A STUDY OF THE VEGETATIONAL HISTORY OF DUBH LOCHAN

- A SMALL LOCH NEAR TO LOCH LOMOND

A Thesis submitted to the University of Glasgow

for the Degree of Master of Science

by

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SUMMARY

A pollen diagram has been prepared from Dubh Lochan - a small loch close to Loch Lomond in an area of semi-natural oak forest. The site selected is near to the edge of the loch, in fen carr, with Myrica as the dominant plant at the actual sampling site.

A complementary diagram of macro-fossil remains has also been drawn up, and together these diagrams give one a regional, and at the same time, local vegetational history of an area which is within the region covered by glacial ice at the time of the Loch Lomond Re-advance.

The diagram has been divided into local pollen assemblage zones, and this zonation has been confirmed by statistical analyses of the results. The sediment at the base of the core is fine silt containing no pollen. Above this there is a short zone where plants typical of cold climatic conditions, immature soils and open habitats flourished. Corylus pollen values rise very sharply at the end of this zone, and Quercus, Ulmus and Pinus must have immigrated into the area shortly after this. There is a brief period when Pinus values indicate local occurrence. Just after the maximum for Pinus there is a very sharp rise in values for Alnus pollen, and this is followed by a further expansion of mixed oak forest. Later, after the decline in Ulmus, pollen of plants typical of open forest, and of plants normally associated with the presence of man, became important members of the pollen spectra.

Comparison has been made with other pollen diagrams from sites in Western and North-Western Scotland and North-Western England. Similarities have been noted and tentative reasons given to explain differences from these.

MAP OF SOUTHERN LOCH LOMOND AREA

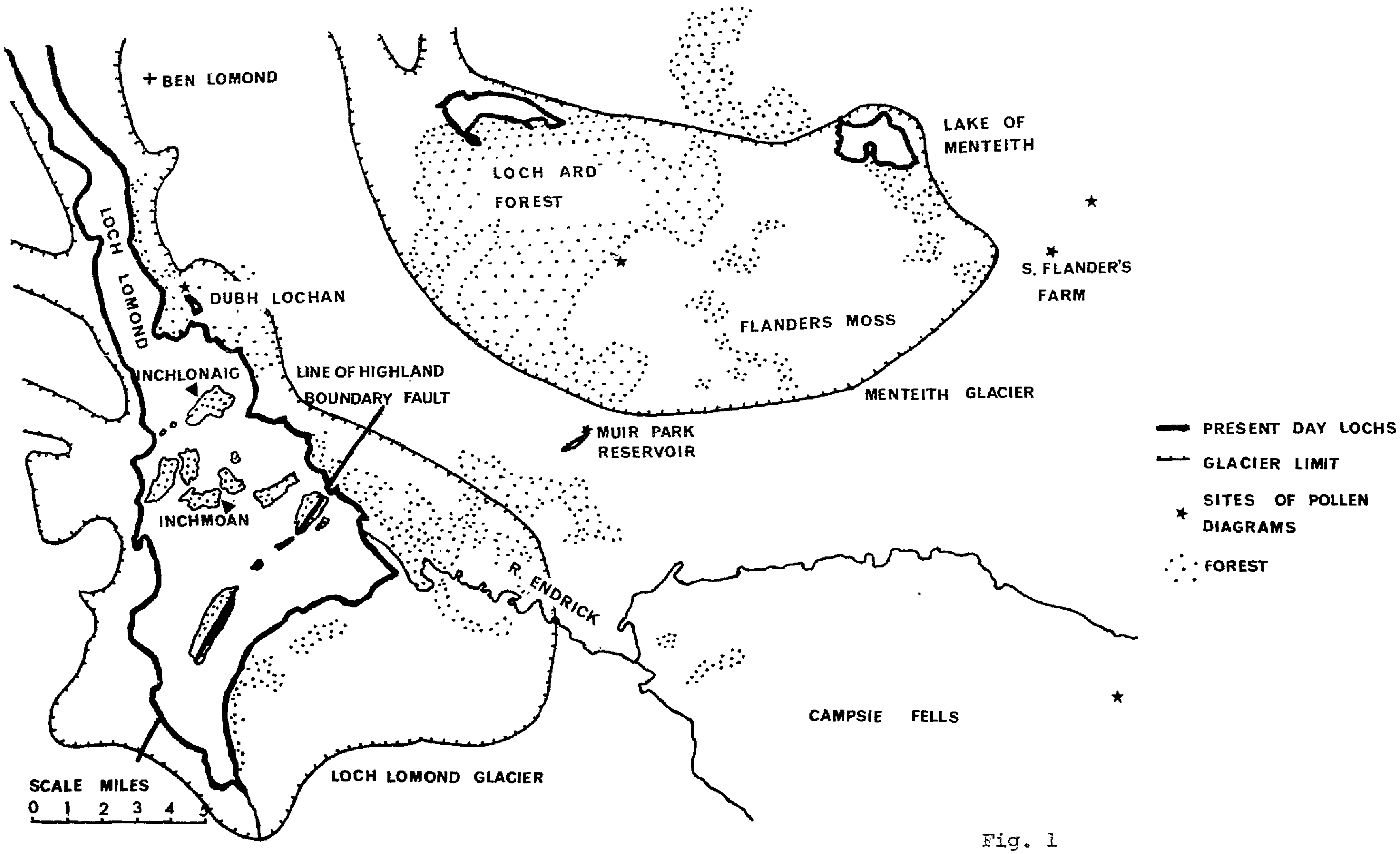


Fig. 1

INTRODUCTION

1. The Scope of the Thesis

Over the past 5,000 years or more man has progressively destroyed the natural vegetation of Britain, and until comparatively recently nothing has been done to try to stop this destruction, and to attempt instead to try to improve the ecological environment, and perhaps make it more productive. The respective roles played by man, animals, climatic and edaphic changes, in the evolution of the present-day ecosystem must be known in order to be able to understand, and perhaps be able to control the ecosystem. In planning for the future the ecologist has to analyse the factors which have influenced the formation of the present environment. A study of changing ecosystems of the past in relation to the above factors can be done by means of pollen analysis. The present study attempts to reconstruct the vegetational history of the past 10,000 years at Dubh Lochan (National Grid Ref. NS 378 965). Dubh Lochan is a small loch close to Loch Lomond (Fig. 1).

In this area the history of vegetation begins with the retreating glaciers at the end of the last glaciation. As the last advance of glacier ice was in the form of valley glaciers there was some vegetation on the surrounding hills. Here the vegetation was a sub-arctic heath, with some *Betula* and *Salix* and with a rich grass and herb element in the flora (Vasari and Vasari, 1968). Radiocarbon dates suggest that the Loch Lomond Re-advance took place during the period 10,800 to 10,300 B.P. (Sissons, 1967). We can therefore presume that the initial colonisation by plants of the area at Dubh Lochan took place later than 10,300 B.P.

The main objective of the thesis is to analyse the appended pollen diagram, and thus give a general picture of the evolution of the vegetation of the area within the Loch Lomond Re-advance. Pollen analysis must take into account the complex relationship between the pollen spectrum and the actual vegetation present. This depends on many inter-related and variable factors, e.g.

(1) The relative amount of pollen produced by different plants. This has been studied in some detail for many of the forest trees, and can be compensated for to some degree.

(2) The position occupied by some plants in relation to others can have a marked effect on their pollen production. Corylus and Juniperus, which produce much pollen when they are dominant members of an ecosystem, produce very little as under-story. Similarly many plants of the forest floor often produce very little pollen.

(3) Another factor which influences the pollen mosaic is the method of dispersal. Pollen found from entomophilous plants is sparse and is normally presumed to be local in origin.

(4) Preservation of some pollen - e.g. Taxus - is very poor, but under what conditions, exactly, preservation may be a limiting factor has been little studied, and this is a factor for which it is very difficult to make allowances.

Pollen transfer has been studied mathematically in relation to various meteorological conditions by Tauber (1965). Pollen deposition is considered to consist of at least three components:

(a) Pollen derived from the trunk space among the trees.

(b) Pollen derived from above the canopy.

(c) Pollen derived from wash-out by rain, which tends to have a more regional derivation.

In the choice of a suitable site - which is discussed later - one must consider whether one wishes a regional or local pollen diagram.

Large differences in the extent of the area represented by a diagram must be expected between basins of different size. Local climate, including rainfall and average wind speed and direction must always be factors to be considered.

Thus the problem of inferring what the composition of a past vegetation may have been is very complex. A study of the present-day pollen production in relation to different types of modern vegetation patterns gives much useful information. This is perhaps the most useful tool in evaluating and reconstructing past ecosystems.

