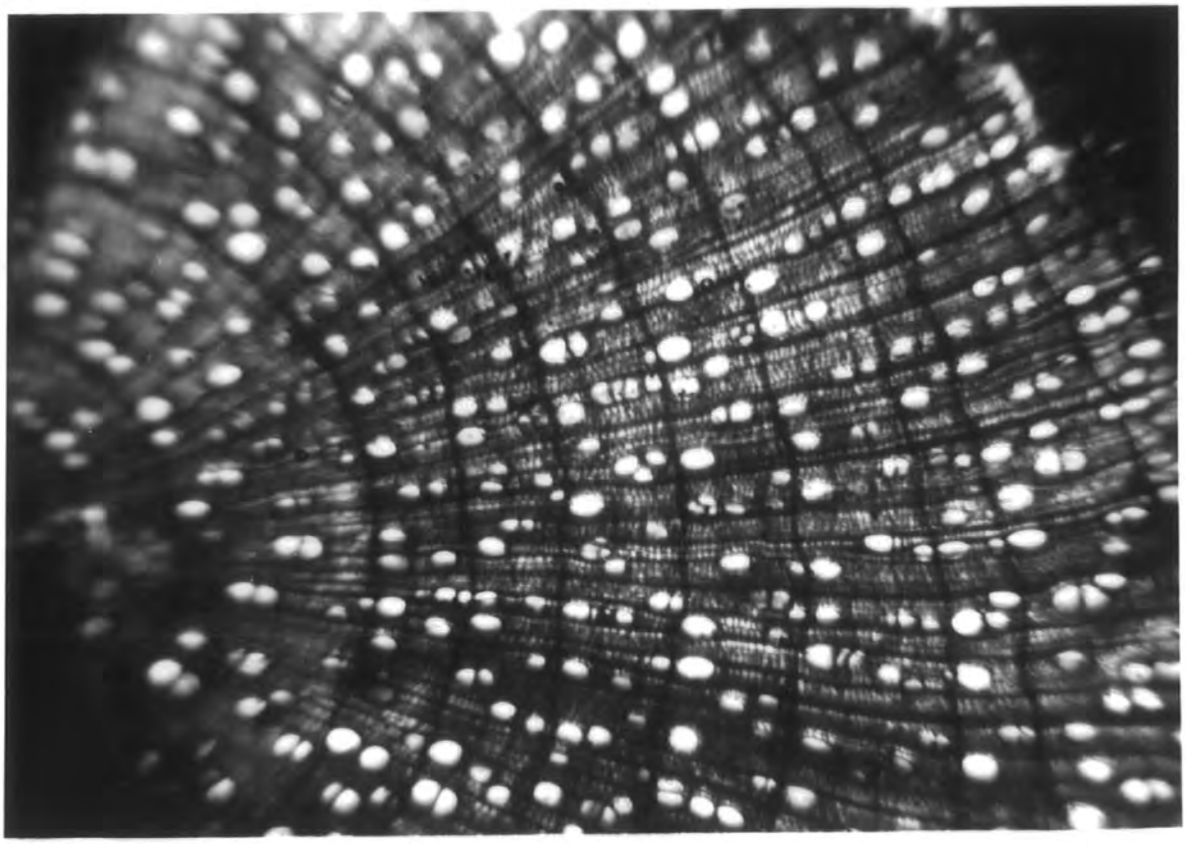
(a) The effect of Altitude shows no correlation.

(b) The association with Phragmites. There seems to be a fair correlation between some sites. It had been hoped that the differences would be greater. Perhaps the biological activity of Phragmites (Haslam 1971a, 1971b), or a high water table, work against the growth of Betula dnt to some extent counteract the benefits of a slightly higher nutrient supply. The mean ring widths of twigs collected from Embleton Fen (0.63 ± 0.07) are not much greater than the mean widths of growth rings from Smiddy Shaw, Hise Hope Burn and Killhope Law. As the altitude of Embleton Fen is only 55m, one would have expected a better performance. In this case, the high water in winter may be the controlling factor in tree growth.

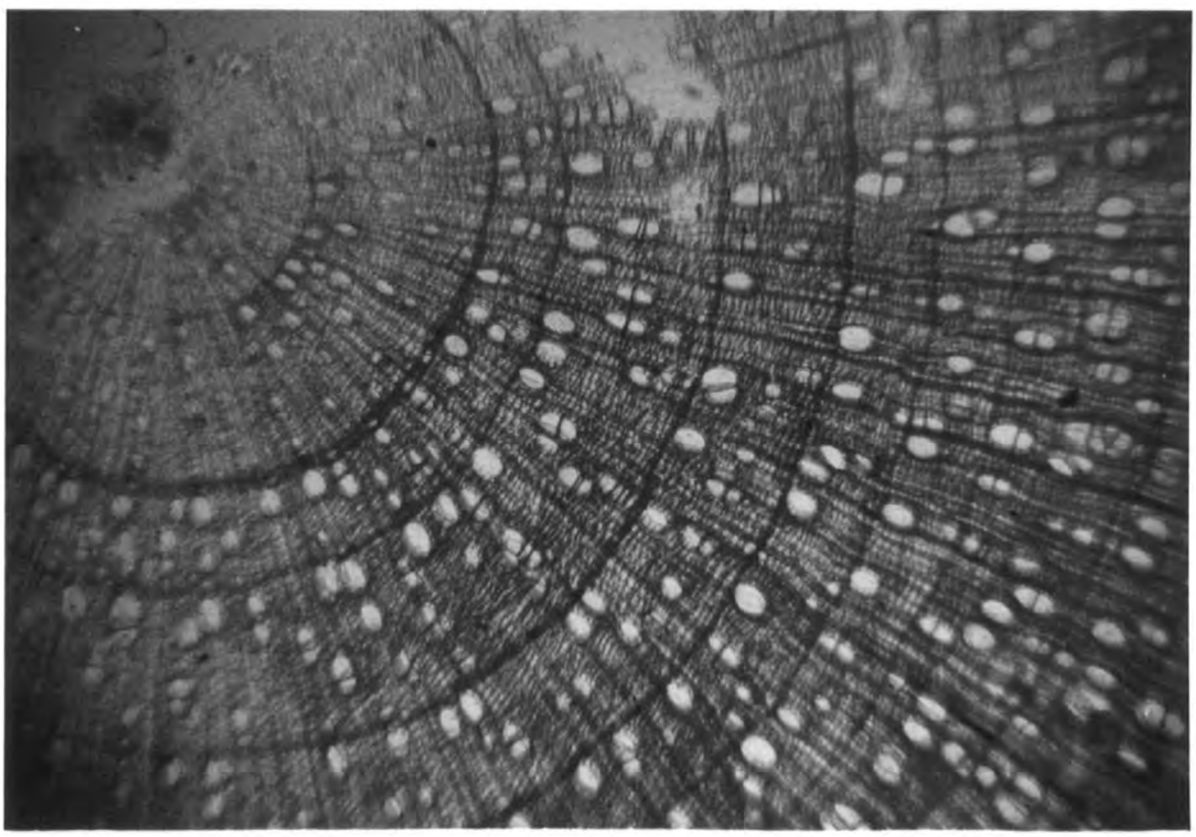
(c) Mineral status of the soil. More significant results have been obtained when comparing the growth ring widths of twigs from sites with two tree layers, one layer being in contact with a mineral soil and the other with the trees growing in peat.

