# The elm decline at Pawlaw pike in Weardale county Durham: (a detailed pollen analysis)

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# THE ELM DECLINE AT PAWLAW PIKE IN WEARDALE, COUNTY DURHAM.

(A detailed pollen analysis)

by

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A Thesis submitted for the Degree of Master of Science at the University of Durham.

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# in Weardale, County Durham.

## ABSTRACT.

In a pollen analysis of a peat profile from a bog at Pawlaw Pike, County Durham, a very close sampling technique, by finely sectioning a core, provided evidence of repeated short duration changes in the upland vegetation prior to the reduction of elm in the forest approximately 4,600 years ago. It is suggested that each of these changes correspond to an opening up of the forest which lasted for about 25 years on the average and were possibly due to burning and other pastoral activities of the early herders.

Frequent occurrences of charcoal and an increase in the pollen of grasses, ruderals and other cultural species at the respective strata indicate that the forest was possibly being cleared to provide better grazing for livestock. It is furthermore suggested that the early herders introduced goats and sheep as well as cattle into the area as their domestic animals, and that they were instrumental in drastically reducing the elm trees in the forest, by selectively grazing on their seedlings which apparently are more palatable than those of other tree species of the high forest.

## DECLARATION:

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# CONTENTS:

Page:

# CONTENTS

Page

Chapter 5 (Continued)

CHAPTER 6

## LIST OF FIGURES

## LIST OF PLATES.

PAGE:

PLATE 2.1

PLATE 2.2

PLATE 2.3

PLATE 2.4

PLATE 3.

## APPENDIX.

PAGE:

APPENDIX 1

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# CHAPTER 1.

# INTRODUCTION.

## 1.1. General introduction.

Pollen analysis is a good method of studying vegetational history. By analysing the pollen composition of sediments, it is possible to demonstrate what changes the flora and vegetation have undergone in post glacial times.

From a large number of such analyses it has been found that following the last glaciation and with the retreat of the ice sheets from northern Europe there was a gradual colonization of the ice free areas by vegetation. This ultimately resulted in the development in favourable places of a forest which was dominated by pine (*Pinus*). Later, about 7,500 years ago, the climate had become wetter and possibly also a little warmer and the forests in northern Europe reached a climax or forest maximum (Godwin, 1940) which was characterized by the growth of alder (*Alnus*), oak (*Quercus*), hazel (*Corylus*), birch (*Betula*) and elm (*Ulmus*). At the end of this period approximately 5,000 years ago there appears to have been a marked decline in the occurrence of *Ulmus*. This event seems to have corresponded to the end of the Mesolithic and the development of the Neolithic period in human history in northern Europe (Godwin, 1940), and it has long been considered of great interest.

In order to facilitate the comparison between pollen assemblages from different sites in northern Europe, detailed pollen diagrams have been constructed and zoned according to schemes such as that of Jessen (1935). His zones, I, II, and III represent the late-glacial and zones IV to IX the post-glacial. According to Jessen a characteristic fall in the pollen curve for the mixed oak forest corresponds to the Atlantic/Sub-boreal transition of the Blytt and

Sernander scheme of climatic periods in Scandinavia, which are, in order : Boreal V, VI, Atlantic VII, Sub-boreal VIII and Sub-atlantic IX.

For the late-glacial in Britain, Godwin (1940) assumed that the same zonation would apply, and he began his post-glacial zonation with zone IV which he identified as a pine/birch zone. This was followed by zone V which he called the pine zone, VI the pine/hazel zone, VII the alder/oak/elm/lime zone and VIII the alder/oak/elm/birch zone. These, he concluded, were applicable to England and Wales. According to this series the Atlantic and Sub-boreal were classified by Godwin (1940) as subzones VIIa and VIIb respectively. During the period indicated as subzone VIIa Ulmus pollen values are relatively high and in subzone VIIb they are low, the transition being the "elm decline".

In Britain zone VII as a whole is characterized in contrast to preceding zones by the presence of Alnus as a dominant pollen type (Godwin et al., 1957). The traditional view is that the dominant vegetation was an oak-forest which in places was mixed with lime, elm and birch, although people have always been aware that the composition of this forest may have differed somewhat in the various areas of Britain and also on a local scale. For example Greig (1982) has summarized evidence which shows that lime forests were the dominant vegetation of certain areas of northern Europe, including several parts of southern Britain. Of the Quercus species Q.robur is likely to have been the most dominant in Britain according to Simmons (1964). During the Atlantic forest period of zone VII Alnus was probably growing on damper soils. For example in the Lake District, Alnus was mainly common on upland basin peat, but on dry ground the forest consisted of oak, elm and birch (Pennington, 1964). The low percentage of grass and herbaceous pollen shows that the country was covered by a continuous primeval forest that protected even steep land surfaces from water erosion, so there were no openings other than swamps and moors. In Scotland and England all the available evidence suggests that Ulmus glabra was the native elm. This species demands base-rich mull soils for effective regeneration, Godwin (1956) and Pennington (1965).

In the Atlantic period Ulmus pollen reached 20% of the total tree pollen in England and the elm decline that divides zones VIIa and VIIb is seen as a sudden drop from this figure to between 2% and 4% (Pennington, 1964). At the same time the Pinus pollen curve becomes discontinuous (Godwin, et al., 1957), and in England and Wales the Tilia pollen frequencies fall away even more sharply and the Corylus curve increases, often reaching a generally high level, save in the north (Godwin, 1956). There was a pronounced average increase in the Quercus and Fraxinus pollen frequencies. In England the Ulmus decline appears to have taken place in two steps and after the second decline the Ulmus curve rarely rises again to its former values (Smith, 1961). In most Irish pollen diagrams on the other hand the Ulmus curve regains its former values soon after the first decline.

## 1.2. Theories concerning the elm decline.

The original explanation set forth by Iversen in 1941 and supported by Godwin (1949), was that the Ulmus decline was caused by a change in climate. This interpretation was based on the fact that it appears to have occurred over a large part of north-west Europe synchronously. In support of this Iversen (1941) suggested that in the Atlantic period the most common Ulmus species in Denmark was not U. glabra, but the more warmth-loving U. carpinifolia. A fall in winter temperature could therefore explain the Ulmus decline in Scandinavia. This explanation is, however, open to criticism. Firstly Fraxinus recedes with Ulmus in many Danish diagrams. Since Fraxinus has similar requirements to elm for a moist fertile soil and is a hardier species, it should have benefited from a recession of Ulmus under deteriorating climatic conditions. Secondly, in south-west Norway Faegri (1940) found a similar fall in the Ulmus curve. If the Ulmus decline in both Denmark and Norway had been caused by deterioration of the climate one would not expect it to effect a hardy species such as U.glabra in Norway in the same way as it did U.carpinifolia in Denmark.

According to Godwin (1956) Melville has demonstrated that fruit formation in the British species of Ulmus is very susceptible to late spring frosts once mild weather has caused the flowers to open. This offers another possible mechanism of climatic control. This suggestion was rejected by van Zeist (1959) since Fraxinus shows an expansion in various areas at the Ulmus decline as has been mentioned earlier, although it is similarly very susceptible to late spring frosts. Pennington (1964) did not find support for the climatic theory in her studies from the Lake District. She states that since Ulmus glabra, as opposed to U.carpinifolia, is a much hardier species than Fraxinus it is difficult to postulate a climatic change that would provide an opportunity for Fraxinus to enter the upland woods of England at the same time as Ulmus is receeding. In Ireland as has already been mentioned the Ulmus pollen often rises to its former values after a short lived decline (Smith 1961 and 1965), and this gives few grounds for assuming that maintained climatic deterioration made conditions less favourable for Ulmus, not only in Ireland but throughout north-west Europe, at this time.

If deterioration of climate had been responsible for the Ulmus decline one would have expected Ulmus frequencies to fall first in the northern most parts and high lying areas and gradually spread to the south. No such trend can be observed from radiocarbon dated sites in England. Dates given by Smith and Pilcher (1973) even indicate the reverse trend in Britain. Similarly in Sweden, there is, no gradual trend in dates from north to south according to Nilsson (1964).

When pollen diagrams from most parts of Europe had become available and it was realized that the elm decline had occurred both in areas that were cool and in those that were mild, it became clear that the elm decline could not be explained entirely on the basis of climatic change (Iversen, 1973).

Another possible explanation is that the Ulmus decline was caused by a disease effecting Ulmus species alone. Rackham (1980) states that elm is attacked by more wood-rotting fungi than any other tree, although these do not always destroy the tree. The most serious disease affecting elms today is the so called Dutch Elm Disease, which in recent decades has nearly exterminated the elm in large areas of Europe and North America. It is caused by a ascomycete fungus, Ceratocystis ulmi, which is carried from tree to tree by elm bark beetles, mainly Scolytus scolytus and S.multistriatus. The present epidemic started in the mid 1960's (Gibbs, 1978) and it had killed some 60% of the non-woodland elms over 20 feet high in England and Wales within 13 years (Rackham, 1980).

It is difficult to prove that such a disease ravaged Europe in a similar way 5,000 years ago. Garbett (1981) suggested that such a disease would have left a large number of trees standing dead in the forest. This might have encouraged Hedera to flower more. He tried to link changes in Hedera pollen percentages to the decline of Ulmus, but he found no evidence for an increase in Hedera pollen at the time of the elm decline at the site he studied. No direct evidence for the involvement of disease in the elm decline has yet been found. However, disease affecting elm trees must remain a possible explanation for the decline of Ulmus.

It has been noted by Rackham (1980) that elms are liable to damage by horses and pigs eating the bark, and apart from Dutch Elm

Disease this kind of damage appears to be a major cause of dead elms today. He also suggests that even though disease alone is unlikely to have caused the Ulmus decline, a combination of agriculture and disease would have had much more impact on the elms than either operating by itself. If there had been such an epidemic damaging elms at the end of zone VIIa, its spread could have been helped by the activities of Mesolithic or early Neolithic cultures as they transported wood and wooden artifacts widely and also rendered the elms more liable to disease by pollarding them. It can also be argued that disease would have helped the spread of civilization (a) by opening up the forest so that movements through the country would have become easier and (b) by aiding the clearing of land for grazing and cultivation. The disease theory should, therefore, not be overlooked as a possible or partial explanation for the elm decline, although it is unlikely to have been its sole or main cause.

A third factor that has been much discussed in connection with the elm decline is soil change. Following the last glaciation the developing soils in Britain and much of Northern Europe were rich in minerals. In many areas these were gradually leached. By the end of the Atlantic period this slow deterioration of the soil could, in places, have reached a level where the soil would not support the growth of Ulmus any more. This could be one of the factors that possibly reduced the distribution of Ulmus in the Sub-boreal period. Conway (1954) found that in the Pennines there was often a change near the level of the Ulmus decline, from an amorphous highly humified peat, to a peat rich in Sphagnum leaves, which she took to indicate a change to wetter conditions. Godwin (1956) refers to the fact that the Ulmus demands base-rich mull soils for effective regeneration and increased precipitation might have depressed it by causing soil degeneration. However, this cannot have been the case everywhere since

Fraxinus makes no less demand on soil quality as has already been mentioned. Pennington (1974) is of the opinion that although leaching might have progressively impoverished the soils of the Atlantic forest, the fall in Ulmus pollen is too abrupt to be attributed to soil leaching alone and it must have been caused by a more catastrophic phenomenon. Her observations in the Lake District indicate that the destruction of the primary forest led to rapid oxidation and loss of organic matter from the soil and that the opened up forest could not prevent bodily removal of soils by erosion. In this way severe erosion occurred and the rich natural soil was removed from the hills and deposited in the sediments of the lake basins. This suggests that deterioration of the soil was the result of the Ulmus decline rather than its cause.

A fourth possible explanation of the elm decline in Europe is the suggestion that it is due to the activities of man. The initial evidence indicating this came from Scandinavia. Agriculture is considered to have been introduced into Denmark at the transition between the Atlantic and Sub-boreal periods (Troels-Smith, 1942) and it was suggested by Faegri (1944) that the Ulmus decline was caused by the introduction of agriculture, the so-called anthropogenic factor and in particular by man's use of the leafy branches of Ulmus as fodder for the first domestic animals. The Ulmus decline could also have been the result of various other methods of exploitation of the forest's natural resources, such as creating a shrub and grassland to attract wild game or for grazing domestic livestock or possibly a systematic felling of pure stands of elm to provide good soil for cultivation.

The first pronounced indications of human interference with the forest in Britain, appear at the zone boundary VIIa/VIIb, and it is significant that this is one of the horizons of great change in the chemical curves from all the lakes investigated by Pennington (1964) in the Lake District. She has discovered that the initial disaster to the elm varied in degree with the amount of human pressure exerted locally and the regeneration of the Ulmus depended on the degree to which the base-rich mull soils remained.

Troels-Smith (1954) suggested that if the first Neolithic farmers utilized Ulmus leaves and branches as fodder for domestic animals, this would open up the virgin forest and make it possible for more light-demanding species to gain a foothold. This suggestion was not accepted immediately. In 1956 Godwin did not support this theory because he considered the regression to have occurred too early and too widely for it to have been an effect of Neolithic forest exploitation. He assumed that man played a part no more significant than that of other vertebrates dependent by hunting, fishing and plant collecting upon the productivity of the environment. But in 1961 he noted that the elm decline does correspond in almost all the dated sites to the first unmistakable evidence of agricultural activity and then concluded that an agricultural economy was making itself apparent even before 3000 B.C.

Similarly in Scandinavia, Iversen (1941) did not at first consider the elm decline connected with human interference although by 1960 he quotes after Nordhagen (1954), that Ulmus is the most highly rated "fodder tree", the foliage of which was used from times immemorial to this century for the stall-feeding of cattle.

Although people will adapt their uses of wood to which ever tree species are available in their surroundings and seldom discriminate between species, animals are more selective, especially when grazing on wood-pastures. They prefer Ulmus, Fraxinus, Corylus and Tilia leaves to those of Quercus, Fagus and Carpinus which are often allowed to remain intact when a wood has been grazed. This animal preference may also have affected the choice of leaves gathered by man for fodder. (Troels-Smith, 1960).

The great extent of the Ulmus decline not only in England but throughout north western and central Europe presupposes a population density which exceeds all likely estimates if one imagines that man destroyed the forest only for fuel and construction timber. But if people were also feeding a large number of animals as their major source of protein, on leaf fodder, then a more modest population density could have had the observed effect on the elm pollen. Thus it may be assumed that the number of domestic animals exceeded the number of people, and that animal grazing, as well as their winter feeding could have caused, or at least accelerated the elm decline, especially since Ulmus would have been the most desirable fodder tree.

A new culture based on animal husbandry could have spread quickly and this change of lifestyle from hunting to herding would have been a technological revolution of similar importance to the population as the industrial revolution was in England in the 19th century. It may well have caused a population boom since more people could be provided for, and a stabler food supply could be obtained from each acre of land. Pennington (1974) remarks that this technological revolution establishes man as the potentially dominant factor in the ecosystem.