A study of the stratigraphy with its associated macrofossils helps to separate out a local element in the flora, and it is hoped that the analysis will succeed in giving at the same time a history of the development of the ecosystem at the sampling site, and a history of the vegetation of the region.

2. Review of some relevant literature on Scottish pollen diagrams

The work most closely associated with the present study is that done at a site near Drymen (Donner, 1957; Vasari and Vasari, 1968), which is outside the end-moraines of the Loch Lomond glaciation (Fig. 1).

Donner studied, by means of pollen analysis, several sites near terminal moraine lines, in order to elucidate the age of the moraines as a means of interpreting late-glacial retreat stages in Scotland. His site, at Muir Park Reservoir, was later studied in greater detail by Vasari and Vasari as part of an enquiry into late- and post-glacial vegetation in Scotland. At Muir Park Reservoir, which is outside the Loch Lomond moraine line, Godwin zones I, II and III are present, whereas at Dubh Lochan the vegetational history begins after the final retreat of the Loch Lomond glacier, at the end of zone III. Donner also studied a site at Gartmore - a site only 5 miles from Drymen, but inside the terminal moraines of the Menteith Glacier (Fig. 1). Here as at Dubh Lochan the polleniferous deposits begin at Godwin zone IV. The Loch Lomond terminal moraine complex has been radiocarbon dated (Sissons, 1967; Vasari, personal communication). Sissons' dates imply that the Loch Lomond Re-advance took place in zone III (10,800 - 10,300 B.P.) which confirms Donner's interpretation which was based on pollen analytical work. Vasari dates the beginning of the Flandrian at Drymen at 10,010 ± 230 B.P. and it is at about this date that, by inference, the polleniferous deposits began to accumulate at Dubh Lochan.

The study of a number of sites in N.E. Scotland (Durno, 1957, 1958, 1959), one in N.W. Scotland (Durno and McVean, 1959) and others in lowland Scotland (Durno, 1956; Mackie, 1961), by Durno, has contributed much to give a general picture of the evolution of Scottish vegetation in relation to changing climatic conditions, and to the part played by man in disturbing this natural vegetation. His site at Flander's Moss (Durno, 1956) is of considerable interest, being only 16 miles from Loch Lomond. The pollen diagram from a nearby site by Turner (1965) is of interest also in terms of recent forest history in relation to man. Here no forest clearances have been recorded before 200 A.D., though it is thought that small temporary clearances probably took place on the surrounding wooded hills before this date. The clearance at 200 A.D., which was an extensive clearance, was temporary and the present treeless nature of the surrounding landscape is of recent origin. Dr Turner, in the same paper, also studied a site at Bloak Moss in Ayrshire, where small temporary forest clearances were recorded between 1,400 and 1,000 B.C., while extensive forest clearance took place around 500 A.D., after which this area became wooded again.

Three very useful and detailed diagrams of areas of very different vegetation today, are those by H.H. Birks (Birks, H.H., 1970, 1972a, 1972b). At two of her sites - Loch Maree and Abernethy Forest - there are still remnants of natural forest. The oak woods at Loch Maree having been little disturbed by man until recent times give a very interesting comparison with those at Dubh Lochan where man has been active since Neolithic times.

A very comprehensive study of lake sediments in N.W. Scotland, complementing a similar study of lakes in the Lake District, has been done by Pennington et al., 1972. The main object of this study is to relate changes in lake sediments to changes in the surrounding vegetation and to changes in edaphic conditions. From chemical evidence the inference is that by 3,000 B.C. blanket peat must have begun to form, owing to increasing oceanicity of the climate.

The book by H.J.B. Birks on the vegetation and the vegetational history of the Isle of Skye (Birks, H.J.B., 1973) contains a number of diagrams of late-glacial deposits and compares them with present vegetation in Skye. It also contains keys for the identification of pollen grains of the more critical genera.

3. Forest History in Scotland

Outside the part of Scotland covered by ice during Late-Devensian times, the lowest pollen assemblages reflect a landscape covered by a treeless, species-rich grassland of which Rumex acetosa was a characteristic herb. Absolute pollen counts in this assemblage zone appear to be low, and although there is some tree pollen it probably represents long distance transport. The low pollen count suggests incomplete vegetation cover, the sediments containing much silt and fine sand during this episode.

In highland western Britain a major climatic amelioration began nearly 1,000 years before Allerød time (Kirk and Godwin, 1963; Coope and Brophy, 1972; Pennington, 1970 and Pennington et al., 1972; Vasari, personal communication). Empetrum heath with, in places, Juniperus, became an important element in the vegetation. The landscape was probably devoid of trees. In more lowland Scotland, Betula with Betula nana and Salix with Salix herbacea were present. Empetrum heath, which was probably present during the previous pre-interstadial period, remained an important element in the vegetation. Juniperus became important during this period, indicating an open vegetation and rather warmer conditions. Grass and sedge pollen counts which were important during the preceding zone remained high. At 12,060 ± 320 B.P. (Vasari, personal communication) there was a return to colder conditions, coinciding with the last advance of glacier ice. There was a decrease in Betula, Juniperus and Empetrum in lowland Scotland, with a return to a herb-rich grassland with Rumex acetosa again being a characteristic species (Vasari and Vasari, 1969), and with Artemisia being an important member of the flora in north-west Scotland (Pennington et al., 1972).

At about 10,000 B.P. the beginning of Flandrian history began. There was initially a transition zone, where a repetition of the vegetational sequence which marked the beginning of the previous interstadial, took place. This appears to have happened quite rapidly, suggesting a sudden rise in temperature. This was followed by a rapid spread of Betula which took place around 8,900 B.P. in some parts of Scotland (Pennington et al., 1972). While in Skye this rapid spread began around 9,655 B.P. or even earlier. A Betula/Corylus period followed, and this appears to have covered much of Scotland until around 7,900 B.P. (Pennington et al., 1972).


B
SCOTTISH
WOODLANDS
RECONSTRUCTED DISTRIBUTION
OF OAK, PINE AND
BIRCHWOOD DURING
THE PRESENT CLIMATIC PERIOD
SCALE
Miles
KEY