The standard errors are low at all the sites, indicating little variability of growth ring widths within the sample. Hence within each site climate is not a key factor affecting the growth of Betula at the time. However, there were a few sections where growth rings showed great variability in width. No doubt this was due to climatic influences. Examples of complacent and non-complacent growth rings from Betula are shown in Plates 3 and 4.

Complacent ring formation in <u>Betula</u> plate 3



Non-complacent ring formation in <u>Betula</u> plate 4



(iv) Multiple Rings. Plate 5.

No quantitative measurements could be made on the incidence of Multiple or false growth rings in the Betula wood. However, in many of the sections used for growth ring measurement such formations were identified. They were particularly frequent in samples taken from Smiddy Shaw, Hise Hope and Foulsike Burn.

The causes of multiple rings are not very well understood. Climatic influences cannot be ruled out. The cause in some instances may be genetic (Stokes and Smiley 1968). However, it is known that young trees are more prone to produce multiple rings than older ones because of their greater vigour and a tendency to produce multiple flushes of growth. In older trees, so called "Lammas" shoots or "Johannestriebe" in German literature, may be caused by the trees receiving heavy rainfall after a period of summer drought. An additional flush of growth is produced late in the season. An increment of late growth occurs from the bursting of the current year's buds (Kramer and Kozlowski 1960) and early Lammas growth may make a tree more susceptible to frost injury. So called "frost rings" are a form of multiple ring.

The significance of multiple rings in Betula twigs used in this study are not understood. The lower incidence of this type of growth ring in sections from the "Phragmites" sites may indicate that a more constant water supply has prevented these intermittent growth flushes. On the other hand, multiple ring formation may be a common feature in Betula wood development. Clearly, more investigation is needed on this subject.

(v) <u>Incomplete Growth Rings</u>. Plate 6.

Incomplete growth rings were found in sections from all the sites. Various causes are given for their formation. They may be formed as a result of unilateral damage (Fritz and Averell 1924) or from the results of epitrophic or hypotrophic damage (Gessner 1961). Climatic causes are considered by Glock (1937). Good examples of incomplete ring formation in arctic willows are given by Muller et al (1963) who suggest that they may be caused by adverse climatic conditions, but this needs confirmation by cross dating. The occurrence of such rings in the *Betula* wood may be the result of all or just one of these factors.

(vi) <u>Reaction Wood</u>.

Wardrop (1964) considers that in general leaning stems and branches of angiosperms are characterised by an eccentricity of growth in both xylem and phloem. This eccentricity is usually, but not necessarily, associated with changes in the anatomy of both types of tissue and may be designated a reaction anatomy. It seems that the formation of reaction wood is associated with movements of orientation in branches and stems. The mechanism behind the formation of reaction wood has not yet been fully elucidated. The idea that it was a stress response is now in some doubt and there is now direct experimental evidence that reaction wood is formed as a result of hormone influence.

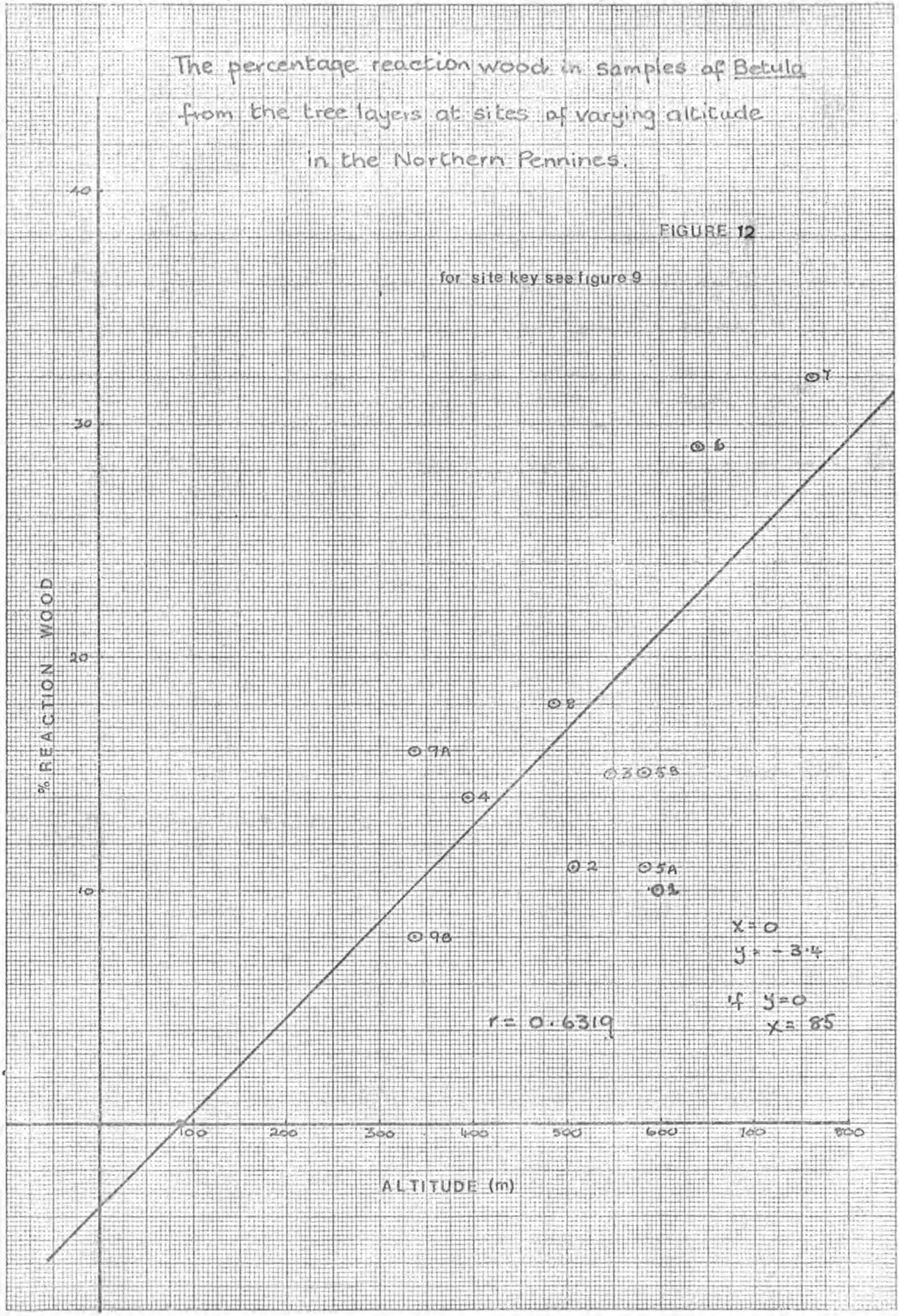
Reaction wood was identified in twig samples from all the sites. Its approximate occurrence is expressed as % of total wood extracted and is shown in Table 9. The % reaction wood is plotted against altitude (Figure12). From the graph there appears to be some correlation between altitude and % reaction wood. (r = 0.6319)