Since it was first put forward, much material to support the theory that the elm decline was caused by the activities of man has been gathered and published. Quercus is often the tree to benefit first from the recession of Ulmus. Morrison (1959) gives two possible interpretations for this relative behaviour of Ulmus and Quercus. The first suggestion is that the Ulmus and Quercus trees were not randomly intermingled in the former woodland but formed two associations within the deciduous formation. The prehistoric people who settled in these forests learned that the richest soil for their cereal crops occurred where the elm grew and therefore deforested the Ulmus-rich areas. Exploitation of these small cleared areas would have impoverished the soil so that seedlings of Quercus had a greater chance of success than those of Ulmus. The second suggestion is that the woodland was truly mixed but that the herders had some special reason for selectively destroying Ulmus or for conserving the Quercus, a theory of selective felling or selective utilisation. This theory leaves us at least three options as explanations. Firstly Quercus may have been untouched simply because its wood was so much more difficult to cut than that of Ulmus or Tilia. Secondly Quercus may have been spared on account of its masts which are valuable for hog fattening. The third possibility is that Quercus was left untouched because its leaves were less valuable for fodder than those of Ulmus

In a stratigraphical investigation done by Troels-Smith (1954) in Swiss Lake settlements from the Younger Stone Age, he found that the elm decline correlated with the settlement and the archeologists did in fact find collections of leaves from various trees, elm included, on the floors of the houses. Iversen (1960) suggests that the trees were pollarded and their twigs lopped every few years. Such regular pollarding will prevent the Ulmus trees from flowering since the twigs must be seven or eight years old before flowering can occur, and the pollen productivity of the genus would therefore rapidly decline. Pennington (1965) assumes that this would result in the final death of exploited trees, and colonization of their places by more light demanding taxa like Fraxinus and by the expansion of Quercus and Corylus.

Pennington (1974) comes to the conclusion that the first domestic animals were kept stalled or confined to small enclosures and fed with gathered foliage in summer and on leaf litter in winter, because of the virtual absence of grassland at the time, and that hay cutting of meadows is a later and more demanding agricultural practice.

In his studies in Scandinavia, Iversen (1960) found evidence that the leaves of Fraxinus are also valuable fodder, and new Fraxinus shoots flower two or three years after lopping. He points out that today pollarding begins before the trees grow to any considerable height and the same applied no doubt in the stone age. He assumes it would have been an enormous enterprise to lop so many and so tall elms as those of the Atlantic forest. It would have been far easier to kill off the Ulmus and Fraxinus trees by girdling them to create a fodder producing shrub forest. In the present century poor peasants in the Balkan peninsula still used bark-peeling in mountain forests in order to produce undergrowth for cattle to graze on (Heybroek, 1963). Young Fraxinus, in contrast to Ulmus, sprout immediately below the peeled ring. Both lopping and ringbarking methods could therefore explain the fact that the Ulmus curve, in contrast to the Fraxinus curve, does not rise again in the Sub-boreal period. The recession of Fraxinus in some areas is also quite consistent with this theory as well, since the foliage of Fraxinus, like that of Ulmus, is regarded as optimal for fodder and may, therefore, also have been over-exploited in these areas. Iversen (1973) concludes that lopping of Ulmus would result in an increased Quercus pollen production and the production of masts would be increased greatly because the Quercus trees would be standing in better light.

This type of animal husbandry may even be the cause of the decline of ivy in Denmark, as Hedera leaves are used as winter fodder even today, and ring-barking of trees would certainly result in the cutting of Hedera stems growing up along those trees.

Iversen (1960) has shown that the Danish "Ertebølle culture" axes are well suited for bark-peeling and that these stone age people could easily, and in a short time, have converted considerable areas of forest into coppice suited for the picking of foliage. He has also pointed out that the bark of elm is rich in a number of nutrients and is digestible. Ulmus bark has thus been used right up to the present day as a bread-reserve in years of need. Bark could also be used for a number of other things like making bast and as winter fodder for pigs etc. (Iversen, 1973).

The pattern of radiocarbon dates for the early Neolithic period in Britain and Ireland suggests that this new economy spread over the whole region comparatively rapidly (Clark and Godwin, 1962).

Decreases in total tree pollen usually follow shortly after the Ulmus decline although in some areas they occur at the same time. Such decreases have been named the "Landnam" clearances. Iversen (1941) discovered that the elements of the high forest, Quercus, Tilia, Fraxinus and Ulmus, undergo a distinct but temporary decrease just above the Ulmus decline in many Danish pollen diagrams. Radiocarbon dates from south-west Jutland place this phase at 2,500 years B.C. or approximately 500 years after the Ulmus decline. In a few diagrams from Zealand and Scania the Ulmus decline is included in the landnam. Iversen (1941) also pointed out that the "landnam" phase in Ireland is of the same age, and the first Ulmus decline is simply a part of it. He drew evidence from pollen floristic changes and suggested that they express the vegetation developments in a region where land-tilling people have occupied the land and cleared the dense primeval forest with axe and fire. This is supported by the local presence of Neolithic remains and by charcoal layers stratified into deposits, at the same levels as the signs of vegetational disturbance.

The fire-clearance method has formed part of the earliest form of agriculture everywhere in the world. Such a primitive method would be associated with a lack of stability in the settlement. Grain-seeds would be planted in the ash and the same area cropped for a few years and then abandoned when its fertility decreased (Iversen, 1941; Godwin, 1956). The short duration of each settlement is a possible explanation for the surprising rapidity with which the occupation spread over all of northern Europe. The "virgin forest" must have burned much more easily than the forests of today because of the abundance of dead and dry wood. The usual pattern of events drawn from pollen diagrams from Denmark during this period is as follows. In the fire deposits the curves for the pollen of all kinds of trees decrease suddenly compared with the frequencies of the herbaceous plants, bracken and grasses. This is followed by a small short lived maximum of *Salix* and *Populus*. Shortly afterwards the forest regeneration begins with an increase in *Betula* and *Alnus*. The two latter genera have a greater power of dispersal and can grow more quickly in the light than the other forest trees and flower at a younger age, so they have a great advantage in clearings and open areas. *Betula* is the tree requiring the most light and it gets crowded out when the more shade tolerant species begin to spread and grow.

Iversen (1973) states that *Betula* could not have characterized regeneration on common forest mull unless the previous vegetation had been burned. He supports this theory with the fact that birch seeds only germinate when the soil is in a suitable condition; "conditions for its germination are exceptionally favourable in ashy soil" (Iversen, 1949). He verified this by carrying out an experiment where he made a clearance in a forest, using fire to clear one half of the area and chopped down the trees in the other half. In the following years *Betula* sprouted only in the burned area. Today *Betula* is considered to be the pioneer tree following a forest fire.

In England Pennington (1965) in her pollen studies from sites in the Lake District, found evidence that base-rich mull soils must have persisted at low and intermediate altitudes long after the *Ulmus* decline. This she suggests reflects the fact that human pressure was not intense in low lying areas and indicates that the Mesolithic and early Neolithic man occupied the upper valleys and the intermediate heights, which had more open patches in preference to the dense forest of the lowland. This was probably also the case in north-east England since pollen diagrams from Upper Teesdale contain far less tree and more herbaceous pollen than those from more low lying parts of the region (Turner et al., 1973).

Although a lot of evidence has been found which points towards man's involvement in causing the elm decline, the reasons for this selective destruction and the means by which this was done are still far from fully understood and researchers still vary in their opinions.

## 1.3. Aims of study.

Most authorities agree that by using samples of the conventional thickness of 1 cm or more sampled at 2.5 cm or 5 cm intervals large scale clearances, such as "Landnam" clearances can be detected, especially at sites where the peat deposit had accumulated very rapidly, although a temporary flowering or non flowering of a species for 2 to 3 years may be missed. At a site where the rate of peat accumulation was slow, thinner samples taken at smaller intervals are necessary in order to identify changes of short duration.

It is now possible to get much higher resolution on pollen diagrams as for example by the technique used in a recent study by Garbett (1980), who was attempting to detect changes in the pollen frequency of Hedera over periods as short as a couple of years. The method he used enables a peat core to be sectioned so that each sample represents a period of one or two years. His study was performed across the level of the elm decline on a lowland site in the southern part of the Lake District.

It was, therefore, decided to use his method of sectioning to carry out a second very detailed study of the pollen frequency changes associated with the elm decline, but this time at an upland site. Pawlaw Pike, in the northern Pennines, was chosen because it had been noticed by Turner (personal communication) that unusually high amounts of Gramineae pollen were present there before and during the elm decline.

It was hoped that a highly resolved pollen diagram would give an indication of what had caused the elm decline at this particular site, and would contribute to the continuing debate on the different theories that have been put forward in the past to explain it.

# CHAPTER 2.

# THE SITE.

## 2.1. Location and geology.

The study area is a bog at 461 m. It is in the north-eastern part of England (Fig. 2.1), about 1.6 km east of the B6278 road, half-way between Stanhope in Weardale and Eggleston in Teesdale and approximately 2 km north west of Hamsterley Forest (Nat.Grid Ref:NZ.010326). It lies between the hillocks Pawlaw Pike, 488 m, to the south west and Five Pikes, 478.74 m, to the north east. Hawkwood Head is to its west. Drainage streams flow towards the east from the bog and join to form South Grain Beck (Fig.2.2).

The bog has developed over sandstones which lie above the Whitehouse Limestone in the uppermost part of the Namurian ('Millstone Grit Series') which formed during the late Carboniferous period.

Much of the area surrounding the sampling site is covered with peat although the hillocks of Five Pikes and Pawlaw Pike are not (Fig.2.3).

The total depth of the peat in the bog varies from 50 cm at the edge to approximately 5 m in its centre. The eastern part of the bog is dissected by a drainage channel running south east, creating drier conditions there than in the middle and west side of the bog. The size of the bog is approximately 6.5 hectares. Recently, in September 1982, the bog was dissected by a large number of shallow ditches, which are now gradually draining it.

## 2.2. Vegetation.

The dominating vegetation on the low lying areas extending north and east from the bog towards the valley is bracken. The

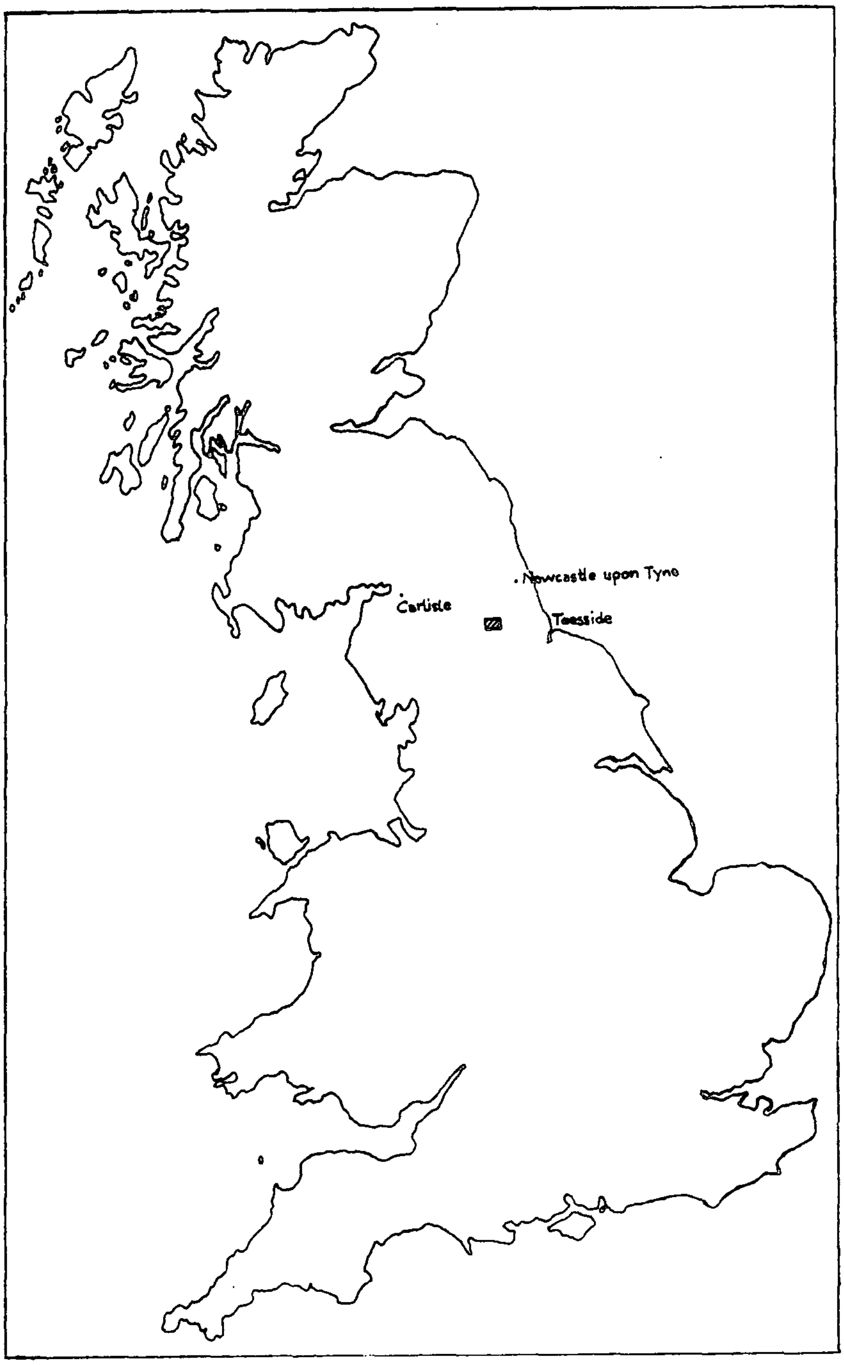


Fig.2.1. General Locational Map.

▨ The Study Area.

Fig.2.2.
Detailed map of study area.

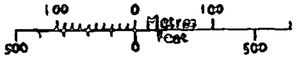
X = Sampling Point

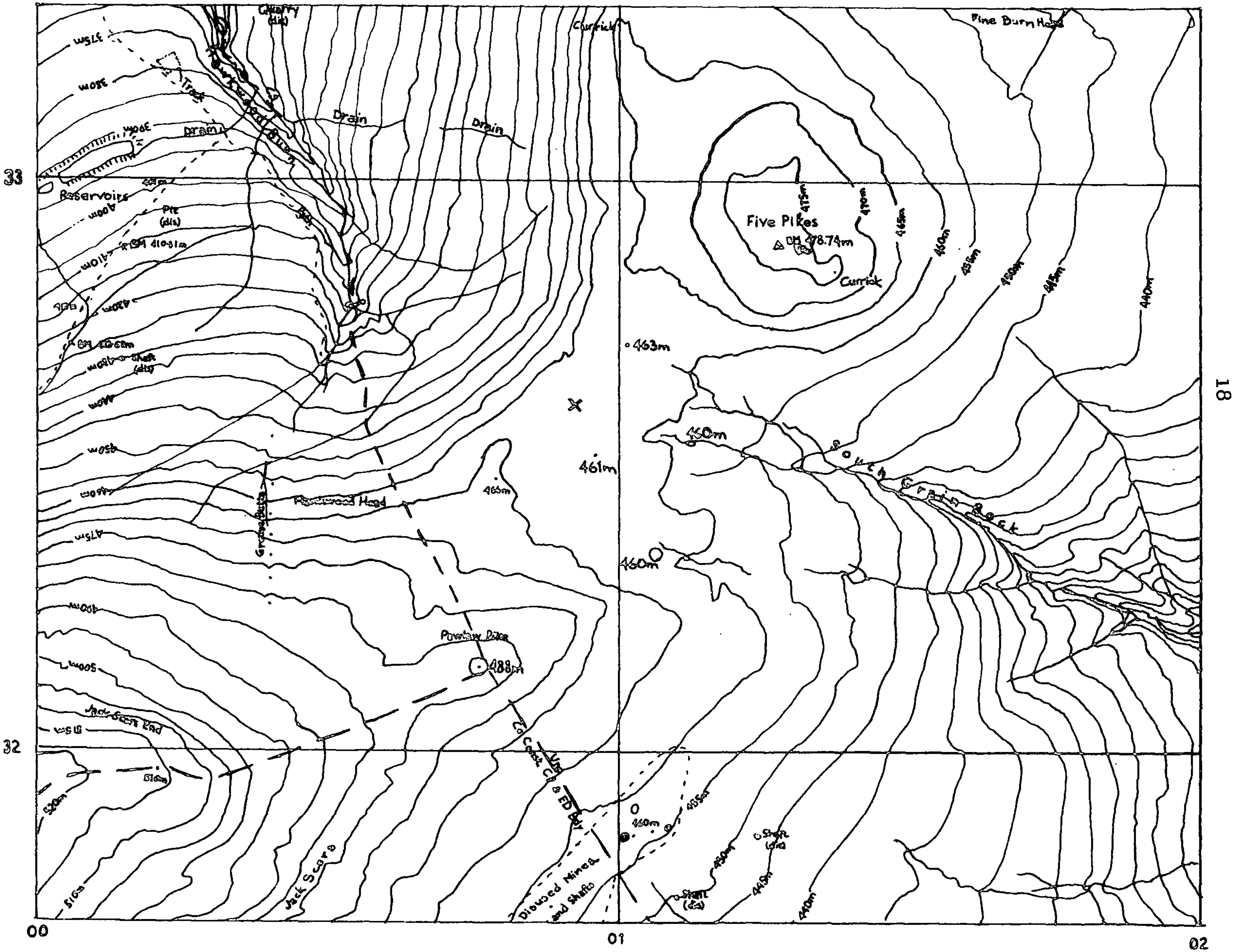
Source : O.S.