Fig. 2

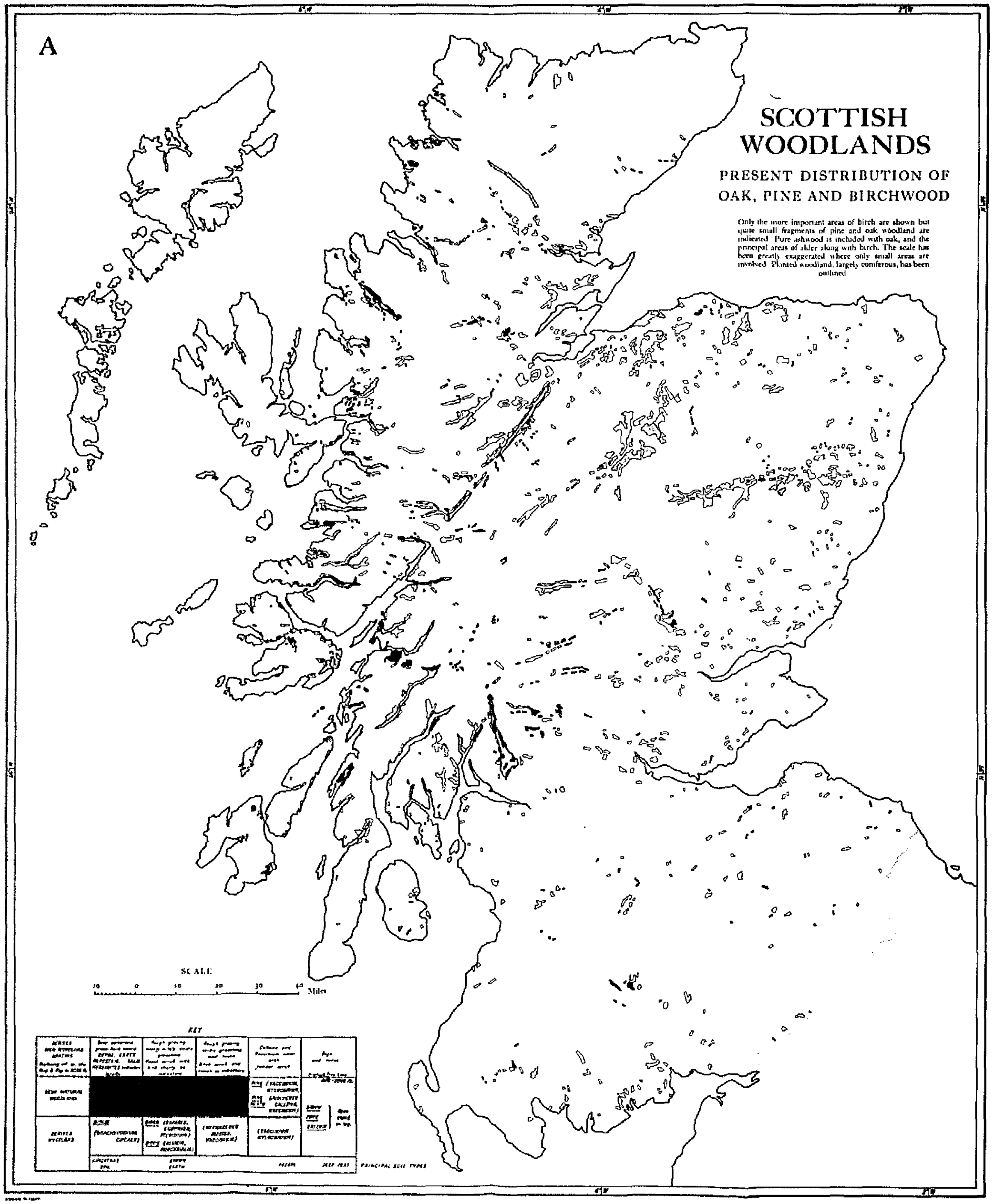

A
SCOTTISH
WOODLANDS
PRESENT DISTRIBUTION OF
OAK, PINE AND BIRCHWOOD
Only the more important areas of birch are shown but quite small fragments of pine and oak woodland are indicated. Pure ashwood is included with oak, and the principal areas of alder along with birch. The scale has been greatly exaggerated where only small areas are involved. Planted woodland, largely coniferous, has been outlined
SCALE
Miles
KEY

Fig. 2

On the Western Isles this Betula/Corylus forest has remained the only important woodland type until the present day. There are today fragments of Betula and Corylus woodlands in Skye. These are usually protected to some degree from grazing animals, or on slopes which are well drained (H.J.B. Birks, 1973). After the Betula/Corylus period, Pinus with Betula and Corylus grew on well-drained soils in highland Scotland, while mixed-oak forest spread over much of the southern part of Scotland and the rich valleys and coastal areas of highland Scotland.

According to Tallantire (1974) the general colonisation of Alnus glutinosa in England and Wales began around 5,000 B.C. It is thought that this spread took place from earlier local colonies established around 6,000 B.C. The expansion took place rather later - at around 4,500 B.C. - in north-western Scotland, probably because of lack of local colonies at the time of the climatic amelioration at 5,000 B.C. It has been associated with increasing rainfall (Pennington et al., 1972). An increase in the oceanicity of the climate led to the formation of blanket peat from around 5,000 B.P. From this time on peat spread over much of Scotland with a progressive decrease in forest.

A reconstructed map of forest types (McVean & Ratcliffe, 1962) shows the hypothetical distribution - using all the available evidence - prior to the destruction of forest by man. From this it is seen that Scotland was largely covered by forest (Fig. 2a and Fig. 2b).

At about this time Neolithic man began to be active in forest clearance. The Elm Decline can be traced in some areas of Scotland, and is largely associated with Neolithic man. Progressive forest clearance has led to the destruction of most of Scotland's natural forest cover, and the introduction of the black-faced sheep, with lack of adequate fencing against the sheep and other grazing animals, together with the management policy towards grouse moors, has led to an almost complete change in the nature of the Scottish landscape. Today only very isolated areas of Scotland have remnants of natural vegetation.

4. Features of the area

(a) Topography

The Highland Boundary Fault crosses Loch Lomond in a northeast-southwest direction (Fig. 2). The area to the north of this is of truly highland topography. The underlying rocks are mainly schists and schistose grits with a belt of slate. The sampling site is on an area of schistose grit, and the local soil is thought to be pervious glacial drift (Tittensor and Steele, 1970). Ben Lomond, which is about 3 miles north of the site, is of mica-schist, with some base-rich outcrops near the summit, which have a correspondingly richer flora than the rest of the area. To the south of the Highland Boundary Fault the landform is more gently undulating, and is underlain by Old Red Sandstone. Much is at present under cultivation.

(b) Climate

The climate in the Loch Lomond area is mild and oceanic. Rainfall during the years 1972 and 1973 at Arrochymore, a weather station close to the sampling site, was 50" and 55" respectively (Metform 3211). The air temperature between summer and winter does not show a large variation. The coldest months are January and February with an average temperature of about 4°C while the temperature in July and August is about 14°C. Precipitation is mostly as rain. There are very few days when snow falls, though as altitude increases there are more days of snow fall. Even on the hills snow rarely lies for longer than a few days at a time. There is rather more rain in winter than in summer, though rain falls all the year. The relative humidity is generally high (> 60%) throughout the year. The average annual number of rain-days (i.e. a day with at least 0.01" of rain) is about 258. Prevailing wind directions are largely from the South-west and West and the average wind speed is about 25 miles per hour; this measurement comes from the nearest station recording wind speed which is some distance away, at Abbotsinch (Climatological Atlas, 1952).

(c) History

The Loch Lomond area is renowned as one of exceptional beauty and the oak woods which flank the hills are a remnant of a once very wide-spread natural mixed oak forest, the composition of which is of great interest to the ecologist. The present day composition of the Loch Lomond oakwoods is well documented (Tittensor and Steele, 1970). Much is also known about the recent history of these woodlands, which have been managed as coppice with standards since the 17th century until fairly recently. What the components of the original natural forest were has long interested ecologists, because oak forest once covered very extensive areas of Scotland. The map showing reconstructed distribution of oak, pine and birchwood during the present climatic period (McVean and Ratcliffe, 1962) shows that oak forest probably covered most of the land south of the Highland Boundary Fault, also the more fertile valleys of the north and west. These natural mixed oak forests must have persisted for several thousand years, from the time when the climate became warm enough some time after the retreat of the ice at the end of the Devensian period until well after the advent of man in this area.

Mesolithic man was present in very small numbers in Scotland, and being a hunter-fisherman may well have made little permanent impact on the forest cover. Stone implements found around Loch Lomond are probably late Mesolithic and date from around 5,000 B.C. During the second half of the 4th millenium B.C. the first groups of Neolithic men with their knowledge of cereal cultivation and animal husbandry began to arrive in Scotland. At this period man first began to make permanent alterations to his environment. Stone axes of this period have been found near Cardross and Gartocharn.

During the Bronze Age there was presumably continued activity in forest clearance. Axes of Bronze Age have been found locally. Bronze Age peoples are thought to have relied a lot on stock-raising, and probably tilled the land with light ploughs. Iron Age hill forts and crannogs are found in the Loch Lomond area. Some of the Iron Age defensive sites are quite large, indicating the presence of man in this area in considerable numbers, associated presumably with continued active forest clearance (Morrison, 1974).

By the 12th century the system of "in-field" and "out-field" had been established, and there were villages at Luss, Bonhill and Aber, so by this time considerable deforestation must have taken place. Chronicles of a Norse raid in 1263 mention the populous islands of Loch Lomond and the mansions on the shore (Idle, 1974).

Shipbuilding at Dumbarton began around 1430 and by the end of the 15th century oak wood from the Loch Lomond woods was being used for this purpose. Iron smelting began in the 17th century - timber being used in the preparation of charcoal. Several sites called "Bloomeries" where smelting took place can still be seen within the oak woods. The second part of the 17th century saw an increase in the use of oak bark for tanning leather, and in fact a factory producing pyroligneous acid was situated at Balmaha until around 1922.

Black-faced sheep were introduced soon after 1745 and by the end of the century were very numerous. Goats, which are still present in small

Photograph 1

View of Loch Lomond with Ben Lomond in the background. This was taken from Inchmoan with Inchlonaig in the foreground. Note that the rounded, dark trees on the island are Taxus baccata. It can be seen that the only trees form a narrow belt round the edge of the loch, and while some of this woodland is planted much is a remnant of semi-natural woodland with oak still being an important member of the flora. On the flanks of the hills can be seen areas of young planted forest - this can be more clearly seen in Photograph 2.

Photograph 2

Dubh Lochan, with the sampling site at the farthest point on the picture.

numbers on the hills are descendants of a more numerous stock which were present long before the introduction of sheep. Roe deer, red deer and fallow deer are all present, fallow deer having been introduced by man in Roman times to Britain. As the forests were not fenced until very recently the effect of this heavy grazing must have been to prevent to a very large extent the natural regeneration of forest trees.