The highest values are obtained from Killhope Law and Milburn Forest sites at the highest altitude. It is possible that the results indicate that the growth form of Betula at these higher altitudes was more of a trailing nature. However, the cause of reaction wood cannot be deduced from these results.

Table 9

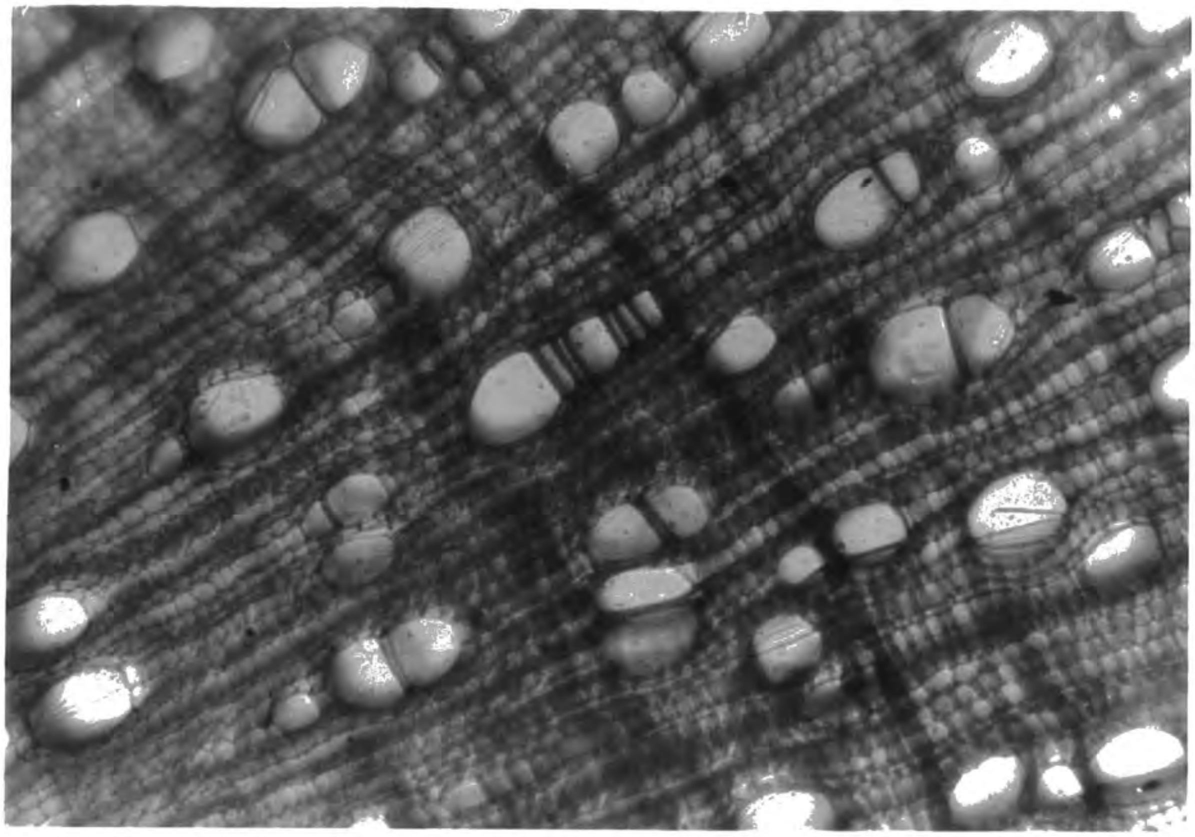
Percent reaction wood found in Betula twigs

| Site | Altitude | % Reaction Wood |
|---|---|---|
| Foulsike Burn | 599 | 10 |
| Green Combs | 502 | 11 |
| Herdship Fell | 548 | 15 |
| Hise Hope Burn | 396 | 14 |
| John's Burn (Lower) | 581 | 11 |
| John's Burn (Upper) | 581 | 15 |
| Killhope Law | 640 | 29 |
| Milburn Forest | 761 | 32 |
| Quickcleugh | 487 | 18 |
| Smiddy Shaw (Lower) | 344 | 16 |
| Smiddy Shaw (Upper) | 344 | 8 |


The percentage reaction wood in samples of Betula from the tree layers at sites of varying altitude in the Northern Pennines.
FIGURE 12
for site key see figure 9
% REACTION WOOD
40
30
20
10
ALTITUDE (m)
100
200
300
400
500
600
700
800
7
6
8
9A
3
5B
4
2
5A
9B
r = 0.6319
x = 0
y = -3.4
if y = 0
x = 85