Sheet : N.Z.

SCALE 1:10,000

Heights (Metres)
Values are given in metres above mean sea level at Newlyn.





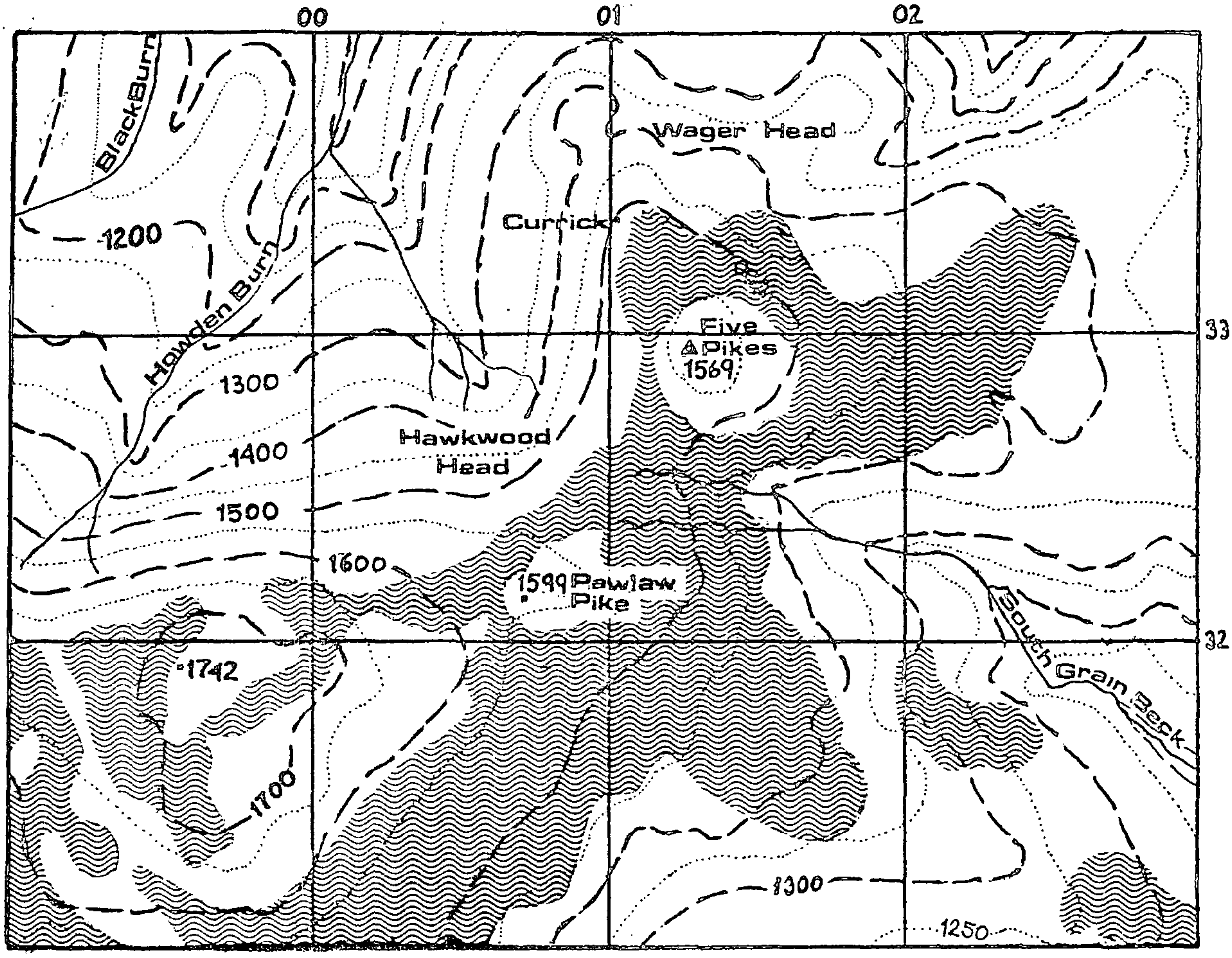


Fig.2.3. Map showing peat distribution in the neighbourhood of Pawlaw Pike bog.

▨ Peat Cover.

PLATE 2.1 The view from Pawlaw Pike looking north east over the bog, the wettest parts of which appear as bright green and yellow patches amongst the darker brownish green vegetation. In the foreground are grasses (Agrostis sp. and Festuca ovina) and burned Calluna vulgaris. Purple flowering heather can be seen on the slopes of Five Pikes beyond the bog.

PLATE 2.2a A view from the centre of the bog towards Pawlaw Pike to the south-west showing the pools surrounded by Sphagnum mosses.

PLATE 2.2b A view looking towards Five Pikes of the drier parts of the bog, with Calluna and Erica tetralix, and dried Sphagnum. A drainage channel crosses the area towards the top right hand side of the picture.

PLATE 2.3a <u>Juncus</u> growing on the hummocks surrounding the wet areas.

PLATE 2.3b <u>Calluna</u> is the dominating species on the drier areas of the bog.

PLATE 2.4a. A view from Pawlaw Pike towards Hamsterley Forest in the S.E. Shows that an extensive forest can grow in the area when protected.

PLATE 2.4b A view towards the east showing the edge of Hamsterley Forest at the far right and Pawlaw Pike at the left. The bog is in the far left of the picture indicating the proximity of the forest.

vegetation on the slopes surrounding the bog is dominated by *Calluna vulgaris*. Among the heather *Rumex acetosella*, *Galium saxatile*, *Festuca ovina* and *Agrostis* species can be found.

The surface of the bog itself is comparatively level and wet with a number of pools and damp hollows at its south west corner. It gradually becomes drier towards the east due to drainage, (Plate 2.1). Vegetation on the bog consists mainly of mosses especially on and surrounding the wet pools and where the water table is near the surface (Plate 2.2a), with plants of Juncaceae and Ericaceae forming tussocks on the margins and on the drier east side (Plate 2.2b).

The most common mosses are *Sphagnum papillosum* and *S. rubellum*, but *Hypnum cupressiforme* var *ericetorum* also occurs. *Polytrichum commune* is also present. *Juncus squarrosus*, *J. effusus* and *Eriophorum angustifolium* are common (Plate 2.3a). On drier areas of the bog, mainly the margins and the eastern part, the vegetation is dominated by a *Calluna vulgaris* sward (Plate 2.3b). Among it *Erica tetralix* is found on hummocks, accompanied by *Drosera rotundifolia*, *Vaccinium oxycoccos* and *Empetrum nigrum*.

The heather is now used for sheep grazing and grouse management and appears to be burned regularly. There is no indication of woodland in the immediate area today, although from Pawlaw Pike one can see the trees of Hamsterley Forest growing at altitudes up to 397 m (Plate 2.4 a and b). It is possible to picture a forest growing here, for the site is placed well below todays treeline in Weardale. Constant grazing and regular burning are undoubtedly preventing trees at present from colonizing the area, which has become a *Calluna* monoculture due to the way it is being managed.

# CHAPTER 3.

## METHODS.

### 3.1. Collection of cores.

Cores for pollen analysis were collected by using a Russian borer, of the type described by Jowsey (1966), that samples a semi-cylindrical core of sediment. The sampling chamber of the borer and its anchor were wiped clean when each 50 cm length of core had been sampled. The borer does not disturb the deposit which is to be sampled, but its head does disturb material below the zone of sampling. To avoid contamination because of such disturbance, two adjacent holes were used for the recovery of alternate half-metre cores.

The whole cores were slid into halved plastic liners that were labelled with a number, the site name, date, and the depth in cm. of the upper and lower end of each core. These were then placed in polythene bags. This meant that they could be taken back to the laboratory intact, where they could be sampled accurately. They were stored in a cold-room.

Since the main objective of this investigation was a detailed study of the elm decline, it was important to be able to recover it in the centre of a 50 cm core and to have one core on which to locate it and another parallel core from which to take the very fine slices. In a previously mentioned study done by Turner, - (personal communication) at Pawlaw Pike, the elm decline had been found to be between 305 and 310 cm from the surface of the bog.

In order to retrieve a complete section of the bog, a set of eight cores, each 50 cm long were collected, set a in Fig. 3. They covered the full depth of the peat from the surface down to 400 cm. To ensure that a parallel core would be available for sectioning in the laboratory if the elm decline were located in the centre of one of the set 3.a

## FIGURE 3.

The fifteen cores taken with the Russian borer, each 50 cm long, are represented and the samples taken from each core are shown.

a) A series of eight cores, from 0 to 400 cm. Twelve 1 cm samples were taken from this series at 32 cm intervals, (i.e. 32 cm, 64 cm, 96 cm a.s.o), except for the three bottom-most samples which were taken at different intervals. The analyses of these samples are shown in Fig. 4.1.

b) A duplicate of the bottom three cores from 250 to 400 cm to include the elm decline in a spare set of cores.

c) A set of cores containing the elm decline displaced by 25 cm from its position in the series a and b. Four samples were taken from this set to determine the approximate position of the elm decline.

d. A duplicate set of two cores for set c which was used for detailed sectioning of the peat surrounding the elm decline.

e) Actual length of the piece of core between 298.5 and 323.9 cm taken from set d. and sectioned finely. Samples used for pollen extraction are also shown to scale. The results from these samples are shown in Fig.4.2.

All depths are given in cm below the surface of the bog.

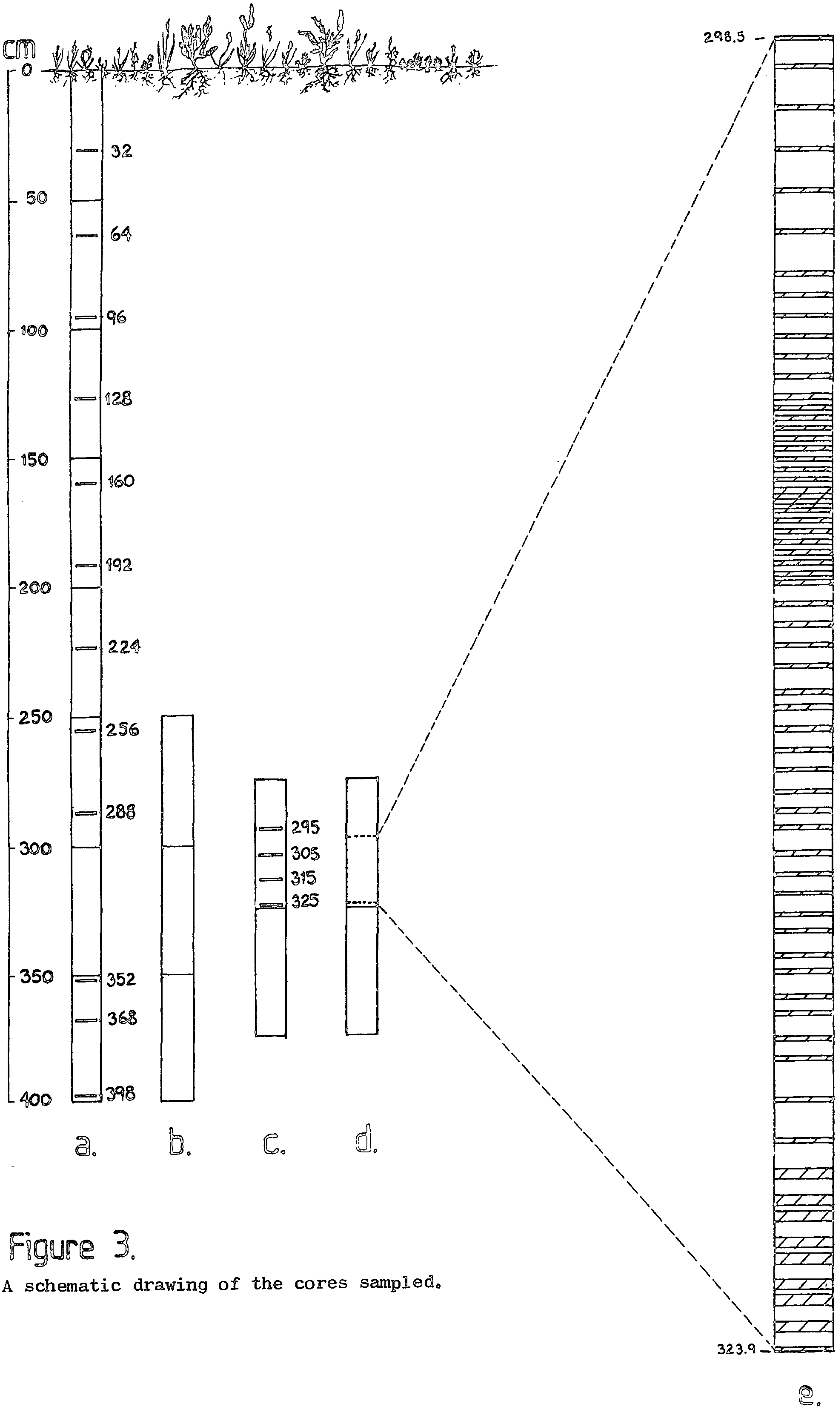


Figure 3.

A schematic drawing of the cores sampled.

PLATE 3.1 Collecting the cores.

The fifteen cores of peat used in this study were collected from the Pawlaw Pike bog on November 21st 1980, with the kind help of Dr. Judith Turner and Dr. Alan Pearson.

cores, a duplicate set of the three cores of peat from between 250 and 400 cm was collected, set b. in Fig. 3.

Since the expected level of the elm decline at this site was near 300 cm there was danger of the horizon falling near a junction in the set a and b cores already sampled. To make sure the horizon would be recovered in the centre of a core, a further two sets of cores displaced by 25 cm from the first two sets were collected from the peat between 275 and 375 cm, sets c and d in Fig. 3. Thus a total number of 15 cores were collected.

## 3.2. Sampling in the laboratory.

In the expectation that the elm decline would be in the middle of one of the set c or d cores, pollen samples to locate its precise position were first taken from between 275 and 325 cm of set c. This was done by cutting four samples approximately 1 cm thick at 10 cm intervals, i.e. at 295, 305, 315 and 325 cm, as is shown in Fig. 3.c. The samples were prepared and counted in the manner described in section 3.3. The elm decline was found to be between 305 and 315 cm below the peat surface.