(d) Local vegetation

This area, which was once the land of natural forest, is now forested, as is shown in photographs 1 and 2, only on the islands of the loch, round the fringe of the loch and on the foothills. This semi-natural deciduous woodland is today largely composed of Quercus petraea. There are relatively few pure individuals of this species, and hybrids with Quercus robur, which was introduced, are more commonly found (Tittensor, 1969). With Quercus, Betula pubescens, Sorbus aucuparia and Ilex aquifolium form an open woodland with Alnus glutinosa growing where the water content of the soil is high. Where woodland has been felled Pteridium aquilinum has become dominant. There is Myrica gale in wet areas and Molinia caerulea is locally important.

There are several large conifer plantations and the trees most commonly planted today are Picea abies and P. sitchensis and both Larix decidua and L. liptolysis. Pinus sylvestris and P. contorta have also been planted locally.

Above the forest is wet moorland, with Calluna vulgaris, Myrica gale and Molinia caerulea - Calluna replacing Pteridium aquilinum as altitude increases. Above this there is a Molinia - Anthoxanthum - Agrostis zone, and as altitude increases there is in places a zone of blanket bog dominated by Sphagnum section Palustria and Eriophorum vaginatum. On the more exposed summits there is Rhacomitrium heath

Photograph 3

This is a view of the sampling site. Note the fringe of *Carex rostrata* with the open *Betula/Salix/Alnus* scrub behind. It is at the junction between these zones that the core was taken. This photograph gives a rather foreshortened view. The tree fringe is in fact rather more open than would appear on the photograph.

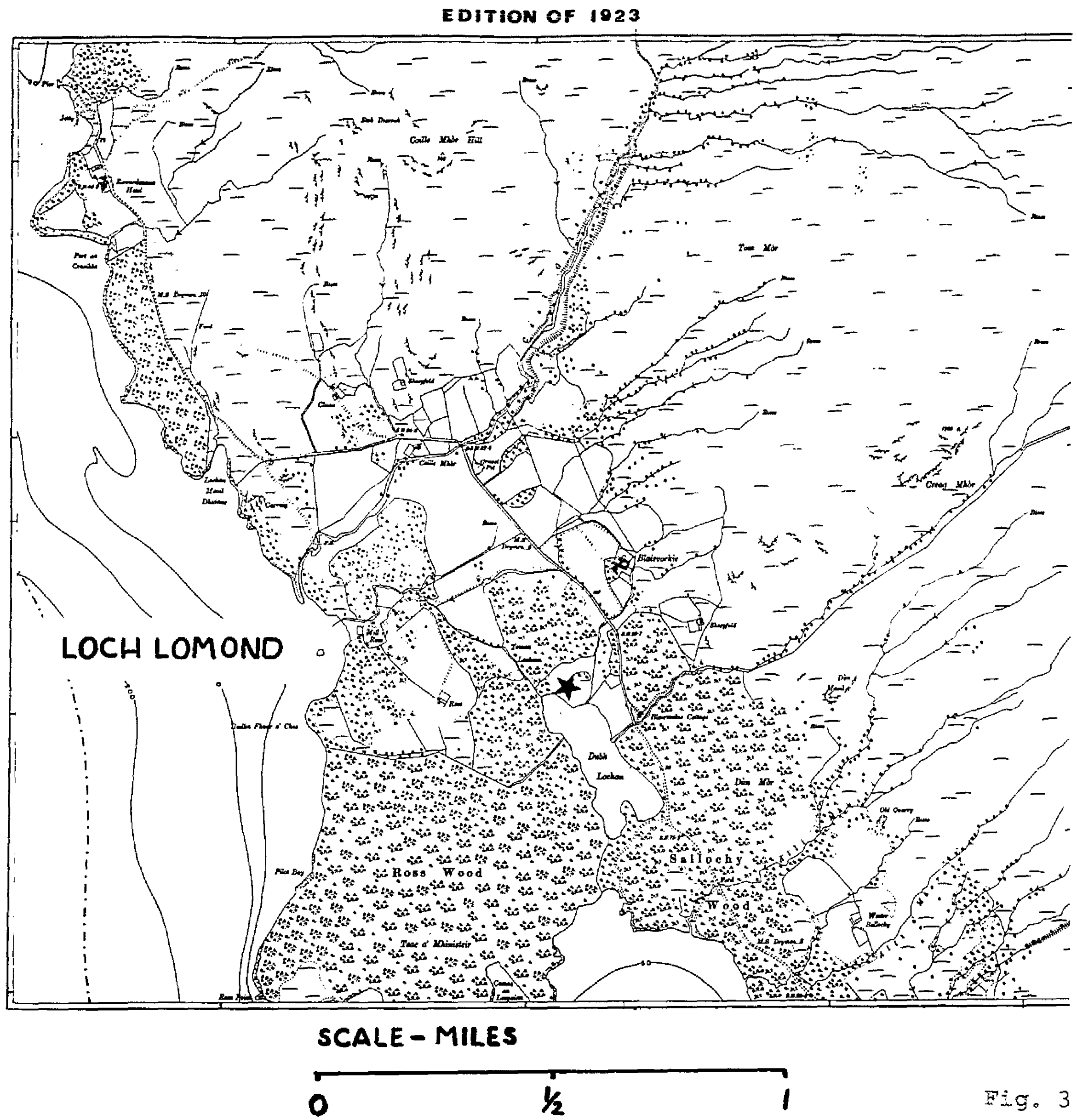

EDITION OF 1923
LOCH LOMOND
Ross Wood
Sallochy
Wood
Blairvockie
Dubh
Lochan
SCALE - MILES
0
½
1

Fig. 3

but this is often replaced by a short turf dominated largely by Nardus stricta and Festuca ovina, with various arctic alpine plants growing in this (Idle, 1974).

In the immediate vicinity of Dubh Lochan there is open woodland, as is shown in photograph 2 and figure 3, with Quercus petraea hybrids, Betula pubescens, Sorbus aucuparia, Larix decidua, Fagus sylvatica, Fraxinus excelsior, Populus tremula (growing sparsely at the edge of the lochan), Ilex aquifolium, Hedera helix, Rhododendron ponticum and Lonicera periclymenum. The ground flora is composed of Pteridium aquilinum, Vaccinium myrtillus, Deschampsia flexuosa, Anthoxanthum odoratum, Dryopteris spp and Blechnum spicant, and the most conspicuous herbs are Potentilla erecta, Melampyrum pratense and Oxalis acetosella.

In the fen area, round the sampling site (Photograph 3) there are Salix cinerea ssp. atrocinerea, Salix aurita, Alnus glutinosa, Betula pubescens, Myrica gale, Erica tetralix, Molinia caerulea, Galium palustre, Ranunculus flammula, Viola palustre and Juncus acutiflorus. There is much Sphagnum section Palustria with some Sphagnum imbricatum right at the actual site.

In the lochan nearby are growing Phragmites communis, Carex rostrata, Equisetum fluviatile, Nuphar lutea, Nymphea alba and Hippuris vulgaris, while Juncus bulbosus, Sphagnum section Palustria, Myriophyllum alterniflorum, Lobelia dortmanna, Fontinalis antipyretica, Littorella uniflora and Isoetes lacustris are growing in other parts of the lochan.

MATERIALS AND METHODS

Preliminary investigation of sediment depth and character to determine the best site for sampling was carried out using a small Hiller-type peat borer. When the most suitable site was selected sampling was done using a Thomas Farnell modification of a Hiller sampler. The cores were examined briefly in the field to note colour and any other obvious features. A more detailed study of the sediment lithology was carried out in the laboratory. Samples were double-wrapped in polythene, sealed and labelled for transport back to the laboratory where cores were stored in a cold room at 2°C. Cores were examined stratigraphically in the laboratory. After samples were taken for pollen analysis the rest of the core was examined for macrofossils - the pollen washings also being examined. The Troëls-Smith classification and nomenclature was used to describe the properties of the samples (Troëls-Smith, 1955). Samples were initially taken at 20 centimetre intervals - later others were taken at closer intervals where there were changes either in lithology or the pollen spectrum. The preparation of samples follows the method outlined by Birks (H.J.B. Birks, 1972). A smear of the sediment was always examined before each extraction was carried out and the preparation was modified as a result of this. Early Flandrian samples, for example, required to be boiled for one hour in 40% hydrofluoric acid because of the very high inorganic content. An examination of samples for diatoms and other siliceous organisms was done on the smear and small amounts of the sediments were kept aside for further investigation for these.

Slides were mounted in glycerine jelly and stained with safranin, as was the reference collection.