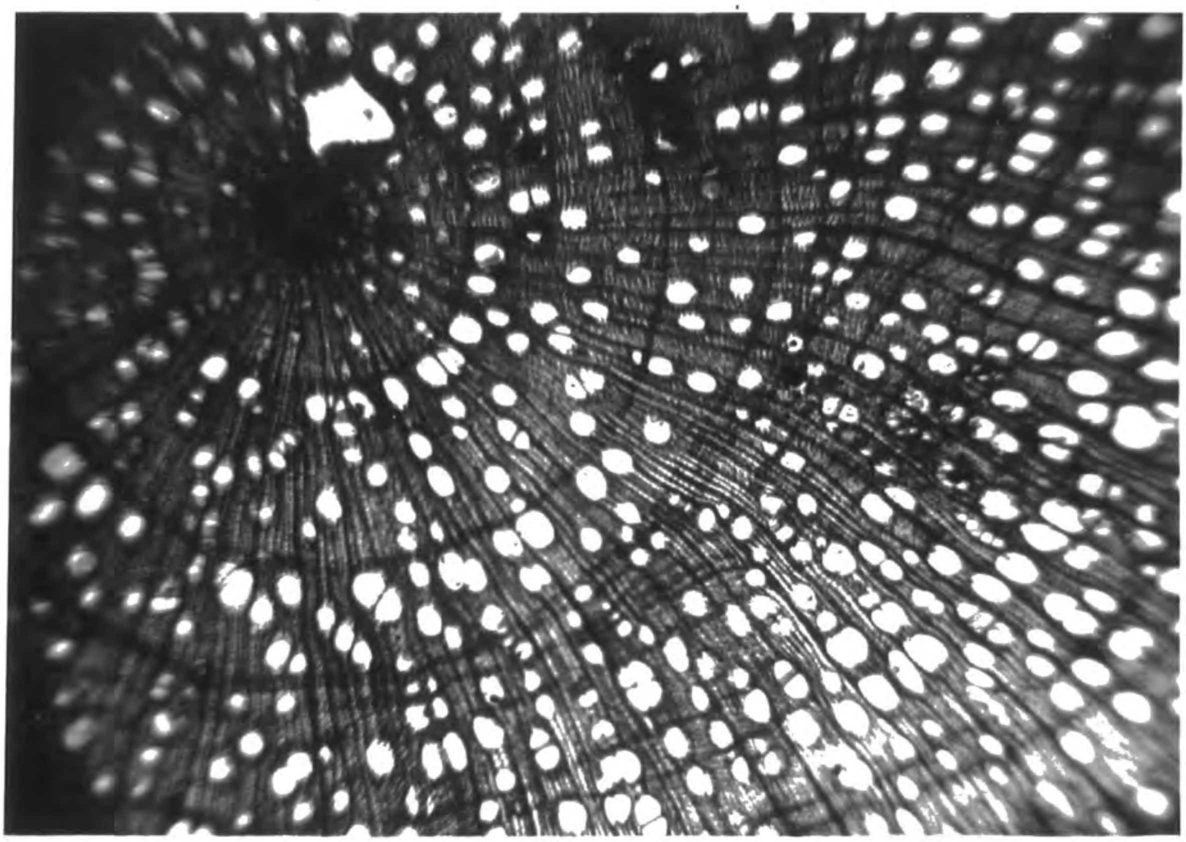
Multiple rings in <u>Betula</u>

plate 5



Incomplete rings in <u>Betula</u>

plate 6



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## SUMMARY

The preparation of pollen diagrams and the examination of macro-plant remains from peat samples obtained from nine sites in the Northern Pennines has helped to provide information concerning the nature of the forest as represented by the tree layers in the peat.

An attempt has been made to measure the growth of Betula twigs from these tree layers by using twig diameters and annual growth ring widths as parameters of growth of the trees at these sites.

The effect of altitude, presence of Phragmites, age of the peat (i.e., pollen zone) and influence of mineral or peat substrate on the growth of Betula have been considered. The results have shown that the information from twig diameters and mean growth ring width indicate that the nutrient status of the soil had the greatest effect on the growth of Betula at these sites. The significance of the occurrence of Multiple rings and reaction wood have also been discussed.

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# APPENDIX

## FOUL SIKE

| TWIG DIAMETERS (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 0.52 | 1.17 | 0.21 | 0.71 | 0.75 | 0.42 | | | | | | | | | | | | | |
| 7.0 | 0.66 | 0.38 | 0.63 | 0.89 | 0.59 | 0.28 | 0.47 | | | | | | | | | | | | |
| 10.0 | 0.33 | 0.75 | 0.56 | 0.38 | 0.33 | 0.31 | 0.66 | 0.45 | 0.33 | | | | | | | | | | |
| 11.0 | 0.38 | 0.80 | 0.94 | 1.20 | 0.47 | 0.71 | 0.73 | 0.80 | | | | | | | | | | | |
| 16.5 | 0.68 | 1.20 | 0.66 | 1.70 | 0.71 | 0.33 | 0.42 | 0.23 | 0.45 | 0.47 | 0.47 | | | | | | | | |
| 13.5 | 0.35 | 1.24 | 0.47 | 0.41 | 0.42 | 0.99 | 1.13 | 0.42 | 0.42 | 0.23 | 0.33 | 0.75 | 0.38 | 0.33 | 0.38 | | | | |
| 17.0 | 0.52 | 0.94 | 1.17 | 0.56 | 0.35 | 0.23 | 0.42 | 0.45 | 0.77 | 0.47 | 0.47 | 0.38 | 0.38 | | | | | | |
| 11.0 | 0.52 | 0.59 | 1.17 | 0.77 | 0.82 | 0.89 | 0.38 | | | | | | | | | | | | |
| 6.5 | 0.54 | 0.28 | 0.45 | 0.38 | 0.28 | 0.23 | 0.23 | 0.23 | 0.19 | 0.38 | | | | | | | | | |
| 7.5 | 0.42 | 1.10 | 0.70 | 1.17 | 0.70 | 0.18 | 0.33 | 0.35 | 0.35 | 0.23 | 0.28 | | | | | | | | |
| 20.0 | 0.70 | 0.18 | 0.26 | 0.35 | 0.77 | 1.10 | 0.47 | 0.42 | 0.49 | 0.26 | 0.54 | 0.91 | 0.56 | 0.26 | 0.47 | 1.17 | 0.68 | | |