In order to get a broad outline of the vegetational changes which had taken place during the deposition of the full depth of peat and to place the finely sectioned core surrounding the elm decline into context both in time and scale, twelve approximately 1 cm thick samples were taken from the eight cores of set a which ranged from the surface to 400 cm. These samples were taken at 32 cm intervals. The two bottom-most samples were found to contain too much silt to be examined for pollen, so two new samples were taken 16 cm and 46 cm below the last good sample and treated with HF before acetolysis (See p.31 section 3.3).

Detailed sampling was carried out on the set d core from 275 to

325 cm (shown in Fig. 3.d and e) as follows. The peat was placed in a deep freezer at -20°C for at least 72 hours. Then the frozen core was sectioned in a cold-room at 1°C. A hand-microtome was used for the sectioning of the core. The sample chamber of the microtome is 2.5 cm deep. Thus 2.5 cm sections were marked on the core with chalk and each length given a letter of the alphabet from A to K, starting at 325 cm and finishing at 297.5cm. The 2.5 cm long sections were cut out of the core with a sharp blade, one at a time, starting at the core's lower end. The remaining part of the core was replaced in the freezer. The 2.5 cm lengths of core were trimmed by vertical cuts with a clean sharp blade to minimize any possible disturbance caused by the borer when it slid past the material being sampled. Then the small length of core was rounded off to fit the sample chamber of the hand microtome. A rotary microtome knife was used to section the core, because thinner blades bent when applied to the frozen core. The knife was sharpened after sectioning each 2.5 cm length of core. Throughout the period of cutting and trimming, chalk marks were used to label the orientation of the small lengths of core.

An adhesive tape printed with a scale showing 1 mm intervals was placed on the racked mechanism of the microtome so that after levelling the surface of the peat sample with the top of the microtome, 0.1 cm of peat could be pushed up above the surface by screwing the piston up through one interval. Each 0.1 cm length of peat was cut off with the microtome knife resting firmly on the surface of the microtome and the sample was placed in a numbered bottle. Care was taken that the knife and the microtome surface were wiped free of peat when each sample had been cut.

The last 0.5 cm of each 2.5 cm section of core had to be sliced after inserting two five pence pieces and a one pence piece underneath it, since the microtome piston did not extend over these last few millimetres.

A total number of 254 samples were taken in this manner so that the entire core between 298.5 cm and 323.9 cm had been sectioned into approximately 1 mm thick samples. The samples were then stored in a cold-room until required for pollen analysis. The samples eventually used for pollen analysis are shown in figure 3.e.

This method of sectioning was first used by Garbett in 1980 and is described in detail in his M.Sc. thesis.

## 3.3 Pollen extraction, preparation and counting.

The peat samples were treated in the laboratory by sodium hydroxide (NaOH) digestion to break down humic compounds, and sieving to remove large plant fragments. Then cellulose was removed by acetolysis, see Moore and Webb (1978, p.23-24), using a mixture of ten parts acetic anhydride $(CH_3CO)_2O$ and one part conc. sulphuric acid $(H_2SO_4)$, see Gray (1965, P.571). Acetic acid $(CH_3COOH)$ was used to keep the cellulose ester in solution (Faegri and Iversen, 1950, p.63). Compaction of pollen grains was achieved by centrifugation (Gray, 1965, p.571). The samples were mounted in glycerin jelly, stained with safranin (Faegri and Iversen, 1950, p.109) and placed on microscope slides under a thin cover slip. Two samples, mentioned on page 29 in section 3.2, had to be heated in hydrofluoric acid (HF) to remove fine-grained mineral compounds before acetolysis could be applied.

Pollen counting was carried out using a Reichert binocular light-microscope. A magnification of x 100 was used for scanning and x 400 for identification. Anisole was used instead of immersion oil for x 1000 magnification when critical grains were examined.

A representative sample consisting of a total of at least 150 arboreal (tree) pollen grains, excluding Corylus grains, was counted on each slide as this sum has become a standard (Moore and Webb,1978).

Booberg (1930, p.226, cited in "Faegri and Iversen, 1950, p.99") states that experience has shown that if this number of arboreal grains is counted in each spectrum, the main arboreal diagram curves should be comparatively safe. This is also in accordance with Faegri and Iversen's statement that in order to define short-term vegetational fluctuations, only a decrease of distance between samples can give more details, not an increase in the total number of grains counted for each sample.

In some cases the practice of counting every individual grain was stopped where there was a predominance of a certain taxon. This applies to Calluna, Sphagnum and Cyperaceae in samples containing well over a hundred grains of the taxon. In such cases individual grains were counted until a total of 50 or 100 arboreal grains had been reached, thereafter the proportional representation was calculated for the taxon concerned. On the whole the tree pollen sum, excluding Corylus, lay between 148 and 185 grains. This method gave a total pollen sum of between 318 and 1179 grains.

Of the 254 samples sectioned from the core between 298.5 and 323.9 cm only 66 samples were prepared and counted (Fig.3.e.). Every other sample was counted between 305.4 and 307.1 cm and between 307.8 and 309.1 cm., giving a sample interval of approximately 0.1 cm. Between 307.2 and 307.7 cm every sample was counted. From 303.0 to 305.4 cm and from 309.1 to 318.3 cm every fourth sample was counted, giving a sample interval of approximately 0.3 cm. Between the level of 320.3 and 323.5 cm the concentration of pollen grains in each sample was so low that a total count of 150 arboreal grains could not be reached even though every grain on each slide was counted. Therefore, when preparing samples from this part of the core, two adjacent samples were pooled, so that the combined sample represented an average thickness of 0.2 cm instead of the usual 0.1 cm.

All the samples from this finely sectioned part of the core, are drawn to scale in Fig.3.e.

## 3.4. Method of estimating the amount of charcoal.

Among the particles found in the peat samples were fragments of charcoal of various sizes and abundance. Whenever these occurred they were recorded and their amount estimated and rated into four categories.

The scale used to plot the amount of charcoal was derived as follows. Using x 100 times magnification, 5 widely spaced traverses were made over each slide. If charcoal occurred in all five traverses it was said to be present and given the rate of one unit. If charcoal occurred in every field of five traverses it was rated as two units. If charcoal was more common than pollen in every field of five traverses and gave a sample a greyish colour it was represented by three units. And if charcoal covered a large part of every field of five traverses and was the main constituent of the sample it was rated as four units.

## 3.5. Method of reconstructing forest composition.

Pollen percentages only give a relative picture of changes occurring in the vegetation and not the absolute composition of the community, because different plant species produce varying amounts of pollen.

In order to transform percentage pollen diagrams into diagrams showing the vegetational composition Andersen (1967) collected pollen from surface moss polsters and compared the tree pollen percentages to the trunk areas of trees growing within 30 m from the sampling points, and in a later study he chose to compare the surface pollen percentages with tree crown areas (Andersen, 1970). This he did by dividing the pollen deposition at the sample point by the area occupied by the species within the same plot. Thus he found correction factors which could be applied to the pollen percentages of the most abundant tree species growing in Danish forests. These correction factors have subsequently been applied to tree pollen percentages from most north European forests.

The pollen counts from Pawlaw Pike have been re-calculated using the correction factors suggested by Andersen (1970). To do this *Pinus*, *Betula*, *Quercus* and *Alnus* pollen counts have been divided by four, *Ulmus* pollen counts by two, and *Tilia* and *Fraxinus* pollen counts multiplied by two, before the tree percentages were calculated. *Corylus avellana* pollen has been found to present special problems because when it is shaded its areal coverages correspond well to its pollen percentages, but when it forms part of the high canopy its pollen production is considerably larger (Andersen, 1973). In this study *Corylus* pollen has been included in the total tree pollen sum and has been presumed to be over-represented, so that its values have been divided by four as was suggested by Iversen (1947, cited in Andersen, 1970)

The results from these calculations are given in the Appendix.

# CHAPTER 4.

## RESULTS.

(See diagrams 4.1 and 4.2 in a folder at the back).

### 4.1. Stratigraphy.

The detailed stratigraphy of the core from Pawlaw Pike is as follows:-

| Depth in cm: | |
|---|---|
| 0 - 16 | Well preserved *Sphagnum* peat with remains of *Eriophorum* between 10 and 14 cm. |
| 16 - 25 | Moderately humified peat. |
| 25 - 128 | Weakly humified peat containing *Eriophorum* at five levels, between 30 and 36 cm., 45 and 50 cm 72 and 80 cm, 93 and 100 cm, and 118 and 122 cm. Two small pieces of wood were encountered at 82 cm and a root at 120 to 135 cm. |
| 128 - 224 | Moderately humified peat gradually becoming more humified, with a small shoot of *Calluna* at 170 cm and small pieces of wood at 180 and 184 cm. |
| 224 - 300 | The degree of humification increases and continues to do so until the peat becomes highly humified. A large piece of *Betula* wood was found at 297 to 299 cm. |
| 300 - 310 | Moderately humified peat with a small piece of *Betula* at 310 cm. |
| 310 - 368 | Highly humified peat. |
| 368 - 389 | Mud of light brown colour containing silt, with no visible plant remains. |
| 389 - 400 | Darker coloured mud containing some plant remains as well as silt. |

The stratigraphic profile of the bog at the sampling site is shown in the first column of figure 4.1 using sediment symbols based on those given by West (1968).

The symbols used for the different sediments are:

▦ Mud, Light brown.

▩ Mud, Dark Brown.

≋ Peat. The closer the lines are together the higher the degree of humification indicated.

ɩ *Eriophorum*, macro remains.

v *Betula*, macro remains.

## 4.2. Diagrams

The diagrams shown in figures 4.1 and 4.2 represent the proportions of the various pollen taxa as a percentage of arboreal pollen (A.P.), *Betula*, *Pinus*, *Ulmus*, *Quercus*, *Tilia*, *Alnus*, *Carpinus*, *Fraxinus*, *Acer* and *Corylus*. These make up the total tree pollen sum on which all the calculations are based. They are shown at the left hand side of the diagram.

Since no macro remains of *Myrica* were found, nor any pollen grains definitely attributable to that species, all the Coryloid pollen is attributed to *Corylus avellana* and referred to as such. The assumption that *Corylus* was not a constituent of the high canopy of the Atlantic forest (Mitchell, 1965) led to the convention of not including its pollen in the total tree pollen sum. The abundance of *Corylus* pollen in the samples from this site implies that the tree was not shaded, since *Corylus* flowers sparsely under a heavy tree canopy, but is considered a great pollen producer when growing in open areas. Thus there may even have been pure *Corylus* stands in parts of the forest. For this reason it was decided in this study to include *Corylus* in the total tree pollen sum.

*Salix* was excluded from the tree pollen sum because at the beginning of the project it was thought that *Salix* was more likely to have been present at the edge of the bog than to have been growing in the surrounding forest.

The diagrams are arranged in the conventional way, with arboreal taxa first, folled by Salix and Hedera, and then by herb pollen taxa and finally the spore taxa.

Gramineae, Cyperaceae and Calluna are the main contributors to the herb pollen and so have been placed first. The remaining herbs have been arranged so that those indicating possible pastoral activity come before those indicating arable land. Finally are the herbs that do not fall within either of the two categories. These classifications are based on information gathered from Iversen (1941 and 1949), van Zeist (1959), Turner(1964 a), Pennington (1964), Simmons (1969) and Vuorela (1977).

In the diagrams the horizontal axis represents the proportional abundance of the pollen types and the vertical axis the depth in cm. The pollen frequenceis are shown by a black bar. Single pollen grains are shown as a cross.

Figure 4.1 shows the pollen percentages from the whole profile of the bog from 0 to 400 cm and also the stratigraphy of the bog.

Figure 4.2 shows the pollen percentages from the peat surrounding the elm decline which has been studied at 0.1 or 0.3 cm intervals. Included in this figure is a tree/shrub/herb diagram and at the far right the estimated amount of charcoal in the samples is shown.

Figure 4.1.

The stratigraphy of the bog is shown at the far left of the diagram. See section 4.1 for description and symbols.

The pollen diagram shows twelve 1 cm samples taken at 32 cm intervals from the cores between 32 cm and 398 cm. The sample intervals at the bottom of the diagram vary because the two bottom-most samples originally taken contained too much silt to be examined for pollen, so a second set of the samples had to be prepared (see 3.2). The diagram also includes the 66 samples taken between 298.5 cm and 323.9 cm, which are shown in detail in figure 4.2.

The four major tree pollen taxa are Corylus, Quercus, Betula and Alnus.

On climatic grounds there seems no reason why the whole area surrounding the site should not have been forested during the "forest maximum" since it lies well below todays treeline in Weardale. Throughout the profile of the bog a fair amount of NAP, mostly Gramineae, Cyperaceae and Calluna is incorporated into the deposit.

In the bottom-most sample Betula and Pinus percentages are higher and Alnus percentages lower than in the following samples. There are appreciable amounts of Ulmus and Quercus pollen already present but these show an increase in the second sample. This indicates that the first sample in figure 4.1., at 398 cm, probably belongs to the end of the Boreal period of the Blytt and Sernander climatic scheme or zone VI of the Godwin system and that the Boreal/Atlantic transition lies between 368 cm and 398 cm.

The following samples at 368 and 352 cm belong to zone VIIa of the Godwin scheme (the Atlantic period). It is characterized by the replacement of Betula by Alnus as the dominant pollen type. The Pinus curve falls at the beginning of the zone. The Quercus curve rises gradually and the Corylus curve rises more abruptly. Gramineae and Calluna pollen frequencies increase towards the end of the zone.

The end of zone VIIa is marked by the Ulmus decline at 307 cm. It is accompanied by a sudden increase in Betula and Salix pollen as well as in the pollen of Gramineae and other herbs. It is followed by a further decrease in the Pinus curve. This can be identified as the transition between the Atlantic and Sub-Boreal period or between zone VIIa and VIIb. This part of the diagram is shown in detail in figure 4.2 and is discussed in a later section.

It is difficult to place an upper boundary to the Sub-boreal period. The most prominent changes taking place after the *Ulmus* decline occur at the levels of 160 cm and 192 cm, with an increase in Gramineae, Ericales, *Plantago lanceolata*, *Rumex* and *Urtica* pollen and *Pteridium* spores. A high peak in *Sphagnum* spores occurs at the same time. These changes represent a large scale clearance of the forest.

A major feature of the diagram is the steady increase in *Calluna* pollen from the beginning of the Atlantic period onwards. It reaches its maximum at 128 cm and decreases only slightly after that.

## Figure 4.2.

The pollen diagram from between 298.5 cm and 323.9 cm, covering only 25.4 cm of the whole core, is shown in detail. A total of 66 samples were counted. The relative thickness of each sample and the intervals between samples are drawn to scale. The samples taken were 1 mm thick, as has been mentioned earlier, but at the lower end of the core two adjoining samples had to be combined because of the low pollen content of each sample. This is indicated in the diagram by the use of broader lines.

Gramineae, Cyperaceae and *Calluna* percentages are drawn to half scale.

To the right of the main diagram is the tree/shrub/herb ratio. The tree curve is composed of *Betula*, *Pinus*, *Ulmus*, *Quercus*, *Tilia*, *Alnus*, *Carpinus*, *Fraxinus* and *Corylus*. The shrub curve consists of *Salix* and *Hedera*, and the herb curve of all the herbs encountered except *Myriophyllum* and *Sparganium*. Within the tree percentage curve lies a line indicating the pollen percentages of trees requiring a dry soil. These are *Ulmus*, *Quercus*, *Tilia*, *Carpinus*, *Fraxinus* and

Acer. Another line lies within the herb pollen curve. It separates Calluna and Cyperaceae which were probably growing locally on the bog from the remainder of the herb taxa such as grasses and ruderals (including open-ground herbaceous plants).