Counting was carried out using a Vickers Patholux microscope at a magnification of x 800. This is a higher magnification than is normally used in routine counting and counting is thus slower, but was preferred. For unknown pollen or difficult genera an oil immersion objective was used. A micrometer scale was routinely used. Counts are normally over 500, as whole slides were counted to eliminate possible errors due to non-random distribution on the slides.

All pollen samples were prepared from a uniform weight of material. It was hoped thus to give some very crude idea of relative pollen amounts at different levels. This, however, presumes a constant sedimentation rate, which we cannot necessarily presume, although from work carried out by various people it has been found that, in any one lake, the sedimentation rate is surprisingly constant (Birks, H.H., 1972; Pennington et al., 1972; Davies, 1967). Where the lake becomes overgrown and forms a hydrosere the rate changes little. The rate of accumulation of a hydrosere has been found to have a modal rate of 21.60 centimetres/1,000 years (which compares with a sedimentation rate of 40 centimetres/1,000 years at Loch Maree (Birks, H.H., 1972)). It has been found that this rate does not change significantly with changes in the hydroseral succession (Walker, 1970).

CHOICE OF A SITE

There are various factors one must consider when looking for a suitable site. The best conditions cannot always be found, but the following considerations were borne in mind when the choice was made.

(1) A lake deposit is preferable to a peat deposit.

(2) Too large or too small a lake should be avoided.

(3) A lake surrounded by an extensive bog should be avoided.

(4) Samples should be taken from a protected area, where there is no wind or water action.

(5) Avoid where a stream enters lake, otherwise there is risk of contamination.

(Faegri and Iversen, 1964)

There are various other factors to be considered, viz:

(a) Information required: The consideration as to whether one wishes to obtain a regional history, or a detailed study of the development of a localised ecosystem is very important. For a regional picture a sample from the centre of a lake is to be preferred but unfortunately at the time of sampling a suitable sampler for doing this was not available. Subsequently samples have been taken with a Mackereth sampler, but owing to lack of time, these have not been examined. If one chooses, as has been done in this study, a site at the edge of a lake, the recent history is not very reliable, as build-up of deposits must be influenced by periodic fluctuation in water level. Good samples are also difficult to take near the surface because of the presence of intact roots and underground stems. There is a strong local bias in the pollen spectrum, which can to some degree be compensated for by stratigraphic analysis.

(b) State of pollen preservation: Where this is poor, the ratio of pollen types is very difficult to assess owing to differential preservation. It is my experience, for example, that pollen of Betula and Alnus are recognisable even when the general state of preservation is poor.

Various sites were considered. One site on a peat bog on Inchmoan (see Fig. 2) was considered. The present vegetation is largely Calluna and Vaccinium myrtillus, with an open canopy of Alnus and Betula, growing on peat. This site was suitable in many ways and the pollen preservation is good; however, as peat cutting had taken place the top surface could not with certainty be taken to be the real surface.

A site on the island of Inchlonaig (Fig. 1) was also investigated in the hope of elucidating the history of Taxus baccata which, according to legend, was planted in the 14th century by order of King Robert the Bruce to provide long-bows for his archers. Yew is considered to be indigenous to the west of Scotland but there has not, as yet, been palaeontological proof of this (Mitchell, 1974). However, Taxus pollen could not be found in any but samples near the surface. Even in surface samples there was only 19 % Taxus yet the trees were flowering copiously at the time the samples were taken. Taxus pollen appears to have been badly preserved at this site, as of course is common with Taxus.

A site was also considered in an area of fen near the mouth of the River Endrick (Fig. 1). This site proved unsuitable. The pollen was poorly preserved, and sampling was difficult because of the gravelly nature of the deposits. There appeared to be much water movement with probable reworking of the sediments. Ring bog, as this area is called, was a wet meadow possibly a hundred years ago (Mr E.T. Idle, personal communication). The drainage channel subsequently silted up, causing the present nature of the surface deposits.

The site finally selected at Dubh Lochan is in an area of fen carr at the north end of the lochan. Several places were investigated and the one finally decided on is in an area of Sphagnum with Myrica and Molinia growing nearby. A few Alnus and Betula trees are growing within 10 metres of the sampling site. Phragmites, Carex vesicaria and Equisetum fluviatile are growing in the lochan close by. The site is far enough from the stream which drains the lochan so that the sediments are not disturbed by excessive water movement.

RESULTS

1. The Pollen Diagram

The enclosed diagram was constructed using as a pollen sum the total pollen and spores of terrestrial plants, designated henceforth $\Sigma P+S$. From this *Sphagnum* was excluded. The production of spores in *Sphagnum* species is so variable its inclusion in the total percentage calculation was thought not to be justifiable. The variability of *Sphagnum* in surface samples taken from *Sphagnum* peat has been found to be considerable. In two samples taken quite close to the sampling site - both from among *Sphagnum* - the percentages were 0.1% and 28% $\Sigma P+S$. This has been investigated also by Heim, (1970).

The diagrams have been divided into local pollen assemblage zones - this term being used as defined by Birks (H.J.B. Birks, 1973). Similarities between these local zones and zones on other pollen diagrams from the west of Scotland have been noted, and tentative regional pollen assemblage zones have been suggested.

The local assemblage zones are designated with the initials of Dubh Lochan, and they are numbered consecutively from the bottom. They are named from one or more taxa particularly prominent or diagnostic of the assemblage.

2. Pollen Determination and Nomenclature

(a) General

Various keys etc. were used including the following:-

Andrew, 1970
Erdtman, ~~Berglund and~~ Praglowski, 1961
Erdtman, Praglowski and Nilsson, 1963
Sorsa, 1964
Reitsma, 1966
Birks, 1973

Nomenclature and conventions are after Birks. Constant use has been made of the type collection in the Botany Department, University of Glasgow.

(b) Determination of Myrica

In the samples prepared from this site at Dubh Lochan the pollen preservation is mostly good and in most cases I felt it was appropriate to separate Myrica from Corylus. There were, however, some pollen grains which I felt were borderline cases and these I have called Coryloid.

The principal diagnostic features of Myrica are the larger, wider pore with a more sloping edge to the shoulder, and there is often a rough area just below the pore, which takes rather a darker stain. On the whole Myrica tends to stain more darkly than Corylus. The slope of the pore in Corylus is rather more v-shaped in optical section, while that of Myrica is u-shaped (Andrew - personal communication).

3. Divisions of the diagram

Zone DL - 1 (596-575 cm)

Betula - Empetrum - herb zone

This zone is characterised by very high pollen values for Betula and Empetrum. Betula includes fairly large proportions of Betula nana. Juniperus and Salix (including Salix herbacea) pollen is also important. Gramineae and Cyperaceae values are high, and spores of Filicales including Dryopteris filix-mas type are prominent. The upper boundary of this zone is where Empetrum and Juniperus pollen falls to negligible amounts. This zone has been sub-divided.

Zone DL - 1a (596-590 cm)

Artemisia - Rumex - Lycopodium sub-zone a

In this sub-zone Gramineae and Cyperaceae pollen is higher than in the upper part of the zone and pollen of *Artemisia*, *Rumex* and *Lycopodium* spp. is significant.

Zone DL - 1b (590-575 cm)

Betula - Empetrum sub-zone b

Empetrum and Juniperus values are high then begin to fall and herb values are also falling. Corylus values begin to rise.

Zone DL - 2 (575-520 cm)

Betula - Corylus zone

This zone begins with a very rapid rise in the *Corylus* curve. *Betula* values are very high and *Quercus*, *Ulmus* and *Alnus* are minor components in the pollen spectrum.

Total arboreal pollen has increased by the beginning of this zone to 80% ΣP+S and continues to increase to over 90%, at which value it remains during the rest of this zone.

The lower boundary of this zone is where *Corylus* begins its rapid rise. The upper boundary of this zone is where *Corylus* falls to 20% and *Pinus* and *Quercus* begin to rise.

Zone DL - 3 (520-500 cm)

Betula - Pinus - Corylus zone

Pinus pollen reaches its highest level of >20% total arboreal pollen in this zone. *Quercus* values are rising and *Alnus* remains at between 5 - 10% total arboreal pollen. Total tree pollen remains very high at over 90% ΣP+S. The lower boundary of this zone is where *Pinus* pollen values reach 5% and continue to rise. The upper boundary is where *Pinus* values have just begun to fall after reaching their maximum value, but the most significant change influencing the position of this boundary is the very sharp rise in the curve for *Alnus*.

Zone DL - 4 (500-285 cm)

Quercus - Alnus zone

This zone is again typified by very high tree pollen counts. The Alnus curve which rises very steeply remains high at about 40% total arboreal pollen. Quercus values continue to rise and remain about 30% total arboreal pollen during this zone. Pinus and Betula values are falling and Pinus falls to below 10% total arboreal pollen and Betula to about 20% total arboreal pollen. A feature of this zone is the very high, but fluctuating values of Isoetes microspores.