N = 117   = 65.0   SD = 0.297

$\bar{x}$ = 0.556   = 46.479   SE = 0.027

Variance = 0.088

GREEN COMBS

| TWIG DIAMETER (mm) | RING WIDTHS (mm) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 15.0 | 0.66 | 0.38 | 0.35 | 0.33 | 0.38 | 0.68 | 0.28 | 0.26 | 0.24 | 0.38 | 1.01 | 0.26 | 0.24 | 0.33 | | | | |
| 15.5 | 0.80 | 0.63 | 0.33 | 0.33 | 0.66 | 0.33 | 0.80 | 0.33 | 0.21 | 0.33 | 0.71 | 0.33 | 0.19 | 0.19 | 0.56 | | | |
| 12.5 | 0.28 | 0.38 | 0.52 | 0.24 | 0.26 | 0.24 | 0.24 | 0.19 | 0.19 | 0.28 | 0.24 | 0.19 | 0.24 | 0.24 | 0.38 | 0.33 | 0.33 | 0.31 |
| 10.5 | 0.24 | 0.28 | 0.63 | 0.38 | 0.42 | 0.28 | 0.38 | 0.31 | 0.31 | 0.75 | 0.56 | | | | | | | |
| 8.5 | 0.24 | 0.47 | 0.49 | 0.31 | 0.73 | 1.10 | 0.38 | 0.19 | 0.66 | | | | | | | | | |
| 11.5 | 0.21 | 0.52 | 0.75 | 1.18 | 0.71 | 0.42 | 0.40 | 0.40 | 0.40 | | | | | | | | | |
| 9.5 | 0.33 | 0.45 | 0.28 | 0.66 | 0.47 | 0.26 | 0.24 | 0.38 | 0.19 | 0.24 | 0.31 | | | | | | | |
| 10.5 | 0.24 | 0.52 | 0.28 | 0.71 | 0.45 | 0.21 | 0.24 | 0.24 | 0.38 | 0.28 | 0.24 | 0.40 | | | | | | |
| 13.5 | 0.42 | 0.47 | 0.42 | 0.33 | 0.45 | 0.38 | 0.33 | 0.19 | 0.31 | 0.24 | 0.33 | 0.28 | 0.19 | 0.19 | 0.31 | | | |
| 11.5 | 0.47 | 0.56 | 0.49 | 0.33 | 0.66 | 0.52 | 0.75 | 0.28 | 0.28 | 0.33 | 0.33 | | | | | | | |
| 11.5 | 0.42 | 0.49 | 0.68 | 0.71 | 0.38 | 0.59 | 0.33 | 0.33 | 0.35 | 0.33 | | | | | | | | |

N = 136 $\bar{x}$ = 0.40

= 54.47 SD = 0.189

= 26.62 SE = 0.016

## HERDSHIP FELL

| TWIG DIAMETER (mm) | RING WIDTHS (mm) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 9.0 | 0.42 | 0.71 | 0.56 | 0.18 | 0.24 | 0.17 | 0.38 | 0.42 | 0.19 | 0.19 | 0.24 | 0.19 | 0.24 | 0.19 | 0.28 | | |
| 9.0 | 0.38 | 0.28 | 0.56 | 0.75 | 0.38 | 0.28 | 0.28 | 0.42 | 0.42 | 0.38 | 0.33 | 0.38 | 0.33 | | | | |
| 7.5 | 0.24 | 0.24 | 0.38 | 0.41 | 0.18 | 0.09 | 0.24 | 0.14 | 0.18 | 0.18 | 0.17 | 0.18 | 0.35 | | | | |
| 8.0 | 0.28 | 0.42 | 0.28 | 0.38 | 0.47 | 0.47 | 0.38 | 0.56 | 0.23 | 0.14 | 0.14 | 0.18 | | | | | |
| 9.0 | 0.28 | 0.23 | 0.47 | 0.28 | 0.23 | 0.28 | 0.18 | 0.14 | 0.28 | 0.47 | 0.33 | 0.28 | 0.33 | 0.23 | | | |
| 12.5 | 0.42 | 0.71 | 0.59 | 0.19 | 0.17 | 0.14 | 0.14 | 0.31 | 0.54 | 0.49 | 0.19 | 0.24 | 0.24 | 0.14 | 0.14 | 0.28 | |
| 11.5 | 0.42 | 0.28 | 0.28 | 0.47 | 0.45 | 0.23 | 0.45 | 0.24 | 1.32 | 0.28 | 0.19 | 0.09 | 0.28 | 0.42 | 0.33 | 0.4 | 0.24 |
| 7.5 | 0.31 | 0.19 | 0.24 | 0.28 | 0.42 | 0.17 | 0.09 | 0.32 | 0.31 | 0.35 | 0.09 | 0.24 | 0.19 | 0.42 | | | |
| 7.0 | 0.47 | 0.28 | 0.28 | 0.66 | 0.32 | 0.14 | 0.19 | 0.14 | 0.19 | 0.14 | 0.19 | 0.40 | 0.28 | | | | |
| 12.0 | 0.28 | 0.42 | 0.47 | 0.94 | 0.47 | 0.14 | 0.17 | 0.19 | 0.21 | 0.19 | 0.14 | 0.19 | 0.24 | | | | |

N = 138 $\bar{x}$ = 0.3228

= 44.55 Variance = 0.0198

= 17.12 SD = 0.1407

SE = 0.012

# HISE HOPE BURN

## RING WIDTHS (mm)

| TWIG DIAMETER (mm) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13.0 | 0.78 | 1.21 | 1.69 | 1.58 | 1.30 | 1.01 | 0.51 | | | | | | | | | |
| 10.0 | 0.80 | 0.52 | 0.39 | 0.61 | 0.78 | 1.04 | 0.45 | 0.65 | | | | | | | | |
| 11.0 | 0.66 | 0.39 | 0.41 | 0.32 | 0.57 | 0.52 | 0.80 | 0.45 | | | | | | | | |
| 10.5 | 0.32 | 0.26 | 0.32 | 0.52 | 0.52 | 1.56 | 1.30 | 1.05 | | | | | | | | |
| 9.0 | 0.71 | 0.28 | 0.41 | 0.31 | 0.52 | 0.36 | 0.58 | 0.53 | 0.89 | 0.52 | | | | | | |
| 12.8 | 0.65 | 1.54 | 0.67 | 0.44 | 0.45 | 0.53 | 0.57 | 0.39 | 1.01 | 0.52 | | | | | | |
| 15.0 | 0.44 | 0.70 | 0.42 | 0.63 | 0.66 | 0.61 | 0.55 | 0.50 | 0.33 | 0.26 | 0.27 | | | | | |
| 12.0 | 0.50 | 0.35 | 0.35 | 0.18 | 0.26 | 0.24 | 0.26 | 0.26 | 0.19 | 0.18 | | | | | | |
| 10.5 | 0.71 | 0.13 | 0.96 | 0.50 | 0.42 | 0.59 | 0.29 | 0.26 | | | | | | | | |
| 16.5 | 0.50 | 0.31 | 0.65 | 0.96 | 1.11 | 1.20 | 0.44 | 0.49 | 0.63 | 0.44 | 0.39 | 0.63 | 0.65 | | | |