At the far right of the diagrams the amount of charcoal is shown. This is featured in section 4.3.

## Zonation.

The detailed diagram has been divided into five zones or episodes based upon their own characteristic features, mainly changes in the Ulmus pollen frequencies. This has been done to facilitate the description and interpretation of the changes in the pollen stratigraphy. The episodes have been labelled A to E, starting from the base of the diagram.

### Episode A. 323.9 - 320.4 cm.

During this episode Ulmus values decrease steadily from about 10% at 323.4 cm to about 4% at 320.5 cm. Betula and Pinus percentages vary greatly, rising and falling together. Quercus values are relatively high but decrease throughout the episode. Tilia does not form a continuous curve, but one or two grains do occur in some of the samples. Fraxinus values are low at an average of 1%. The main feature of the episode is the great drop in the Cyperaceae and Sphagnum curves about half way through it, complemented by an increase in Calluna which reaches its highest values only one level above the boundary between episodes A and B. A sharp rise in Gramineae percentages follows the initial drop of the Sphagnum curve. It is complemented by a drop in total tree pollen mainly due to a fall in "dry tree" pollen. The Gramineae pollen frequency then decreases gradually as the tree pollen curve recovers partially. A second smaller rise in Gramineae occurs before the end of the episode at the same time as the "dry tree" curve falls for the second time and it does not recover fully after that.

Episode B. 319.9 - 314.7 cm.

This episode is characterized by marked fluctuations in the Ulmus percentage which averages 6.8%. Betula pollen increases at the beginning of the episode at which point the Quercus curve is at its lowest. As the Betula curve falls the Quercus curve rises and continues to do so although it shows great fluctuations.

The other tree pollen curves remain fairly steady except for irregularities in the ratio of total "dry tree" pollen to all other taxa between 317.9 cm and 316.2 cm, while the Gramineae and herbal (mainly Melampyrum and Potentilla) pollen curve is rising. The Gramineae percentage increases gradually from 25% to 43%. When it reaches its peak there is a complementary fall in the total tree pollen percentages. The Gramineae and herbal curve decreases abruptly at the close of the episode.

Episode C. 314.3 - 309.4 cm.

The Ulmus percentages fluctuate slightly at the beginning of this episode and thereafter they remain fairly steady at the lower average of 4.85%. The most significant characteristic of this episode is the initial drop in the total tree pollen curve followed by an abrupt increase, from the centre of the episode it starts to fall again showing marked short term fluctuations at the same time. Tilia pollen occurs more frequently than in episodes A and B. The Fraxinus curve has relatively high values at the beginning and end of the episode but has low ones in the middle. By contrast the Betula pollen has a distinct maximum in the centre of the episode. At the beginning of the episode the *Potentilla* curve increases abruptly to 31.2% at 313.8 cm and then it begins to drop gradually. The Gramineae curve reaches a short lived maximum of 58.2% shortly after the *Potentilla* maximum. This is followed by a sudden drop to 21.7% only two samples higher. It then begins a slow increase which is continued throughout the remainder of the episode. Gramineae and *Potentilla* are the main components of the "Gramineae and dry herbs curve" which has its highest values at 313.7 cm. Two samples later it falls and remains low for the rest of the episode. *Melampyrum* values on the other hand remain very low throughout. The *Calluna* curve reaches a prominent peak at the beginning of the episode from which it falls as rapidly as it rose and then it recovers partially. Ericales pollen is first encountered at 313.7 cm where the *Calluna* curve has dropped, the Gramineae curve is at its highest and *Betula* is increasing. Odd Ericales grains are found in most of the following samples.

### *Episode D.* 309.3 - 303.6 cm.

The most important feature of this episode is the drop in *Ulmus* pollen frequencies. In the first half of the episode the decrease is associated with short term fluctuations. The *Quercus* curve drops at the beginning but recovers quickly. Also of interest is the fact that the *Fraxinus* curve fluctuates around a lower average than in previous episodes, rising and falling in every other or every third sample. The *Tilia* curve increases gradually up to its highest value of 3.5% at 308.3 cm, thereafter it remains steady at a slightly lower mean value until it drops sharply at 305.4 cm and remains low up to the D/E episodes boundary. Other tree pollen curves remain fairly steady throughout the episode, but the ratio of total tree pollen to herb pollen decreases from the beginning of the episode. Above 307.6 cm this fall is more gradual but with large short term fluctuations.

Before the end of the episode the tree pollen ratio recovers partially.

The second most important feature of episode D is the increase in herb pollen frequencies. The most prominent change is the continuous gradual increase in the Gramineae pollen values culminating in a peak in the second half of the episode, followed by a slight decrease. At 306.8 cm two monoporate grains which were larger than average Gramineae grains and with an annulus larger than 9μ were found but they could not be positively identified as Cerealia pollen. There is an increase in the *Potentilla* curve which corresponds with the increase in the Gramineae curve. Even the minor fluctuations appear to coincide with those of the Gramineae curve except that the *Potentilla* curve does not begin to fall before the close of the episode. There is also a gradual increase in *Salix* pollen throughout the episode coinciding with the decline in *Ulmus*. This is also reflected in a higher ratio of shrub to tree and herb pollen in the upper part of the episode. The Ericales curve remains fairly steady at a notably higher average than before. *Melampyrum* pollen begins to make more regular appearances at the beginning of the episode with frequencies gradually increasing from then on to form a slightly rising curve. The *Rumex acetosella* type curve which was rather fragmentary at pre-elm decline levels becomes continuous with the highest values in the middle of the episode. *Urtica* pollen makes its first appearance here and *Plantago lanceolata* occurs in many of the samples in the upper half of the episode. *Filipendula* and *Ranunculus* pollen becomes more common. Single grains of a large number of different herbs seem to cluster around the centre of this episode. These include *Artemisia*, Rosaceae, *Cirsium*, *Caltha*, Rubiaceae and *Scabiosa*. The pollen of most of these herbs disappears as the Gramineae curve begins to fall.

Episode E. 303.6 - 298.5 cm.

The single most important feature of this episode is the sudden increase in Betula pollen. It rises until it has more than doubled its values from previous episodes, from an average of 17% up to a maximum of 58.2% at 299.8 cm. Salix is the only other pollen which does not show a drop in its frequencies. The Salix curve continues to rise gradually to a peak of 21.8% at 303.0 cm, after which it decreases only slightly. A corresponding decrease occurs in the pollen frequencies of all trees and most other taxa as well. Pinus values fall in the upper half of the episode. The Ulmus curve remains very low and so do the Tilia and Fraxinus frequencies. The pollen of these taxa disappears almost completely in the latter half of the episode. The Quercus and Alnus curves drop steadily. Many of the tree taxa however begin to recover in the last samples, for example, Pinus, Alnus and Quercus. Tilia and Fraxinus grains also reappear. The Corylus curve decreases throughout the episode. The Gramineae curve continues to drop sharply through the first part of the episode, thereafter it remains fairly steady. There is a small recovery at 299.8 cm, after which it continues to fall. Potentilla frequencies decrease gradually throughout the episode. The Melampyrum pollen curve continues to rise to reach a maximum of 9.3% at the centre of the episode. The Cyperaceae and Calluna frequencies drop, followed by a complementary increase in the Sphagnum percentages to a peak of 19.2% before it also decreases. Filicales spores have increased in the last three samples for the first time after the initial fall in the first samples of episode A.

In order to minimize the effect of Betula possibly being over represented in the last samples the results from the eight samples of episode E and the topmost samples from episode D, were re-calculated excluding Betula from the A.P. sum. These showed that there was no apparent change in the overall composition of the tree pollen percentages apart from the increase in Betula. There also appears to have been a slight increase in Corylus and Gramineae, and a much greater increase in Salix pollen and Filicales spores. This indicates that local over representation of Betula caused the apparent drop in the other pollen curves and that no appreciable change in the forest composition took place except for this increase in Betula.

## 4.3. Occurrence of charcoal.

All the slides between 298.5 and 323.9 cm were examined for charcoal.

No charcoal was present on the two bottom slides. On all the remaining slides charcoal was found in varying amounts.

The diagram at the far right of figure 4.2. shows that charcoal is less common at the bottom and top ends of the piece of core than at its centre, and that the highest concentrations are between 316.6 and 312.6 cm and between 308.9 and 304.6 cm, with peaks between 316.6 and 316.2 cm, 314.3 and 312.6 cm, 308.9 and 307.3 cm and between 305.9 and 304.6 cm.

When the occurrence of charcoal is compared with the pollen frequency changes in the tree/shrub/herb ratio, it is apparent that the high levels of charcoal coincide with high ratios of herbs to trees.

## 4.4. Dating of the diagrams.

### Rate of peat formation.

No radiocarbon dates are available from Pawlaw Pike, so correlations have been made using diagrams from nearby sites which have been dated, and these dates used to estimate an approximate rate of peat development. It was decided to use datings from three sites in Teesdale as the basis for these calculations. These are Dufton Moss, Fox Earth Gill (Squires, 1970 and Harkness, 1981) and Valley Bog (Chambers, 1978).

I have used two marked changes in the diagram as the basis for the estimations of rate of peat growth. One is the Ulmus decline and the other the boundary between zones VI and VIIa, where Pinus and Betula pollen decreases and Alnus and Quercus pollen increases.

Using the radiocarbon dates given for the end of the elm decline at Dufton Moss of 4560±60 years, at Fox Earth Gill of 4780±50 years and at Valley Bog of 4596±60 years it may be expected that the elm decline at Pawlaw Pike occurred at approximately 4645±60 years B.P., which is the average of the three radiocarbon datings. This has been divided by the level of the end of the elm decline at Pawlaw Pike, which is 303.7 cm, giving a mean of 15.29 years for each cm of peat to be formed between 4600 years ago and the present.

Using the dates for the transition between zones VI and VIIa from Dufton Moss of 5700±50 years and Fox Earth Gill of 5400±50 years it may be expected that this transition occurred at approximately 5550±50 B.P. at Pawlaw Pike, which is the mean age of this boundary at the two sites. Dividing this by 368 cm, which is the level of the VI/VIIa transition at Pawlaw Pike, gives the mean deposition rate of peat at Pawlaw Pike as 15.1 years/cm. The fact that both methods of calculation give similar results, i.e. 15.29 y/cm and 15.1 y/cm, adds strength to the assumption that the rate of peat growth at the site was relatively uniform throughout.

Length of the elm decline.

These radiocarbon dates allow only about 6000 years for the formation of the whole 4 m core from the bog. The calculations indicate that 1 cm of peat was deposited in approximately 15 years assuming a uniform rate of peat formation. This implies that each 1mm sample shown in the detailed diagram in Fig.4.2 represents a period of 1.5 years or between one and two years of peat growth.

According to this the finely sectioned core between 298.5 and 323.9 cm was formed in approximately 381 years and it took Ulmus approximately 84 years to decline during episode D in Fig. 4.2.

Whilst these rates are only estimates of the true time-scale they do provide an order of magnitude which is important for envisaging the ecological processes represented by the pollen frequency changes shown on the diagrams.

# CHAPTER 5.

## INTERPRETATION OF THE DIAGRAMS

The pollen analysis of the core from the bog at Pawlaw Pike has made it possible to visualize certain vegetational changes that have taken place at the site during past periods.

### 5.1. The Boreal period (Zone VI). *398 cm

The diagram shown in figure 4.1. opens at the end of pollen zone VI. The pollen grains from this level have been deposited in the surface layers of a soil rather than in peat, which indicates that the area was drier and that the bog did not extend as far at that time as it does today, but the high percentage of Cyperaceae pollen shows the presence of damp areas in close vicinity of the sampling point.

Betula pollen is the largest component of the tree pollen total at this level and if one recalculates its percentages using Andersen's (1970) correction factors the results show that it was also the most common tree species in the forest. Quercus was also common and Ulmus was an established component of the forest. Alnus however did not play a major part in the forest composition. Pinus pollen is abundant reaching values of more than 10%. This may indicate that Pinus was growing near the sampling site at the time of deposition of the first sample.

### 5.2. The Atlantic period (zone VIIa). 368 cm

The following samples show characteristics indicating the onset of

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*Numbers shown in the margins of this chapter refer to depth in cm of the samples being discussed at that point in the text, (see figures 4.1 and 4.2, which are in a folder at the back).

zone VIIa. Trees such as Quercus, Ulmus and Alnus replaced the Betula and the Pinus trees of zone VI. The contribution of Pinus pollen to the tree pollen sum has at this point been reduced to below 10%, which most probably means that Pinus had retreated and was at that time not growing in the immediate vicinity of the bog. The Pinus however remains in the North Pennine forests (Turner et al., 1973; Turner and Hodgson, 1981), and the final drop in its pollen frequencies does not occur until much later.

In the mixed oak forest Alnus was probably the tree that competed with Pinus at the time of the Boreal/Atlantic transition and replaced it during the first part of the Atlantic period, and it was probably the most common tree taxon at the time. Later Quercus expanded rapidly and became the most common forest tree, according to calculations based on Andersen's (1970) correction factors. This is similar to the evidence from Teesdale (Turner et al., 1973). Tilia pollen is now present in the samples. It was the tree most directly responsive to the climatic optimum in England and Wales (Pigott and Huntley, 1978 and 1980). There is an increase in Corylus pollen as well. Smith (1970) suggested that a Corylus maximum during the Alnus rise indicated an opening up of the forest by early human activity, and there is now a reasonable amount of evidence that Mesolithic man was capable of managing the Corylus in the forest (Simmons et al., 1981).

## 5.3. Details of zones VIIa and VIIb.

The detailed diagram shown in figure 4.2 represents the end of zone VIIa and the beginning of zone VIIb, a period of approximately 381 years. In the diagram episodes A, B and C belong to zone VIIa of the Godwin system, episode D represents the transition between zone VIIa and VIIb, and episode E belongs to zone VIIb.

By using Andersen's (1970) correction factors it appears that during eipsodes A, B and C the overall composition of the forest remained relatively unchanged, with Quercus, Alnus, Betula and Ulmus making up the tree cover together with Corylus. The less common species show more changes, Pinus decreases and Tilia increases, but Fraxinus remains stable. During episodes D and E however there is an abrupt fall in Ulmus accompanied by a fall in Fraxinus at which time Betula becomes the most common tree of the forest again and it dominates all others although Quercus and Alnus are still common.

At the beginning of episode A much of the upland was probably forested as already described, but the amount of non-arboreal pollen incorporated in the deposit suggests the presence of open woodland.

### i) The first forest opening.

323 cm-
322 cm

The gradual fall in Ulmus and Quercus pollen throughout episode A complemented by an increase in Corylus pollen suggests an opening up of the forest. This view is supported by the fact that Fraxinus, which is less shade tolerant than Ulmus, increased at the same time. A simultaneous increase in Potentilla pollen, which may come from P.erecta, a plant, characteristic of open woodland also indicates improved light conditions and a recession of the forest.

These changes are reflected in the ratio of tree to herb pollen which falls in the centre of episode A. This coincides with the first occurrence of charcoal on the slides. Variable amounts of charcoal were observed on every counted slide thereafter.

After the initial decrease of the tree pollen there is a complex sequence of variations in the herb pollen frequencies, some of which have been interpreted as arable indicators others as pastoral indicators. However, the frequencies concerned are so low it is unlikely that the changes represent forest clearance of the type described by Iversen (1973) and usually referred to as "landnam".