The lower boundary of this zone is where Alnus pollen values begin to rise very quickly. The upper boundary of this zone is where the Ulmus pollen frequency falls to practically nothing.

Zone DL - 5 (285-155 cm)

Salix - Betula zone

This assemblage zone is defined by very high values for Salix pollen. There is also an increase in Betula pollen at the expense of Quercus, Alnus and Corylus. Pteridium and Sphagnum spores increase and are present continuously from this zone onwards. Plantago lanceolata pollen occurs in small but continuous amounts and Rumex acetosa and Rumex acetosella pollen types are found sporadically during this zone. The lower boundary of this zone is delimited by the big increase in Salix pollen. The upper boundary of this zone is where there is a decrease in Salix pollen to under 4% total pollen.

Zone DL - 6 (155-0 cm)

Myrica - Calluna - Sphagnum zone

This zone is typified by very high values for Myrica pollen. There is an increase in the pollen values of Calluna and Gramineae during this zone, and Sphagnum spores increase.

The lower boundary is where there is a sharp rise in the curves for Myrica and Calluna. The upper boundary is the present day surface.

4. Statistical Analysis of the Results

A statistical analysis of the results was carried out by Miss Brenda Miller of the Statistics Department, University of Glasgow. This was done after zones had been determined by inspection. Various methods have been used for this type of analysis, including chi-squared tests on adjacent levels (Kershaw, 1970). There is often a sharp transition between zones, where the chi-squared statistic will be large, but there can be smaller and more continuous changes which are difficult to find using the chi-squared statistic. Also more of the data than just boundaries must be taken into account, as zones must be moderately homogeneous.

Three methods of analysis using agglomerative techniques were used, and two using divisive procedures. In the agglomerative methods the most similar levels were grouped together and both first and second dissimilarity coefficients were used (DC1 and DC2). In method 1 pairs of levels with the smallest DC's were grouped, but only if the stratigraphic order was retained. In method 2 there was no stratigraphic constraint. This method gave reasonable results when using DC1, but not using DC2, as stratigraphic order was rather confused. Method 3 was a combination of methods 1 and 2 with stratigraphic constraint. A program called CONSLINK was used for this. This method has been found to give good results in zoning pollen diagrams (Gordon and Birks, 1972). The results obtained were very similar to those obtained by method 1 using DC1.

In the divisive procedures the computer is programmed to compare variance between successive levels. The two methods used are similar

	Sample 1		Sample 2	
	Vegetation	Pollen	Vegetation	Pollen
Betula		7	+	37
Pinus		< 1		1
Quercus		2		2
Alnus		1		1
Salix		< 1		< 1
Myrica	+	65		19
Gramineae	+ (*Phragmites*)	2	+ (*Phragmites* and *Molinia*)	2
Cyperaceae	+	1	+	3
Calluna		< 1		2
Herbs	+	1	+	1
Sphagnum	+	1	+	21

Table 1. This table gives percentages of total pollen plus spores in surface samples of *Sphagnum* taken from within 1 metre quadrats immediately adjacent to the sampling site. The vegetation present in the quadrats is also noted. *Betula, Salix, Alnus, Ilex, Dryopteris felix-mas, Dryopteris dilitata, Thelypteris limbosperma, Blechnum spicant* and *Phalaris arundinaceae* are growing within 10 metres of the site.

but use a different definition of divergence. Divisions become apparent where variance is large. These programmes are called SPLITLSQ and SPLITINF. These gave similar results with the present data.

Considering all the methods of analysing the data the most important divisions are as follows:-

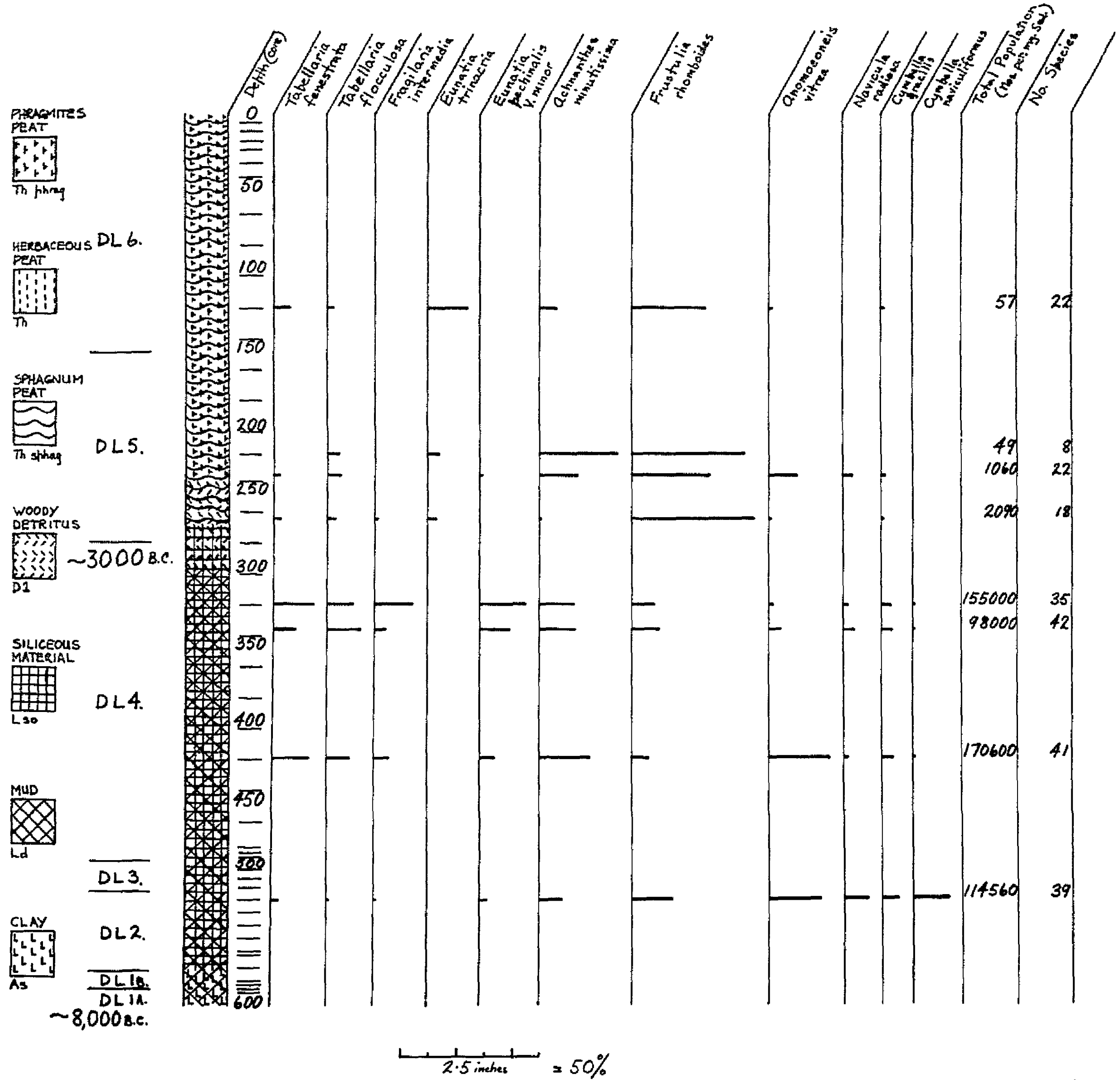
Level (by statistical analysis)	Level (by observation)	Zone boundaries
145 - 165 cm	155 cm	DL-6/DL-5
(265 - 285 cm or (285 - 305 cm	285 cm	DL-5/DL-4
495 - 503 cm	500 cm	DL-4/DL-3
515 - 525 cm	520 cm	DL-3/DL-2
575 cm	575 cm	DL-2/DL-1c
590 - 591 cm	590 cm	DL-1b/DL-1a

Level DL-1c stands on its own in the statistical analysis but as a zone of only one level is meaningless in ecological terms, it has been described along with zone DL-1b.

Level 85 cm stands on its own also. This has not been considered a valid disjunction, as _Myrica_, which has a very large peak at this level, was growing on the site, and surface samples taken around the site amongst _Myrica_ show just as large variations of _Myrica_ pollen (Table 1).