N = 93.0 $\bar{x}$ = 0.597

= 55.6 Variance = 0.6008

= 43.12 SD = 0.3276

SE = 0.0341

JOHNS BURN. LOWER TREE LAYER

| TWIG DIAMETER (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16.5 | 0.47 | 0.47 | 0.80 | 0.47 | 0.63 | 0.47 | 0.61 | 0.68 | 0.71 | | | | | | | | |
| 19.5 | 0.47 | 0.94 | 1.2 | 0.61 | 0.85 | 0.68 | 0.47 | 0.87 | 0.89 | 0.75 | | | | | | | |
| 11.5 | 0.19 | 0.75 | 0.47 | 0.21 | 0.66 | 0.47 | 0.82 | 0.63 | 0.42 | 0.47 | 0.45 | | | | | | |
| 14.0 | 0.42 | 0.42 | 0.78 | 0.54 | 0.54 | 0.54 | 0.63 | 1.01 | 0.78 | 1.01 | 0.61 | | | | | | |
| 22.0 | 0.47 | 0.82 | 1.18 | 0.82 | 0.52 | 0.92 | 0.96 | 0.16 | 0.56 | 1.08 | 0.94 | 0.33 | | | | | |
| 12.0 | 0.38 | 0.47 | 0.40 | 0.52 | 0.47 | 0.47 | 0.26 | 0.24 | 0.73 | 0.47 | | | | | | | |
| 10.0 | 0.24 | 0.85 | 0.24 | 0.47 | 0.59 | 0.49 | 0.19 | 0.33 | 0.33 | 0.33 | | | | | | | |
| 19.0 | 0.52 | 0.89 | 1.36 | 1.13 | 0.78 | 1.22 | 0.68 | 0.85 | 0.71 | 1.13 | 2.11 | | | | | | |
| 10.5 | 0.24 | 0.33 | 0.14 | 0.47 | 0.56 | 0.59 | 0.33 | 0.24 | 0.52 | 0.38 | 0.40 | | | | | | |
| 13.0 | 0.31 | 0.38 | 0.71 | 0.47 | 0.42 | 0.38 | 0.33 | 0.66 | 0.61 | 0.87 | 0.31 | 0.35 | 0.47 | | | | |

N = 107 SD = 0.339

$\bar{x}$ = 0.58 SE = 0.03

= 63.21

= 48.69

## JOHNS BURN. UPPER TREE LAYER

| TWIG DIAMETER (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.0 | 0.42 | 0.19 | 0.61 | 0.38 | 0.52 | 0.80 | 0.38 | 0.78 | 0.21 | 0.71 | 0.47 | 0.28 | 0.73 | | | | |
| 12.5 | 0.24 | 0.47 | 0.52 | 1.22 | 0.96 | 0.59 | 0.24 | 0.33 | 0.24 | 0.26 | 0.42 | 0.28 | 0.21 | | | | |
| 12.0 | 0.66 | 0.47 | 0.47 | 0.68 | 0.35 | 0.71 | 0.26 | 0.52 | 0.47 | 0.28 | 0.78 | 0.33 | | | | | |
| 13.5 | 0.45 | 0.92 | 0.12 | 0.54 | 0.24 | 0.38 | 0.89 | 0.31 | 0.26 | 0.40 | 0.89 | 0.56 | 0.33 | 0.38 | | | |
| 14.0 | 0.42 | 0.80 | 1.06 | 0.49 | 0.33 | 0.19 | 0.16 | 0.19 | 0.21 | 0.59 | 0.52 | 0.52 | 0.26 | 0.38 | | | |
| 14.0 | 0.28 | 0.19 | 0.47 | 0.45 | 0.49 | 0.66 | 0.35 | 0.82 | 0.28 | 1.03 | 0.40 | 0.14 | | | | | |
| 11.0 | 0.33 | 0.94 | 0.99 | 0.56 | 0.31 | 0.24 | 0.28 | | | | | | | | | | |
| 16.5 | 0.28 | 0.63 | 0.45 | 0.56 | 0.35 | 0.47 | 0.42 | 0.49 | 0.31 | 0.14 | 0.52 | 0.96 | 0.63 | 0.75 | 0.47 | 0.45 | 1.27 |
| 13.5 | 0.45 | 0.26 | 0.47 | 0.24 | 0.21 | 0.24 | 0.33 | 0.26 | 0.80 | 0.61 | 0.47 | 0.33 | 0.14 | 0.80 | | | |
| 10.0 | 0.28 | 0.24 | 0.31 | 0.45 | 0.56 | 0.54 | 0.26 | 0.24 | 0.26 | | | | | | | | |