The initial changes occurring are that *Pteridium* spores and *Succisa/Scabiosa* type pollen increase as the total tree pollen decreases. Then, about 7 years later *Melampyrum* and *Potentilla* pollen increase. These are both herbs of open forests and this increase supports the suggestion that the tree canopy had become less dense. There is an increase in the pollen of Ranunculaceae, a family which contains a number of pastoral plants such as species of buttercup. Gramineae shows a sudden rise from 15% to 40%. As the Gramineae pollen begins to decrease the first grains of *Rumex acetosa/acetosella* type are encountered and a single grain of *Plantago* was found (possibly *Plantago maritima*), the appearance of which indicates human interference with the natural vegetation of the area.

After the Gramineae maximum the total tree pollen recovers partially. There is a slight increase in *Salix* pollen and a few *Hedera* grains occur. A second and much smaller increase in Gramineae and *Potentilla* pollen follows. These changes are finally shadowed by the rise in *Calluna* pollen at the close of the episode, and it does not fall again until approximately 48 years later. 321.4cm

Specks of charcoal were found in small amounts in most samples from this episode. Because *Betula* and *Pteridium* are considered the pioneer taxa in the succession following forest fires, and neither of these appear to play a major part in the forest regeneration following this small temporary opening up of the forest, it must be assumed that the opening up of the forest involved more than the use of fire, possibly coppicing, ringbarking or felling of trees and grazing of the forest sward.

The first half of episode B is a period of forest regeneration shown by an increase in pollen of all the forest trees, except for *Quercus* and *Fraxinus* and some irregularities in *Ulmus* percentages. 319.9cm-317.3cm

### ii) The second forest opening. 317.6cm-315.0cm

Then follows a second opening of the forest with an increase in Gramineae, which lasts approximately 44 years. There is a sudden peak in charcoal between 316 and 317 cm and only then does the proportion of tree pollen decrease slightly. This is accompanied by an increase in the pollen of *Melampyrum*, *Potentilla* and Ranunculaceae, and there is a slight rise in the Filicales curve. *Rumex acetosa/acetosella* type grains were found throughout the episode with a peak just before the 317.9cm actual rise in the Gramineae curve. Grains of Cruciferae, Compositae (Tubuliflorae), Chenopodiaceae, Umbelliferae, *Filipendula* and a number of *Succisa/Scabiosa* grains, and the first *Plantago lanceolata* grains appear in that order, the finding of which strongly suggests a 315.5cm vegetational disturbance caused by human activities in the area. This opening of the forest is very similar to the one in episode A, except that this time the proportion of *Potentilla* and *Melampyrum* is much higher than before, but again it is not a permanent opening. As the forest begins to recover there is a rise in *Calluna* similar to the one at the boundary of episodes A and B, but this time it lasts only approximately 26 years.

### iii) The third forest opening. 313.0cm-312.6cm

At the beginning of episode C there is a third opening up of the forest. Here *Potentilla* reaches its highest values and the Gramineae maximum is more pronounced than before and lasts approximately 29 years.

The clearance differs from the previous ones in many respects The use of fire appears to have been more intense, as reflected by an increase in charcoal specks found in the samples and the fact that *Betula* plays a larger part in the forest regeneration following the forest opening. *Calluna* begins to recover as before but it is not allowed to establish fully.

For the remainder of the episode the proportion of Gramineae and herbs is low and the forest recovers quickly mainly because of the rapid regeneration of Betula. The Ulmus curve remains at a lower average percentage than before. The fact that it does not recover along with the other tree pollen percentages is interesting, it may indicate the beginning of whatever eventually caused the elm decline. In the last sample before the C/D boundary, Ulmus and Quercus show a sudden recovery. This gives the impression that the forest had been allowed to rest before exploitation started again. 312.3cm-309.4cm

Thus there appear to have been three periods during which the woodlands were opened up, each characterized by a decrease in Ulmus and Quercus, one in each of episodes A,B and C.

They are all three characterized by an increase in Gramineae and Potentilla, followed by an increase in Calluna, which reaches a peak at approximately 75 year intervals, but Salix and Betula do not play a major part in the regeneration following these openings. They all coincide with increased deposits of charcoal, which appear at the onset of the first increase in herbs and Gramineae in episode A, and are found in large amounts at the beginning of the periods of woodland openings during episodes B and C.

The main difference between the three periods is that the percentages of Potentilla pollen gradually advance with each new opening phase. This might indicate that repeated human activity may have benefited the growth of plants of this genus, which contains many species of successful weeds. The opening in episode B differs from the other two by its large peak in Melampyrum pollen. These periods of forest openings lasted 15, 44 and 29 years respectively or for 25 years on the average. This may well correspond to the human lifespan at the time, which means that each opening could have been created by one or at the most two generations of humans.

iv) The elm decline 309.1-303.8cm

At the beginning of episode D both the Ulmus curve and the Quercus curve begin to decrease, but their characteristics differ. Ulmus begins decreasing slowly showing short term fluctuations during the first half of the episode. In the second half it falls more rapidly and steadily. 306.5cm Quercus on the other hand falls abruptly to begin with, then it recovers partially but continues to fluctuate throughout the rest of the episode.

By the large amount of charcoal deposited in the peat it may be reasoned that the initial fall of both Ulmus and Quercus involved burning of relatively pure stands of these trees. As with the other openings this may have been done to create larger open areas for grazing livestock.

The gradual decrease of the forest continues although its composition does not appear to change much, except for the Ulmus fall. This indicates that during this period the pressure on Ulmus was more intense than on any other taxon. As Ulmus normally grows on rich mull soils, another possible explanation for the selective destruction of Ulmus is that the human inhabitants of the area may have discovered that the soil on which Ulmus was growing was more productive than that elsewhere and therefore cleared all stands of Ulmus in the nearby forest in order to grow their crops in the best available soil .. The finding of cereal pollen would have supported this theory, but no such pollen has been identified in these samples, although two monoporate grains which were larger than average Gramineae grains were found, but these could not be definitely attributed to Cerealia.

However, the absence of cereal pollen is not in itself significant since most cereals are self pollinated and only produce a small amount of pollen, so the possibility of cultivation of cereals cannot be entirely excluded on the basis of not having found cereal pollen (Behre, 1981).

Complementary to the *Ulmus* fall is the gradual rise of the *Salix* curve. The negative correlation observed here cannot be due to competition between the species since *Ulmus* and *Salix* have quite different edaphic requirements. But *Salix* will benefit from the removal of a heavy tree canopy for it is a light demanding pioneer in forest clearings.

During the period of forest destruction Gramineae percentages increase gradually and remain high for at least 68 years, which indicates that the exploitation of the human population was of a longer duration than before, of at least two if not three generations.

As was mentioned above there is evidence of intensive burning throughout the episode reflected by the large amounts of charcoal found in the samples. The continuous use of fire during this period may have caused the slow but gradual destruction of the forest, followed by the spread of grasses. The Gramineae frequencies approach 306.3-305.0 cm 70% of total tree pollen. It should be kept in mind that the Gramineae percentages are drawn to half scale in the diagram. If they are re-calculated in terms of total tree pollen excluding *Corylus* pollen, the Gramineae percentage reaches 120% when it is at its highest. This, was interpreted by Turner (1965) at Bloak Moss as representing a clearing of woodland from more than half the area contributing pollen to the bog.

The rise in Gramineae is accompanied by an increase in *Melampyrum*, *Potentilla* and Ericales. The large number of *Rumex*, Ranun- 307.4-305.6cm culaceae and *Plantago lanceolata* grains occurring in the following levels point to this having been a clearing of woodland to produce grassland for pastoral activity. But a few grains of herbs such as *Compositae* (Tubuliflorae), Chenopodiaceae and the first appearance of 306.3cm *Urtica* grains support the suggestion that arable farming also may have played a part in the utilization of the forest opening. In natural conditions species of Chenopodiaceae grow only at the sea-shore, so Iversen (1941) states that finding Chenopodiaceae pollen inland indicates disturbance caused by man. Such plants require a very nitrogenous open soil and cannot tolerate shade. These facts strengthen the theory that the vegetational changes occurring were caused by human activity.

As the proportion of Gramineae and ruderal pollen decreases the occurrence of charcoal decreases as well. This more pronounced opening up of the forest, which as was mentioned before, lasted approximately 60 to 70 years assuming a uniform rate of peat accumulation, is followed by a succession characterized initially by a gradual, but pronounced, increase in *Salix*, replacing first Gramineae then *Potentilla* in the diagram, and the disappearance of *Plantago lanceolata* pollen from the samples. This suggests that pressure on the vegetation has decreased and that regeneration was beginning to take place. Then follows the very pronounced increase in *Betula*.

*Calluna* percentages remain more stable than during previous episodes at an average of 20%. The regular 75 year cycles observed in episodes A, B and C with peaks of 40 to 50% at the episode boundaries and lows of 10% in their middles are disrupted. Instead there is a small peak at the beginning of episode D and another in the middle. 308.7cm As *Calluna* percentages are drawn to half scale these peaks may 306.5 cm not appear large on the diagram, but they do show a pronounced shortening of the cycle of *Calluna* maxima to about 40 years.

## 5.4. Later periods (zone VIIb and thereafter).

It has been mentioned earlier that in this study it has not been possible to place any natural zone boundaries above the end of zone VIIa. After the elm decline the *Betula* curve maintains higher values than before. Here the *Tilia* curve ceases. This was at one time thought to indicate a change towards less favourable climatic conditions. But like Ulmus, Tilia was an important source of bast and nutritious leaves and it tends to grow on good soil, so the decrease in Tilia could also have been caused by the anthropogenic factor (Turner, 1962). 288.0 cm There is an increase in Fraxinus pollen (Fig. 4.1.), but Fraxinus is a pioneer tree in forests and it is rather light demanding, so its increase is probably the result of the opening up of the forest. There is also a gradual increase in Calluna pollen. Constant grazing and regular burning will have benefited the Calluna and prevented regeneration of the forest trees. The removal of the tree canopy will eventually have resulted in podzolization of the soil and because Calluna grows well on soils of low base-status, and can tolerate a high degree of acidity (Pennington, 1974), a heath was established which has remained the dominating vegetation of the area since.

256.0cm-224.0cm The decrease of Cyperaceae pollen followed by an increase in Sphagnum spores may indicate actual changes in the vegetation growing on the bog immediately at or near the sampling point, which could have been caused by a local alteration in the bog surface towards wetter conditions.

192.0cm-160.0cm There is one more phase of forest opening or an actual clearance apparent between 160 cm and 192 cm. It seems to be of a larger scale than the one accompanying the Ulmus decline. The increase in Gramineae is slightly more than before, and Plantago lanceolata, Rumex acetosella and Urtica pollen percentages reach much higher values than they did during the Ulmus decline. If one assumes that the rate of deposition was uniform throughout, this clearance occurred approximately between 2,400 and 2,900 years ago or during the late bronze age. The last and less pronounced clearance follows at 64 cm. This is estimated to have occurred around the year 1,000 A.D., possibly during the Viking invasions and settlements.

The detailed diagram from Pawlaw Pike confirms in many respects results obtained in previous studies of the elm decline, but this method of finely sectioning the core does give a new time dimension to the study of the vegetational changes. The diagram shows surprisingly marked and complex changes in the pollen percentages during the short timespan of the finely sectioned core.

# CHAPTER 6

## DISCUSSION

### 6.1. Assumptions.

i) Certain assumptions have been made in the interpretation of the diagrams. The first is that the sedimentation rate in the bog was uniform throughout the whole period. There were without doubt variations in the rate of peat formation and the accumulation of inorganic materials in the bog from time to time. According to Turner (1964,a) there can be great irregularities in the rate of growth even when the peat appears uniform throughout the bog's profile. This in turn may have affected, not only the estimated timescale of the vegetational changes but also the timespan in which the peat in the 1 mm thick pollen samples were deposited. In either case it is likely that the samples will represent fairly accurately short-term fluctuations in the pollen "rain" such as those caused by particularly good or bad flowering seasons for individual species growing in the area. If so, then some of the 1 mm samples could contain pollen laid down during as little as one summer of rapid peat formation while others might contain the pollen produced during two or more flowering seasons during a time of slower peat accumulation.

ii) The second assumption is that there is little serious mixing in the pollen deposited from one sample to another. This can be concluded from the fact that abrupt changes in pollen percentages often occur between two adjoining samples in the detailed diagram (Fig.4.2). It has been observed that the main deposition of pollen in forested areas occurs in spring when the production of pollen is at its highest, but some of the pollen released gets caught on leaves and branches of the forest trees and is not brought to the ground until the following fall or winter when leaves are shed and the deposition rate of litter is high (Krzywinsky, 1977). This might result in some mixing of pollen from one year to the next and this could mean that each 1 mm sample represented a little more than the estimated average of $1\frac{1}{2}$ year pollen deposition, it may possibly be containing as much as three or four years pollen.

iii) The third assumption made is that the source area is rather small. This area has been defined by Jacobs and Bradshaw (1981) as the area from which most of the pollen sampled at a site has been derived. For this assumption there are two main factors relevant as has been noted by Roberts, Turner and Ward (1973). These are the nature of the upland and the size of the bog. Faegri (1947) states that a large percentage of the pollen deposited at any site is derived from vegetation growing within a radius of 10 km, but much of the pollen is from a source area smaller than that. Andersen (1970) and Jacobson and Bradshaw (1981) estimated that most pollen grains were deposited within 20-30 m of their source and Birks (1977) found that there was a good match between pollen in surface samples at Ickenthwaite and the present day forest composition within a 30 m radius of the pollen sampling point. At Pawlaw Pike the site is exposed to the north west and south east so that some of the pollen could have originated from the two valleys on either side and thus the source area could be extended in those directions. The size of the bog was approximately 30,000 $m^2$ at the time of the elm decline but it has expanded to at least twice that size since. The pollen deposited in a bog of this size is likely to have derived mostly from the local vegetation and the surrounding forest while the area was mainly woodland (Jacobson and Bradshaw, 1981). As the forest was gradually replaced by Calluna heath the pollen grains are likely to have been derived from a larger area (Dimbleby, 1962).

During the Boreal and Atlantic periods it is likely that the whole source area was covered by a forest except for the surface and immediate surroundings of the bog from which the samples have been obtained. There may already have been small open patches among the trees or along the bog's margin providing conditions for Gramineae and Calluna to be established in the area prior to the Ulmus decline. After the Ulmus decline the bog gradually expanded in area eventually filling up the whole of the present bog basin. The peat must thus have expanded gradually into the forest which formerly had been growing on the dry slopes around the bog's margin. Since peat acts as a sponge maintaining the moisture as it expands, it is perfectly possible for mosses, sedges and heather to increase at the expense of the forest, which gives way to the encroaching peat.

Based on measurements of the peat's profile and the pollen counts, an attempt is made graphically in Fig.6.1 to show the changes that took place in the area of the bog and the surrounding vegetation by diagramatically reconstructing the Pawlaw Pike bog at 5,000 years B.P.(Fig. 6.1.a) and at present day (Fig.6.1.b.). The drawing indicates how the filling up of the bog basin by peat increases the bog's surface and it's vegetation and consequently encroaches up on the surrounding forest causing it to retreat.

## 6.2. The detailed pollen diagram and the elm decline.

The detailed diagram (Fig.4.2) shows a series of at least three forest openings during the period before the actual elm decline. The combined evidence of a decrease in forest tree cover, an increase in Gramineae and a number of herbs associated with human interference of natural habitats, and the presence of large amounts of charcoal in the deposits from before and during the elm decline, suggests that a human population was affecting the vegetation of the pollen catchment area. These late Mesolithic or early Neolithic people appear to have entered the area at least four times during the period spanned by the

Figure 6.1.