5. _Macro-fossil Diagram_ (see enclosure)

This diagram is constructed using a six point scale, as shown on the diagram. Mosses are represented as leaves or leafy stems. There is a very strong hydroseral component in the plants, with such plants as _Nymphaea alba_, _Nuphar_, _Potamogeton_, _Isoetes lacustris_, _Menyanthes_, _Nitella_, _Chara_ and _Sphagnum_. There is much submerged _Sphagnum_ growing in the loch today so it is presumed that much of that shown in the diagram is this type - mainly _Sphagnum_ section _Palustria_.



Depth (cm)
Tabellaria fenestrata
Tabellaria flocculosa
Fragilaria intermedia
Eunotia trinacria
Eunotia pectinalis v. minor
Achnanthes minutissima
Frustulia rhomboides
Anomoeoneis vitrea
Navicula radiosa
Cymbella gracilis
Cymbella naviculiformis
Total Population (per mg. Sed.)
No. Species
PHRAGMITES PEAT
Th phrag
HERBACEOUS PEAT
Th
SPHAGNUM PEAT
Th sphag
WOODY DETRITUS
Dl
SILICEOUS MATERIAL
Lso
MUD
Ld
CLAY
As
DL 6.
DL 5.
~3000 B.C.
DL 4.
DL 3.
DL 2.
DL 1B.
DL 1A.
~8,000 B.C.
0
50
100
150
200
250
300
350
400
450
500
600
57
22
49
8
1060
22
2090
18
155000
35
98000
42
170600
41
114560
39
2·5 inches = 50%

Fig. 4

Identification and Nomenclature

Use was made of a seed and fruit reference collection. Information about these was obtained from the following:-

Aalto, 1970

Dickson, 1970

Katz, Katz and Kipiani, 1965

Godwin, 1956

Nomenclature of mosses is after Dickson, 1973. Nomenclature of vascular plants is after Clapham, Tutin and Warburg, 1962.

6. Diatoms

An investigation into the diatoms from a lake core at Dubh Lochan is under way, but as a preliminary investigation Dr Roger Tippett examined a few samples from the present core. Percentages of the principal species are shown in Fig. 4.

It can be seen that in the lacustrine part of the core there was a diverse flora, although it is of note that a few species were associated with the hydroseral portion of the core, suggesting that the vegetation in the hydrosere was saturated with water. Those few species, however, represent an impoverished flora. Eunotia trinacria, Frustulia rhomboides, Achnanthes minutimina, which are attached forms were present, as were Tabellaria fenestrata and Fragilaria intermedia, the last two species often being planktonic. Tabellaria flocculosa, which can also be planktonic, but which is mainly found in association with rooted vegetation, was also present. Thirteen species of Eunotia were present. This is a genus characteristic of waters poor in minerals and most of these are found in the lacustrine sediment, although E. trinacria is characteristic of the hydrosere. Eunotia robusta v. tetraodon is the only member of this genus which was present in both parts of the core. Epithemia argus and Rhopalodia parallela, which are present in small numbers in the lowest sample, are characteristic of more eutrophic waters than the others, while *Cymbella naviculiformis*, which is present in all the lake sediment samples, also occurs in fairly eutrophic waters.

Sponge spicules are found throughout the core and cysts of *Chrysophycaetes* species (e.g. *Dinobryon*) are found in all samples.

DISCUSSION

Zone DL-1; Betula - Empetrum - herb zone

At the base of the core there is fine grey sterile silt with no pollen and no organic content. This fine silt is typical of inwash from unstable soils (Saarnisto - personal communication). This would be the situation in the surrounding countryside immediately after the retreat of the Loch Lomond glacier. The fact that no pollen is present suggests very rapid accumulation. Where pollen begins to appear at 596 cm the frequency of arboreal pollen, which is relatively high, is probably a reflection of mainly distance transport. From the pollen diagram at Muir Park Reservoir, Drymen (Vasari and Vasari, 1968) it would appear that Betula was present during late glacial times, but only probably very locally in sheltered situations. The true birch period begins there later than 10,000 B.P. (Vasari, personal communication) Betula may have survived in suitable refuges quite close to the end of the glacier. This can be seen today in areas like Alaska whose climate is probably rather similar today to the climate in Scotland about 10,000 years ago. From these sheltered refuges Betula could spread quickly into the area when the ice retreated.

The amount of pollen in the lowest samples is small. The ground cover would initially be incomplete, so that pollen productivity per unit area would be low, and with incomplete ground cover the rapid sedimentation from the immature soils would continue, however at a progressively slower rate as the land gradually stabilised.

The taxa present in this zone are those which flourish on open soils with no shade.

This zone is sub-divided into two sub-zones.

Sub-zone DL-1a; Artemisia - Rumex - Lycopodium sub-zone

Many characteristic late-glacial taxa are present in this zone e.g. Rumex acetosa, Thalictrum, Filipendula ulmaria, Gramineae, Cyperaceae, Salix and Lycopodium spp. Rumex acetosella agg., which is also present, could have been Rumex tenuifolius, a tetraploid form of Rumex acetosella. From its present distribution and from the fact that Rumex tenuifolius has been found by Vasari to be present as a late-glacial species at Drymen, being distinguished not by its pollen from Rumex acetosella s. str. but by its rather smaller fruits (Löve, 1943). Ecologically these plants have different preferences, Rumex tenuifolius growing rather on poorer more acid soils, while Rumex acetosella s. str. is associated with human interference and forest clearance.

Saxifraga aizoides and Saxifraga stellaris, together with Thalictrum, Selaginella selaginoides and Cyperaceae may originate from open flush communities, of base-rich origin (Cariceto - saxifragetum aizoides, McVean and Ratcliffe, 1962). Saxifraga oppositifolia is an exacting calcicole (McVean and Ratcliffe, 1962). Today there are only a few areas of base-rich outcrops on Ben Lomond and just north of the Highland Boundary Fault on Inchcailloch. Saxifraga aizoides and Saxifraga oppositifolia are still very locally present in the few base-rich outcrops below the summit of Ben Lomond. Other characteristic late-glacial taxa present are Urtica and Rubiaceae (probably Galium).

There is a high fern count which includes a large proportion of Dryopteris felix-mas type. (Following Birks (H.J.B. Birks, 1973), this includes Dryopteris felix-mas, Dryopteris borreri, Dryopteris abbreviata, Dryopteris aemula, Thelypteris robertiana.)

Dryopteris villarii and Thelypteris robertiana are unlikely to have been present, as these grow today on limestone. *Thelypteris limbosperma*, which is today quite a common fern in the area, is a fern of wetter climates, being only found locally in dryer eastern districts. *Dryopteris aemula* is shade loving, so is unlikely to have been found abundantly at this time. *Dryopteris abbreviata*, *Dryopteris borreri* and *Dryopteris felix-mas* are also found in woods and shady places, but are also found today on screes in damp habitats (Clapham, Tutin and Warburg, 1962). Note also the presence of *Dryopteris assimilis*. This is native to Scotland, but is only certainly known from Ben Lawers at present, but probably occurs elsewhere (Clapham, Tutin and Warburg, 1962).

Salix is present in this zone at between 5% and 8% ΣP+S. Owing to the low production and poor dispersal of *Salix* pollen these values probably indicate local occurrence (Heim, 1970). *Salix herbacea* is present but has not been separated quantitatively; its distribution closely coincides with the 23°C maximum summer isotherm.

High values for *Empetrum* in this zone also give an indication of climate. The following table (Brown, 1971) shows the present distribution of *Empetrum* in the British Isles is correlated with:

1. Low July sunshine duration.
2. Low July temperature maxima.
3. High January temperature minima (either actually or effectively by snow cover insolation).
4. Low mean annual temperature fluctuation.

In view of the poor dispersal of *Empetrum* pollen high values indicate local growth (H.J.B. Birks, 1973). *Empetrum* is interpreted at least in part as a result of solifluction in unstable soils.

There is a *Juniperus* peak following the *Empetrum* rise. The increase in *Juniperus* pollen suggests an improvement in climate as the best climatic condition for *Juniperus* is a humid maritime climate (Vaga and Eichwald, 1960). High frequency of *Juniperus* pollen is a common feature of the transition from the herb-dominated late-glacial flora to the open birch forests of the early Flandrian. In severe climatic conditions *Juniperus* is dependent on snow cover as a protection. It is generally under-represented and a true reflection of its pollen is only given in open tree-less situations, under conditions where the vigour of *Juniperus* is not restricted by too severe a climate, and even then the representation may be too low (Vasari and Vasari, 1968). The growth form which gives reasonable pollen counts is the tall form, which only flowers in open conditions (H.J.B. Birks, 1973).