N = 178 SD = 0.2939

$\bar{x}$ = 0.33 SE = 0.022

= 58.86

= 34.61

# KILLHOPE LAW

| TWIG DIAMETER (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13.5 | 0.47 | 0.81 | 0.66 | 0.94 | 0.85 | 0.85 | 0.70 | 0.77 | 0.94 | 0.59 | 0.49 | 0.47 | 0.30 | 0.23 | | | | | | | |
| 11.5 | 1.10 | 0.70 | 0.30 | 0.28 | 0.23 | 0.23 | 0.33 | 0.75 | 0.56 | | | | | | | | | | | | |
| 13.5 | 0.85 | 1.62 | 0.85 | 0.63 | 0.49 | 0.68 | 0.35 | 0.26 | 0.19 | 0.38 | | | | | | | | | | | |
| 12.0 | 0.75 | 0.70 | 0.28 | 1.3 | 0.16 | 0.61 | 0.33 | 0.38 | | | | | | | | | | | | | |
| 14.5 | 0.54 | 0.47 | 0.56 | 0.38 | 0.61 | 0.63 | 0.45 | 0.23 | 0.81 | 0.77 | 0.47 | 0.38 | 0.38 | 0.56 | 0.47 | 0.58 | | | | | |
| 12.0 | 0.30 | 0.77 | 0.99 | 0.80 | 0.82 | 0.47 | 0.42 | 0.52 | | | | | | | | | | | | | |
| 12.0 | 0.80 | 0.85 | 0.23 | 1.13 | 0.38 | 0.75 | 0.33 | 0.28 | 0.33 | 0.28 | 0.23 | 0.28 | 0.23 | 0.19 | 0.28 | 0.28 | 0.12 | | | | |
| 14.0 | 0.89 | 0.42 | 0.42 | 0.80 | 0.66 | 0.23 | 0.89 | 0.87 | 0.47 | 0.92 | 0.33 | 0.30 | 0.19 | 0.38 | 0.35 | 0.23 | 0.19 | 0.26 | 0.26 | 0.26 | 0.28 |
| 9.0 | 0.85 | 0.75 | 0.66 | 0.52 | 0.30 | 0.85 | 0.47 | | | | | | | | | | | | | | |
| 13.0 | 2.1 | 0.33 | 0.38 | 0.56 | 1.17 | 0.47 | 0.96 | 0.58 | 0.47 | 0.56 | | | | | | | | | | | |

N = 120 $\bar{x}$ = 0.548

= 65.76 Variance = 0.103

= 48.37 SD = 0.3206

SE = 0.0293

## MILBURN FOREST

| TWIG DIAMETER (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14.5 | 0.24 | 0.24 | 0.33 | 0.47 | 0.61 | 0.94 | 0.89 | 0.80 | 0.49 | 0.33 | 0.19 | 0.47 | 0.33 | 0.52 | 0.47 | | | | | | | |
| 20.0 | 0.47 | 1.03 | 1.55 | 0.94 | 0.94 | 0.85 | 1.74 | 0.85 | 0.52 | 0.38 | 0.75 | 0.45 | 0.28 | 0.52 | 0.33 | 0.31 | 0.52 | 0.42 | 0.52 | 0.47 | 0.28 | 0.71 |
| 14.0 | 0.24 | 0.57 | 0.66 | 0.94 | 0.95 | 0.63 | 0.40 | 0.56 | 0.71 | 0.78 | 0.71 | 0.71 | 0.94 | 0.57 | | | | | | | | |
| 10.5 | 0.35 | 0.47 | 0.57 | 0.49 | 0.47 | 0.42 | 0.33 | 0.71 | 0.47 | | | | | | | | | | | | | |
| 32.0 | 0.85 | 0.52 | 0.66 | 0.47 | 0.57 | 0.61 | 0.40 | 0.47 | 0.47 | 0.87 | 1.01 | 0.94 | 1.03 | 0.94 | 0.71 | 0.80 | 0.71 | 0.66 | 0.78 | 0.75 | 0.71 | 0.78 |
| 11.5 | 0.38 | 0.52 | 0.26 | 0.42 | 0.47 | 0.47 | 0.54 | 0.59 | 0.66 | 0.59 | 0.59 | 0.59 | 0.52 | | | | | | | | | |
| 15.0 | 0.57 | 0.54 | 0.52 | 0.52 | 0.45 | 0.24 | 0.24 | 0.33 | 0.40 | 0.45 | 0.52 | 0.40 | 0.33 | 0.47 | 0.52 | 0.33 | 0.33 | 0.38 | | | | |
| 12.5 | 0.33 | 0.47 | 0.38 | 0.45 | 0.49 | 0.38 | 0.61 | 0.49 | 0.47 | 0.61 | 0.61 | 0.85 | 0.66 | | | | | | | | | |
| 14.0 | 0.42 | 0.47 | 0.33 | 0.42 | 0.42 | 0.33 | 0.26 | 0.40 | 0.49 | 0.57 | 0.47 | 0.78 | 0.33 | | | | | | | | | |
| 8.5 | 0.42 | 0.61 | 0.66 | 0.57 | 0.59 | 0.78 | 0.31 | 0.49 | | | | | | | | | | | | | | |

N = 147  $\bar{x}$ = 0.56

= 82.61  SD = 0.24

= 54.39  SE = 0.02

# QUICKCLEUGH

| TWIG DIAMETER (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.0 | 0.38 | 0.38 | 0.33 | 0.28 | 0.71 | 0.89 | 0.52 | 0.56 | 0.47 | | | | | | | | | | |
| 9.0 | 0.38 | 0.33 | 0.33 | 0.56 | 0.82 | 0.28 | 0.52 | 0.50 | | | | | | | | | | | |
| 12.5 | 0.24 | 0.28 | 0.47 | 0.71 | 0.85 | 0.33 | 0.42 | 0.42 | 0.28 | 0.33 | 0.24 | | | | | | | | |
| 8.5 | 0.33 | 0.33 | 0.28 | 0.24 | 0.14 | 0.94 | 0.19 | 0.33 | 0.19 | 0.19 | 0.33 | 0.24 | 0.28 | 0.24 | 0.24 | 0.19 | | | |
| 8.0 | 0.28 | 0.33 | 0.38 | 0.38 | 0.56 | 0.33 | 0.19 | 0.24 | 0.28 | 0.33 | | | | | | | | | |
| 17.0 | 0.56 | 0.28 | 0.47 | 0.56 | 0.33 | 0.42 | 0.33 | 0.56 | 0.47 | 0.61 | 0.24 | 0.38 | 0.38 | 0.47 | 0.33 | 0.19 | 0.33 | | |
| 10.0 | 0.52 | 0.38 | 0.47 | 0.28 | 0.16 | 0.21 | 0.21 | 0.16 | 0.24 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.33 | | | | |
| 11.0 | 0.38 | 0.47 | 0.18 | 0.94 | 0.94 | 0.56 | 0.28 | 0.18 | 0.42 | 0.47 | 0.33 | 0.14 | | | | | | | |
| 9.0 | 0.47 | 0.28 | 0.28 | 0.85 | 0.71 | 0.28 | 0.56 | 0.24 | | | | | | | | | | | |
| 10.0 | 0.56 | 0.56 | 0.85 | 0.56 | 0.66 | 0.66 | 0.52 | 0.24 | | | | | | | | | | | |
| 15.0 | 0.94 | 1.17 | 0.56 | 0.38 | 0.42 | 0.33 | 0.70 | 0.85 | 0.47 | 0.24 | 0.38 | 0.61 | | | | | | | |