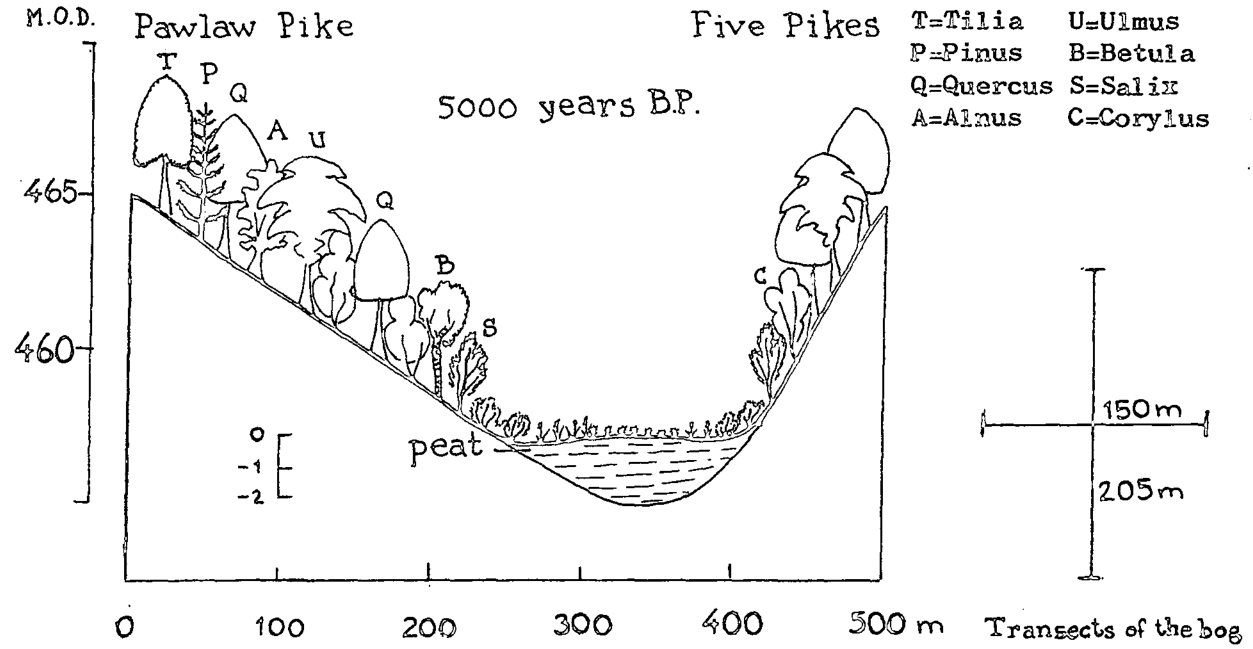

Fig.6.1.a. A diagramatic reconstruction of the Pawlaw Pike bog at 5000 years B.P. when it was surrounded by forest. The estimated area of the deposit is 3 ha.

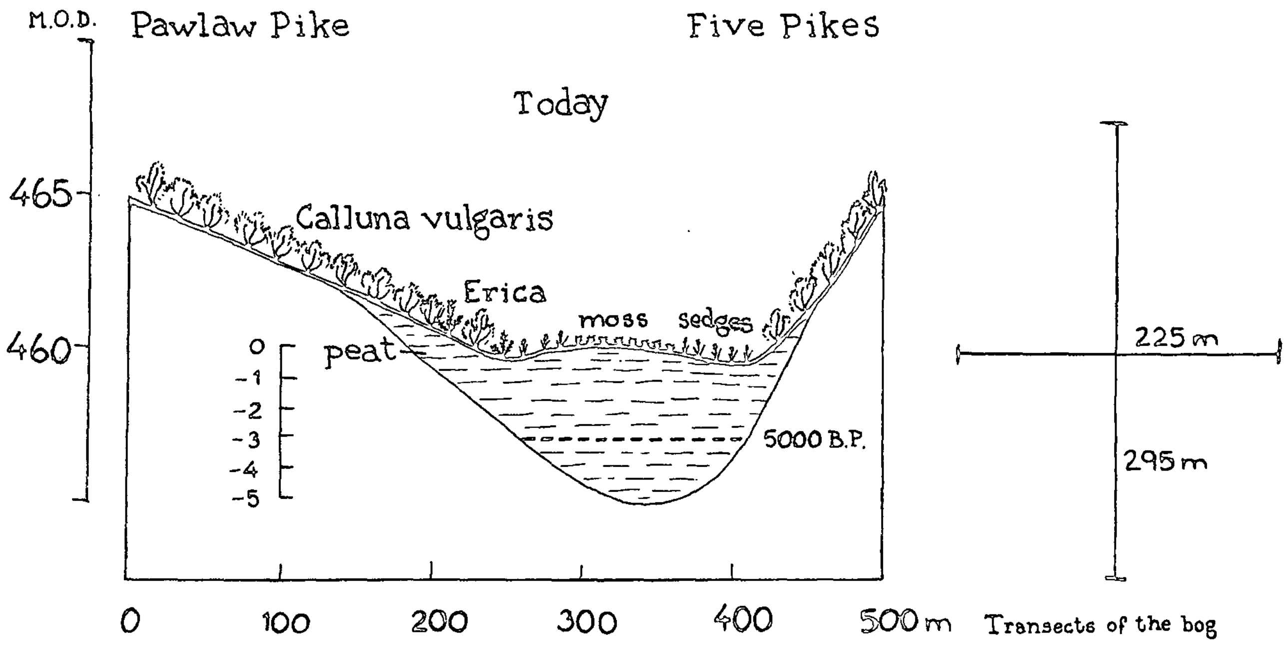

Fig.6.1.b. A diagramatic reconstruction of the present day bog at Pawlaw Pike which is surrounded by heather. The estimated area of the bog is 6.5 ha.

detailed study from this site. Their method of utilization of the forest resources during the first three opening periods, appears to have been broadly similar lasting approximately one generation each, the total period involved being about 210 years.

This means that the elm decline does not precisely correspond to the first interference with the natural vegetation by prehistoric man, but succeeds it by over 200 years. The finding of charcoal in the strata 210 years before the onset of the elm decline is thus of major importance in this study. It suggests that in this part of England man was already using the forest's resources to his benefit, presumably with the intention of improving the grazing for wild game or for his domestic animals.

A deposit of charcoal in pollen profiles, which could indicate a similar development, was discovered by Turner et al. (1973) in the Weelfoot Moss in Upper Teesdale northern England and by Garbett (1980) in the Lake District and similar charcoal deposits have been found in many other pollen profiles.

The first burning of the area corresponds to a decrease in the pollen of Quercus and Ulmus in the diagram. At the same time there appears to have been a drying out of the bog surface as evidenced by the sudden decrease in Sphagnum spores followed by a decrease in Cyperaceae pollen. There may have been a connection between the opening of the forest and the drying of the bog, because on a watershed the destruction of the forest might have lowered the water table of the ground surrounding the bog, and hence of the bog itself. Grasses may then have been able to spread on the dryer bog surface as well as into the more open forest.

It is difficult to point out exactly where the Calluna was growing at this time. It was probably growing at the edge of the bog and on the bog surface and the increase in its frequency at this level could have been a response to the drying out of the bog, as the dryer bog surface would undoubtedly have provided an excellent habitat for Calluna. It is also possible that Calluna was spreading into the more open woods at the same time. Alternatively it could already have been growing in the forest with the heavy tree canopy either preventing flowering or preventing transport of the pollen to the bog surface.

This second hypothesis is however unlikely as one would then have expected the increase in Calluna pollen to have been more rapid than is indicated by the present results, unless it was initially suppressed by steady grazing and burning which the grasses would have tolerated better.

These arguments also hold for the increase in Calluna after the second forest opening, but following the third opening the Calluna seems to have been suppressed by Betula, which apparently was able to flourish as the area was abandoned by man and his animals for a longer period.

The fact that man was exploiting the vegetation for over 200 years before the elm decline means that one must take seriously the theory that he caused or at least contributed to it. It could be argued that burning of the forest was carried out to create a shrub for grazing animals and this followed by heavy grazing caused the elm decline at this site. The larger trees would have remained alive producing flowers and seeds to maintain elm in the forest, and the seedlings would have grown to replace them had there not been long periods of overgrazing. Thus during episodes A to C there could have been continual production of elm pollen in the forest because the old elm trees were standing and flowering although no regeneration was occurring. This period, however, would have come to a sudden end with the death of the old trees during episode D. As the life span of elm in this upland environment may well have been approximately 200 years, the frequency of elm pollen would not drop simultaneously with mans first exploitation of the land, but gradually after a lapse of up to 200 years as is the case in the results from this study.

It is possible that some burning of the forest was carried out to attract wild game such as roe-deer and elk, but it does seem unlikely that a simple hunting culture would have caused a destruction of such great extent as the elm decline, especially since there is evidence that man was already hunting in the northern Pennines much earlier in the Mesolithic.

According to Grigson (1966) domestic animals had become more important than hunted animals to the economy of early Neolithic man and these are likely to have been more effective than wild animals in destroying the vegetation of the forest sward. Cattle, sheep, goats and pigs are known to have been used as domestic animals in southern England in the early Neolithic and it may be supposed that they were also the main domestic species in northern England at this time (Rackham, J. - personal communication).

It is likely that livestock would have been allowed to graze on the open places around a settlement and perhaps also in the forest itself as has been suggested by van Zeist (1959). Both cattle and especially goats and sheep may have browsed on the lower branches and grazed on the developing seedlings of the forest trees and thus hindered the regeneration of the forest. It is suggested that the herders of the upland preferred goats and sheep because these animals are particularly well adapted to grazing on hillsides and could have penetrated dense forests as well as having the potential of being very destructive to tree seedlings.

As was noted in the introduction the leaves and shoots of elm are very nutritious and palatable for animals and will be preferably selected by domestic animals grazing in a mixed forest. It is therefore reasonable to suggest that when domestic animals were brought into a specific area they must have grazed heavily on elm seedlings on the forest floor, since grasses and other pasture species of todays meadows were lacking.

Although the elm decline can reasonably be explained in this simple way other factors may have contributed to its causes. It is worth while to consider more closely the hypotheses set forth by Faegri (1944), Troels-Smith (1954) and Nordhagen (1954), that the elm leaves were selectively used by prehistoric man as fodder for cattle. They suggest that leaves and young shoots of elm trees were cut from the trees by a process of pollarding and lopping and fed to animals which were kept stalled. It is possible that this method of rearing animals may also have played a part in causing elm to decline at this site.

It has also been suggested by Morrison (1959) that the clearing of forest in order to grow crops might have contributed to the decline of elm. This may possibly have been done during the middle of the elm decline at Pawlaw Pike. That is where the occurrence of Plantago lanceolata grains is at its highest and where two Gramineae grains that were larger than the others and with a thicker annulus, were found. In which case it would be expected that an area had been completely cleared of vegetation and all stumps of trees removed or burned down. Following such a clearing the forest would have had to regenerate completely from seed. Even though some crops may have been grown as a part of the utilization of the land near Pawlaw Pike, there is little evidence to suggest that a large enough area was affected in this way to have caused the elm decline at this site.

As mentioned in the introduction the elm decline has been attributed to disease affecting Ulmus species alone. Certainly in this study no evidence has been found to support the theory. There is for example no indication of an increase in Hedera following the elm decline at

Pawlaw Pike, which might have supported the suggestion that Hedera had benefited from an increased number of standing dead elm trees in the forest, although the number of Hedera grains found in the samples may not be enough to be significant. On the contrary there is a decrease in the number of Hedera pollen grains found following the elm decline. This was also the case in Garbett's (1980) study from the Lake District.

If only Dutch Elm Disease or a comparative disease had caused the Ulmus decline one would have expected the niche occupied by the elms to have been invaded by other forest trees, since the destruction of so many Ulmus trees would have opened up large areas of the best mull soil which should readily have been reforested by other species within a short time. But this is not the case. The results from this study show that when the forest was opened up it was not recolonised straight away, but remained opened with Gramineae and other herbs growing successfully for a period of up to 70 years. The concomitant increases in the pollen of weeds, ruderals and other cultural indicators suggests that even if a disease had affected elm, human activities were also doing so, and whilst one cannot rule out the possibility that there was disease, there is no supporting evidence in the Pawlaw Pike data.

After the elm has declined it never recovers again which could be due to several factors. It might have been caused by a deterioration of the soil, which may have occurred following the repeated destruction of the forest cover. The soil could gradually have become more acidified until it reached a stage where it was no longer suitable for the growth of elm, as elm needs a very base rich soil. If this was the case one might expect Calluna to increase at the same time as elm declined, as it grows well on acid soil. However, the main increase in Calluna does not take place until later.

But a medium soil might have been too poor for elm and still too rich for Calluna to grow successfully, while other not so particularly demanding species such as Gramineae, Betula and Salix would be able to replace the Ulmus.

The inability of elm to regenerate may also have been caused by the constant chopping down of the elm trees to create an elm shrub for browsing animals, or, and this is perhaps more likely, because it was grazed to such an extent that it could not recover. Heavy grazing would not have affected Salix, which increases at this time, as Salix is highly capable of regenerating whilst being grazed. Betula which becomes the dominant tree after the elm has declined, may have developed in the protection of the Salix, since these are both trees which benefit from improved light conditions in the forest.

## 6.3. The destruction of the forest and the effects on the environment.

If one considers the possibility of the Ulmus decline to have been caused by the anthropogenic factor alone one must review the previous evidence found to support other theories and consider whether it is in contradiction to this theory or whether it actually supports it.

Pennington (1974) notes that, originally, Blytt and Sernander defined their Atlantic period as one of oceanic climate, separated from the succeeding Sub-boreal period by an increase in continentality of the climate. The main evidence in support of this interpretation was the finding of changes in peat type in Sweden at the transition between the Atlantic and Sub-boreal, by Blytt and Sernander, indicating a drying out of the bogs, retarding the production of ombrogenous peat in them; as well as the disappearance of the Great Sedge (Cladium mariscus) and the decline of ivy (Hedera helix) in Scandinavia. However, such a climatic change can not be shown to have occurred in England as there are no changes in peat type and no corresponding changes in Cladium and Hedera (Pennington, 1974). It is therefore suggested that an alternative explanation for the observation in

Scandinavia may be found, namely that a climatic change was not the cause of the alteration in peat type there, but that it was due to destruction of the large forests, and that this destruction had a similar effect on the peat composition and vegetation as a change in climate would have had. When deforestation occurs in an area it causes a loss of water that was previously bound by the roots of the forest trees and finally results in the lowering of the groundwater level and this may be mistaken for an advance of a drier period.

Pennington (1974) also mentions that the Atlantic/Sub-boreal boundary was also found to be associated with lower winter temperatures in Scandinavia. It should be noted that the effect of forest destruction may appear similar to deterioration of climate since it would cause a great change in the microclimate of the area cleared, resulting in lower winter temperatures at ground level and increasing drought in newly exposed areas. It may also be noted that deforestation will finally result in erosion of the soil and thus increase the mineral content and sedimentary rate in bogs and lakes. These facts show that previous conclusions drawn from evidence available at the time are not inconsistent with the theory that mans exploitation of his environment caused the vegetational changes encountered during the Sub-boreal period.

It is suggested that the anthropogenic effects may have been more drastic and the natural balance of the vegetation was more easily tilted in Scandinavia with its relatively more continental climate than in Britain. When man introduced domestic animals into the woodland and started to deforest the land in Britain, the opening up of the forest may not have caused the same amount of erosion or microclimatic changes as it did in Scandinavia due to the milder and more oceanic climate here. In addition the relatively low hills in Britain are not as inclined to erode as the granite mountain slopes of parts of

Scandinavia. Thus it is suggested here that no marked climatic change took place in northern Europe between the Atlantic and Sub-boreal periods, but that the effects in soil and vegetation which pointed to such changes were man made, caused by his effect on the forest.

## 6.4. Conclusion.

In conclusion it should be pointed out that the results obtained from this study of the Pawlaw Pike bog gives a detailed picture of the changes in the vegetation at this site. By fine sectioning it has been possible to detect several short term changes that might have passed without notice with less detailed sampling methods or might have been presumed to represent only one continuous vegetational change. This has made it possible to estimate the duration of each exploitation period in one particular small area.

The three short-term fluctuations in the tree/shrub/herb composition during the period prior to the elm decline were probably caused by burning and the varying uses of the land by man and the activities of grazing animals.

In the nearby forest the trees withstood the human pressure and continued for a while to shed pollen over the open space of the bog and its surroundings. Gradually the livestock increased its pressure there too and kept on eating its way into the dense forest. And as this would have prevented regeneration of the most sensitive and palatable tree species, such as the elm, so they disappeared from the forest. These events fit the pollen evidence from Pawlaw Pike which shows a drop in elm pollen which takes only approximately 84 years a drop which may reflect the gradual loss of elm trees in the area.

The forest of the lowlands was probably a great obstacle to the herders and their animals of this early period so that they may have brought their livestock to less dense forests of the upland or to other areas where the forest was less dense. Whether there were permanent settlements in the area during the periods of exploitation can not be deduced from the evidence found in this study but it is just as likely that these early herders had summer quarters in the uplands near Pawlaw Pike and moved their animals to open areas in the lowlands such as lake and river banks during winter.

It seems likely that the early herders practised the burning of patches in the upland forest which they managed for some years until the procedure had to be repeated with an average interval of some 25 years. Should one family group have burnt a new patch of forest every year it is understandable that the vegetation changes took place so rapidly and also how quickly the occupation spread over the country and throughout northern Europe.

According to the pollen evidence from Pawlaw Pike these early vegetational changes as well as the destruction of the elm took over 200 years which corresponds to a life span of up to ten generations of the pastoral people who had introduced the new culture to the country. Such a revolutionary change from hunting and gathering to herd keeping is bound to have led to a population explosion, which in turn would have accelerated the spread of this new culture throughout the country. In the days of primitive man such a rapid spread of a culture may seem unlikely, but one has to bear in mind that repeatedly in the history of man the discovery of a new technique to utilize resources has provided means for rapidly increasing growth of populations and it is not uncommon that the newly available resource has been depleted in less than 200 years.

## APPENDIX 1

Relation between pollen counts and forest compositions.

The correction factors which have been used for these calculations are the same as were applied by Andersen (1970).

ZONE VI

| LEVEL | BETULA | PINUS | ULMUS | QUERCUS | TILIA | ALNUS | FRAXINUS | CORYLUS |
|---|---|---|---|---|---|---|---|---|
| | ÷4 | ÷4 | ÷2 | ÷4 | x2 | ÷4 | x2 | ÷4 |
| 398 | 32.9 | 11.4 | 8.2 | 15.1 | - | 5.0 | 3.7 | 23.7 |

ZONE VII a

| LEVEL | BETULA | PINUS | ULMUS | QUERCUS | TILIA | ALNUS | FRAXINUS | CORYLUS |
|---|---|---|---|---|---|---|---|---|
| | ÷ 4 | ÷4 | ÷2 | ÷4 | x2 | ÷4 | x2 | ÷4 |
| 368 | 11.0 | 4.5 | 11.4 | 17.0 | 3.0 | 18.6 | - | 34.5 |
| 352 | 15.9 | 4.5 | 8.9 | 24.8 | - | 12.2 | 3.3 | 30.5 |

Episode A. 323.9 - 320.4 cm.

| | BETULA<br>÷4 | PINUS<br>÷4 | ULMUS<br>÷2 | QUERCUS<br>÷4 | TILIA<br>x2 | ALNUS<br>÷4 | FRAXINUS<br>x2 | CORYLUS<br>÷4 |
|---|---|---|---|---|---|---|---|---|
| | 3.25 | 3.25 | 11.4 | 30.9 | - | 16.3 | 6.5 | 28.5 |
| | 9.4 | 5.9 | 15.7 | 23.6 | 6.3 | 11.8 | 6.3 | 20.9 |
| | 9.9 | 5.9 | 13.4 | 22.9 | 3.2 | 15.4 | 9.5 | 19.8 |
| | 13.3 | 7.0 | 12.6 | 16.7 | 3.0 | 15.2 | 3.0 | 29.3 |
| | 8.9 | 6.6 | 10.9 | 24.8 | - | 14.0 | 3.1 | 31.8 |
| | 4.9 | 2.5 | 9.9 | 22.5 | 2.8 | 17.6 | 5.6 | 34.2 |
| | 10.4 | 1.8 | 9.3 | 21.1 | - | 15.7 | 5.7 | 36.1 |
| | 11.4 | 5.5 | 9.4 | 20.0 | - | 17.3 | 3.1 | 33.3 |
| | 10.7 | 3.4 | 7.6 | 17.2 | 5.5 | 17.9 | 2.7 | 35.1 |
| Mean Values for Episode A | 9.1 | 4.65 | 11.1 | 22.2 | 2.3 | 15.7 | 5.1 | 29.9 |

Episode B. 319.9 - 314.7 cm.

| | BETULA<br>÷4 | PINUS<br>÷4 | ULMUS<br>÷2 | QUERCUS<br>÷4 | TILIA<br>x2 | ALNUS<br>÷4 | FRAXINUS<br>x2 | CORYLUS<br>÷4 |
|---|---|---|---|---|---|---|---|---|
| | 8.9 | 1.9 | 15.2 | 17.1 | 5.1 | 11.4 | 10.2 | 30.2 |
| | 12.0 | 2.3 | 9.3 | 16.3 | 3.1 | 24.0 | - | 32.9 |
| | 18.2 | 2.6 | 14.6 | 11.3 | 5.8 | 17.9 | - | 29.6 |
| | 12.9 | 1.6 | 7.8 | 12.0 | 2.6 | 19.1 | 7.8 | 28.5 |
| | 13.4 | 1.4 | 10.1 | 18.1 | 5.8 | 16.6 | 2.9 | 31.8 |
| | 9.4 | 3.6 | 10.4 | 15.3 | - | 20.8 | 7.8 | 32.8 |
| | 10.7 | 2.9 | 12.3 | 25.0 | - | 18.9 | 3.3 | 27.0 |
| | 9.7 | 1.6 | 15.7 | 12.3 | 2.5 | 15.1 | 10.1 | 33.0 |
| | 8.4 | 2.9 | 14.4 | 16.1 | 6.9 | 19.9 | 2.3 | 29.1 |
| | 8.4 | 4.0 | 5.8 | 21.2 | 2.9 | 18.6 | 5.8 | 33.2 |
| | 11.5 | 4.9 | 12.3 | 23.0 | - | 17.2 | 6.6 | 24.6 |
| | 7.8 | 4.8 | 12.2 | 16.3 | 8.2 | 15.0 | 10.9 | 24.8 |
| Mean Values For | 11.8 | 2.9 | 12.2 | 17.0 | 3.6 | 17.9 | 5.6 | 29.8 |

Episide C. 314.3 - 309.4 cm.

| | BETULA | PINUS | ULMUS | QUERCUS | TILIA | ALNUS | FRAXINUS | CORYLUS |
|---|---|---|---|---|---|---|---|---|
| | ÷4 | ÷4 | ÷2 | ÷4 | x2 | ÷4 | x2 | ÷4 |
| | 11.7 | 2.3 | 10.4 | 20.1 | 2.6 | 19.1 | 7.8 | 26.2 |
| | 10.3 | 2.2 | 10.6 | 16.5 | 12.5 | 10.6 | 10.0 | 27.4 |
| | 10.6 | 4.0 | 5.1 | 20.3 | 4.6 | 13.1 | 13.7 | 28.6 |
| | 20.8 | 1.4 | 9.0 | 17.0 | 2.8 | 14.9 | 2.8 | 31.3 |
| | 18.7 | 2.7 | 8.3 | 18.4 | 2.4 | 16.6 | 4.7 | 28.2 |
| | 17.7 | 1.0 | 9.5 | 15.8 | 5.0 | 13.2 | 2.5 | 35.3 |
| | 24.5 | 0.6 | 7.6 | 14.6 | 5.1 | 10.2 | 5.1 | 32.2 |
| | 12.7 | 4.9 | 9.7 | 11.7 | 7.8 | 14.6 | 5.2 | 33.4 |
| | 12.3 | 3.0 | 7.2 | 16.3 | 2.4 | 15.4 | 12.0 | 31.3 |
| | 10.9 | 2.5 | 8.75 | 18.75 | 2.5 | 11.25 | 12.5 | 32.8 |
| | 16.3 | 2.1 | 7.6 | 17.0 | 8.3 | 14.5 | 5.3 | 28.7 |
| | 11.3 | 2.9 | 7.7 | 17.7 | 10.3 | 12.9 | 7.7 | 29.6 |
| | 10.7 | 1.2 | 11.0 | 17.7 | 7.0 | 13.3 | 7.0 | 32.2 |
| Mean Values of EPISODE C | 14.5 | 2.4 | 8.7 | 17.1 | 5.6 | 13.8 | 7.4 | 28.0 |

Episode D. 309.3 - 303.6 cm.

| | BETULA ÷4 | PINUS ÷4 | ULMUS ÷2 | QUERCUS ÷4 | TILIA x2 | ALNUS ÷4 | FRAXINUS x2 | CORYLUS ÷4 |
|---|---|---|---|---|---|---|---|---|
| | 10.4 | 4.1 | 9.7 | 23.8 | 5.9 | 16.0 | 3.0 | 27.1 |
| | 14.5 | 3.9 | 7.1 | 20.0 | 6.3 | 15.7 | 6.3 | 26.3 |
| | 7.5 | 3.2 | 6.9 | 18.4 | 10.7 | 14.1 | 8.5 | 30.7 |
| | 11.1 | 1.8 | 11.7 | 14.8 | 12.3 | 13.2 | 2.5 | 32.6 |
| | 12.0 | 1.8 | 6.2 | 14.5 | 19.7 | 13.5 | 9.8 | 22.5 |
| | 16.2 | 0.8 | 6.2 | 17.0 | 6.2 | 20.1 | - | 33.6 |
| | 15.0 | 1.7 | 5.8 | 15.0 | 5.4 | 18.4 | 8.2 | 30.6 |
| | 14.8 | 2.1 | 6.9 | 13.7 | 5.5 | 17.2 | 2.7 | 37.1 |
| | 13.0 | 1.0 | 7.3 | 18.0 | 5.3 | 13.0 | 8.0 | 34.3 |
| | 14.0 | 1.9 | 3.8 | 15.5 | 5.1 | 18.7 | 7.6 | 33.3 |
| | 14.1 | 2.7 | 6.9 | 17.2 | 13.7 | 12.0 | 8.2 | 25.1 |
| | 12.7 | 2.3 | 5.9 | 14.0 | 10.4 | 18.2 | 5.2 | 31.3 |
| | 15.8 | 2.2 | 4.4 | 22.1 | 5.9 | 15.1 | - | 34.6 |
| | 13.9 | 3.3 | 4.2 | 14.5 | 7.3 | 13.9 | 2.4 | 40.3 |
| | 11.9 | 1.4 | 6.8 | 18.3 | 5.4 | 15.6 | 5.4 | 35.3 |
| | 18.8 | 1.5 | 4.6 | 19.2 | 3.1 | 17.6 | 3.1 | 32.2 |
| | 11.0 | 1.9 | 3.2 | 18.8 | 7.8 | 15.9 | 7.8 | 33.4 |
| | 12.1 | 2.9 | 3.3 | 10.1 | 10.4 | 21.8 | 5.2 | 34.2 |
| | 15.3 | 2.2 | 2.2 | 20.8 | 5.8 | 15.0 | - | 38.7 |
| | 16.6 | 3.1 | 2.0 | 10.8 | 10.8 | 18.6 | 2.7 | 35.3 |
| | 20.3 | 1.9 | 2.3 | 22.6 | 3.1 | 12.3 | - | 37.5 |
| | 18.8 | 1.1 | 0.7 | 15.2 | 2.9 | 18.8 | 5.8 | 36.6 |
| | 10.3 | 3.8 | 1.8 | 19.1 | 2.4 | 12.4 | 7.1 | 43.2 |
| | 14.9 | 4.0 | 4.4 | 16.7 | 5.8 | 16.7 | - | 37.5 |
| | 19.6 | 2.4 | 0.8 | 25.7 | - | 16.7 | 3.3 | 31.4 |
| Mean Value for Episode D | 14.2 | 2.4 | 5.0 | 17.4 | 7.1 | 16.0 | 4.5 | 31.9 |

Episode E. 303.6 - 298.5 cm.

| | BETULA | PINUS | ULMUS | QUERCUS | TILIA | ALNUS | FRAXINUS | CORYLUS |
|---|---|---|---|---|---|---|---|---|
| | ÷4 | ÷4 | ÷2 | ÷4 | x2 | ÷4 | x2 | ÷4 |
| | 15.3 | 2.7 | - | 22.0 | 3.1 | 20.0 | 6.3 | 30.6 |
| | 21.8 | 4.8 | 1.0 | 18.0 | 8.0 | 13.8 | 6.0 | 26.8 |
| | 23.5 | 1.9 | 0.7 | 14.9 | 9.0 | 16.0 | - | 34.0 |
| | 37.4 | 3.4 | 0.6 | 10.9 | 2.5 | 14.0 | 2.5 | 26.2 |
| | 61.5 | - | 1.2 | 7.7 | - | 8.3 | - | 21.2 |
| | 57.5 | 0.4 | 1.7 | 8.5 | - | 6.4 | | 25.5 |
| | 52.3 | 1.4 | - | 7.0 | - | 10.3 | - | 29.0 |
| | 45.1 | 1.6 | - | 10.6 | 3.3 | 9.3 | 9.8 | 21.1 |
| Mean Values for Episode E | 39.3 | 2.0 | 0.7 | 12.5 | 3.2 | 12.2 | 3.1 | 26.8 |

Rest of ZONE VIIb and thereafter.

| LEVEL | BETULA | PINUS | ULMUS | QUERCUS | TILIA | ALNUS | FRAXINUS | CORYLUS |
|---|---|---|---|---|---|---|---|---|
| cm | ÷4 | ÷4 | ÷2 | ÷4 | x2 | ÷4 | x2 | ÷4 |
| 288 | 19.7 | 1.2 | 2.3 | 18.5 | - | 15.8 | 12.3 | 30.1 |
| 256 | 15.0 | - | 2.6 | 15.3 | - | 15.3 | 20.8 | 30.9 |
| 224 | 17.5 | - | 3.6 | 11.6 | 2.4 | 11.9 | 14.2 | 38.9 |
| 192 | 26.7 | - | 3.6 | 11.0 | - | 10.3 | 25.6 | 22.8 |
| 160 | 8.6 | - | 4.3 | 5.9 | - | 16.8 | 43.2 | 21.1 |
| 128 | 39.8 | - | 1.9 | 14.2 | - | 15.2 | 3.8 | 25.1 |
| 96 | 25.9 | 0.7 | - | 9.7 | - | 13.1 | 8.3 | 42.4 |
| 64 | 26.3 | 3.2 | 2.1 | 26.3 | - | 8.9 | 12.6 | 20.5 |
| 32 | 37.6 | 1.3 | 0.9 | 13.3 | - | 15.0 | 3.5 | 28.3 |

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