N = 160 $\quad$ $\bar{\bar{x}}$ = 0.3356

= 53.7 $\quad$ Variance = 0.0662

= 28.60 $\quad$ Standard Deviation = 0.257

SE = 0.020

## SMIDDY SHAW. LOWER TREE LAYER

| TWIG DIAMETER (mm) | RING WIDTHS (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 12.0 | 0.23 | 0.18 | 0.23 | 0.18 | 0.23 | 0.23 | 0.23 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.94 | | | |
| 11.0 | 0.56 | 0.28 | 0.33 | 0.66 | 0.79 | 0.98 | 0.66 | 1.27 | 0.75 | | | | | | | |
| 14.0 | 0.23 | 0.23 | 0.33 | 0.61 | 0.79 | 0.88 | 0.23 | 0.33 | 0.33 | 0.47 | 0.38 | 0.66 | | | | |
| 17.0 | 0.94 | 0.65 | 0.47 | 0.89 | 0.70 | 1.17 | 1.32 | 2.5 | 1.17 | 0.75 | | | | | | |
| 8.0 | 0.42 | 0.70 | 0.52 | 0.50 | 0.66 | 0.42 | | | | | | | | | | |
| 18.0 | 0.61 | 0.56 | 0.18 | 1.12 | 1.88 | 1.55 | 0.75 | 0.66 | 0.42 | 0.70 | 0.66 | | | | | |
| 10.0 | 0.33 | 0.33 | 0.47 | 0.38 | 0.38 | 0.47 | 0.33 | 0.28 | | | | | | | | |
| 12.0 | 1.22 | 0.79 | 0.56 | 0.66 | 0.38 | 0.38 | 1.74 | 0.66 | | | | | | | | |
| 8.0 | 0.42 | 0.70 | 0.52 | 0.52 | 0.66 | 0.42 | | | | | | | | | | |
| 16.0 | 0.47 | 0.56 | 1.13 | 0.99 | 0.70 | 0.61 | 0.47 | 0.56 | 0.47 | 0.47 | | | | | | |
| 15.0 | 0.56 | 1.47 | 1.83 | 1.64 | 0.61 | 0.52 | 0.47 | 0.56 | 0.47 | 0.38 | | | | | | |

N = 103 $\bar{x}$ = 0.62

= 64.08 SD = 0.413

= 57.34 SE = 0.04

# SMIDDY SHAW UPPER TREE LAYER

| TWIG DIAMETER (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14.0 | 0.66 | 0.63 | 0.77 | 0.82 | 0.26 | 0.21 | 0.33 | 0.38 | 1.8 | 0.16 | 0.24 | | | | | | | | | |
| 9.0 | 0.57 | 0.61 | 0.52 | 0.28 | 0.28 | 0.33 | 0.28 | 0.24 | 0.24 | 0.42 | 0.24 | 0.40 | 0.26 | 0.24 | | | | | | |
| 14.5 | 0.79 | 0.58 | 0.47 | 0.73 | 0.54 | 0.56 | 0.85 | 0.68 | 0.28 | 3.0 | 0.52 | 0.23 | 2.1 | 0.42 | 0.30 | 0.33 | 0.19 | 0.14 | 0.19 | 1.8 |
| 12.5 | 0.79 | 0.47 | 0.45 | 0.77 | 0.66 | 0.19 | 0.19 | 0.56 | 0.66 | 0.33 | 0.30 | 0.28 | 0.42 | 0.28 | 0.35 | | | | | |
| 12.5 | 0.79 | 0.54 | 0.35 | 0.28 | 0.45 | 0.30 | 0.23 | 0.19 | 0.33 | 0.33 | 0.19 | 0.40 | 0.37 | 0.23 | 0.19 | 0.30 | 0.23 | 0.23 | 0.19 | |
| 8.5 | 0.33 | 0.56 | 0.35 | 0.33 | 0.19 | 0.16 | 0.26 | 0.19 | 0.23 | 0.23 | 0.16 | 0.14 | 0.30 | 0.30 | 0.33 | 0.33 | | | | |
| 9.5 | 0.77 | 0.99 | 0.68 | 0.75 | 0.59 | 0.19 | 0.70 | 0.10 | 0.21 | 0.38 | 0.23 | 0.26 | 0.26 | 0.23 | 0.21 | | | | | |
| 17.0 | 0.28 | 0.47 | 0.49 | 0.91 | 0.19 | 0.47 | 0.57 | 0.59 | 0.47 | 0.54 | 0.47 | 0.49 | 0.33 | 0.35 | 0.16 | 0.16 | 0.28 | 0.28 | 0.45 | |
| 15.5 | 0.66 | 0.73 | 0.94 | 0.77 | 0.70 | 0.63 | 0.92 | 0.52 | 0.33 | 0.63 | 0.21 | 0.21 | 0.63 | 0.35 | 0.19 | 0.45 | 0.42 | 0.23 | 0.47 | 0.35 |
| 13.0 | 0.80 | 0.63 | 0.49 | 0.47 | 0.35 | 0.23 | 0.16 | 0.28 | 0.40 | 0.28 | 0.42 | 0.28 | 0.26 | 0.21 | 0.21 | 0.35 | 0.30 | 0.35 | 0.23 | |

N = 173 $\bar{x}$ = 0.391

= 67.57 $\bar{x}^2$ = 0.1526

= 33.159 SD = 0.1977

SE = 0.015

# EMBLETON FEN

| TWIG DIAMETER (mm) | RING WIDTHS (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.0 | 0.45 | 0.56 | 0.35 | 0.23 | 0.47 | 0.68 | 0.47 | | | | | | | | | | |
| 8.5 | 0.37 | 0.28 | 0.49 | 0.18 | 0.18 | 0.30 | 0.23 | 0.33 | 0.28 | | | | | | | | |
| 10.5 | 0.47 | 0.47 | 0.66 | 0.73 | 0.54 | 0.89 | 1.06 | | | | | | | | | | |
| 9.0 | 0.52 | 0.45 | 0.66 | 0.85 | 0.56 | 0.47 | 0.47 | 1.10 | 0.85 | | | | | | | | |
| 8.0 | 1.10 | 0.89 | 1.64 | 2.30 | | | | | | | | | | | | | |

N = 36 $\bar{x}$ = 0.626

= 22.52 Variance = 0.174

= 20.361 SD = 0.417

SE = 0.07