At the onset of this zone the *Betula* pollen count is very high. *Betula* may have been growing on the site. Initially, before the ground stabilised, the total local pollen productivity must have been low. Some of the *Betula* pollen was probably due to distance transport. The apparent decrease, during this zone, in *Betula* pollen is due to the rapid immigration in *Empetrum* then *Juniperus* into the area immediately following *Betula*. Only an absolute count could confirm this, but as *Betula* pollen continues to increase relative to other pollen the inference is that *Betula* continued to spread in the area.

Betula nana pollen is present, but has not been separated quantitatively, though measurement of pore depth to grain size was routinely carried out (H.J.B. Birks, 1968). The lowest samples were boiled for 1 hour in 40% hydrofluoric acid. According to Berglund and Digerfeldt (1970) the mean size of *Betula nana* pollen grains varies with the preparative technique - from 18.4 µ - 22.8 µ. The mean size according to different investigators using similar preparative techniques also varies by as much as 3.1 µ. It would appear thus that *Betula nana* may have been growing locally. *Betula nana* is a species of open situations. It is today associated with two distinct vegetational types:

1. Sub-alpine dwarf shrub type. It is with this type of association that it grows in this country today. The plants associated with it in Scotland are Calluna vulgaris, Empetrum, Salix, Molinia, Vaccinium and Eriophorum (Calluneto-Eriophoretum - McVean and Ratcliffe, 1962).
2. Tundra type. In the tundra type it is associated with arctic-alpine species e.g. Dryas, Armeria, Salix, Kobresia, Bartsia alpina and Saxifraga hirculus, and it is with this type of association that it grows today towards the north of its range. Though the species that were associated with it are Dubh Lochan are not exactly the same as those with which it is associated today, there is more similarity of type than those of the blanket bog type (Hutchinson, 1966).

One pollen grain of Ephedra fragilis type was found in this zone. This adds to the numerous records of this pollen type found in Britain. It is almost certainly due to long distance transport (cf. Maher, 1964). The presence of Picea similarly reflects long distance transport, since Picea has not been native in Britain since the Chelford interstadial. It is unlikely to be contamination since the spruce trees growing locally are immature, and pollen samples were collected in late winter. The spore type labelled Unknown Taxa is possibly Polytrichum commune, which flourishes on wet acid moorland, and may have been present in more exposed areas. It sudden appearance towards the end of this zone could suggest that already soils were becoming leached.

The limited presence of aquatics and algae indicate that there was low lake productivity at this time, perhaps because the water coming from glacier meltwater would be very cold.

Comparative Pollen Zones

A comparison has been made with other dated assemblages zones from the west of Scotland. There is a similar assemblage of plants at the end of zone III and the beginning of zone III/IV at Muir Park Reservoir. This has been dated at 10,010 ± 230 B.P. (Vasari - personal communication). The pollen spectrum found at this site by Donner (1957) is very similar, and as at Dubh Lochan is typified by high values of Betula, Empetrum herbs and Filicales. Juniperus is not present in Donner's diagram, but this is because it was not generally recognised at the time this study was completed. At Gartmore (Donner, 1957), which is only a few miles from Muir Park Reservoir, but is within the limits of the morraine lines for the Menteith glacier (Fig. 1), the diagram begins at Godwin zone IV, with again very similar pollen types to those found at Dubh Lochan. It is also rather similar to the Transition zone between Late Devensian and Flandrian found at Loch Sionascaig and Loch Clair and other lochs in N.W. Scotland where the beginning of the regional zone or chronozone has been radio-carbon dated to 10,300 B.P. (Pennington et al., 1972). In all future references to Loch Sionascaig, Loch Clair or north-west Scotland the reference will be the same.

The Loch Maree zone LME-I presumably also belongs to this same period (H.H. Birks, 1972). In all future references to Loch Maree the reference will be the same.

Comparison with pollen zones in Skye are rather more difficult owing to the small amount of Empetrum at some sites, and the rather extended Juniperus zone. The Lycopodium-Cyperaceae assemblage zone is somewhat similar, although in Skye this is rather an extended zone, extending over 2,500 years from 12,000 B.P. (H.J.B. Birks, 1973). In all future references to Skye the reference will be the same.

Sub-zone DL-1b; Betula - Empetrum Sub-zone

Sub-zone DL-1b; Betula - Empetrum Sub-zone the organic content as estimated by loss on ignition is higher than in zone 1a. These facts suggest that there is increasing plant cover and a corresponding increase in soil stability. The pollen of arboreal species quickly increases during this zone, which in this context indicated the rapid immigration of first Betula and then Corylus into the area.

It is noteworthy that migration of Corylus from northern refugia was thought to be faster than that of Pinus - probably because of less competition. Corylus had arrived at a site in Skye as early as 9482 ± 150 B.P. and at Loch Maree by 8951 ± 120 B.P. A possible refugium from which Corylus migrated to these northern sites has been postulated to the west of the British Isles. Corylus occurs today - albeit as a rare species - right up to the Arctic Circle (Deacon, 1974).

Juniperus pollen values fall because of the changing structure of the community. Juniperus is very sensitive to shading and does not flower freely when present as understory. With the rapid spread of Betula and Corylus it is possible that Juniperus was gradually expelled to the higher ground above the forest limit.

Ferns remain an important element in the flora and many are probably present as understory in the still very open woodland.

Gramineae and Cyperaceae pollen remains at a high level. Filipendula is present at nearly every level which suggests that it was growing locally.

Note the presence of Ilex right at the end of this zone. Being insect pollinated and clearly under-represented it is possible that Ilex has always been present locally from this time. It is still common in this area. Ilex aquifolium is a frost-sensitive oceanic plant, which is today restricted to areas of relatively high winter temperatures

– the northern and eastern limit correlating with the –0.5°C isotherm of the coldest month of the year (Conolly and Dahl, 1970). This is the earliest record of *Ilex* in Scotland.

The presence of *Hedera* similarly suggests winter temperatures similar to those of today – at any rate not lower than –1°C for the mean temperature of the coldest month (Iversen, 1973). This is probably the earliest record of *Hedera* in Scotland, though the record at Aros Moss in Kintyre may be as early.

Comparative Pollen Zones

The assemblage zone designated III-IV at Muir Park Reservoir (Vasari and Vasari, 1968) and the zone called IV at Muir Park Reservoir (Donner, 1957) are similar to DL-1b. Donner's zone IV includes DL-1a. Donner's zone IV at Gartmore also includes DL-1a. The zones NWS 1 and 2 at Loch Sionascaig and Loch Clair are also similar to DL-1b. The zone LME-1 at Loch Maree also is similar to DL-1a and b. In Skye there is a very short zone called the *Gramineae* – *Rumex* zone or the *Juniperus* zone – dated around 9,300 B.P. which is comparable with DL-1b at Dubh Lochan.

Macro-fossils of zone DL-1

In pollen zone DL-1 it is evident that *Betula* was present near the site at a very early date – spreading probably rather quickly behind the retreating glacier. *Carex*, *Cyperaceae*, *Sphagnum* and *Rhacomitrium* are the only other macro-fossils present at this level, probably representing a hydroseral fringe to the loch. *Sphagnum*, which is mostly *Sphagnum* section *Palustria*, is present at most levels. The above species are not specific climatic indicators. The *Rhacomitrium* leaf had lost its leaf-tip, hence it could not readily be determined whether this was in fact Rhacomitrium lanuginosum, which might have been anticipated from the pollen assemblage.

Zone DL-2; Betula - Corylus zone

Betula and Corylus woodlands continued to spread during this zone at the expense of Juniperus and Empetrum. The woodland communities may have been similar to those still in existence in Skye (H.J.B. Birks, 1973). The Corylus - Betula woodland type was probably similar to the Betula pubescens - Cirsium heterophyllum association which has an abundance of tall herbs as these woodlands have been in one way or another protected from grazing. Pollen of arctic alpines has become rare in this zone, indicating that these plants of open habitats were suffering from increased competition from woodland, as an indirect result probably of amelioration of climate. The soils may have become leached, and consequently more acid, and as many of the montane plants which were present in the previous zone were basiphilous species, this would have an effect. Ulmus and Quercus may have begun to arrive in the area and initially found refuge in more sheltered habitats. The pollen values increase gradually suggesting a slow immigration.

The presence of Cladium is of interest as it is more warmth-loving than Ulmus (Iverson, 1973).

Populus tremula is always much under-represented (Heim, 1970), so it may have been quite an important member of the open forest community at this time. It is still present today, growing sparsely at the side of the Lochan.

The minor presence of Pteridium suggests that the forest was incomplete as Pteridium does not readily produce spores in shaded situations. Most of the finds of Pteridium in Scotland date from later parts of the Flandrian. There is an early record of Pteridium at Loch Maree before 9,085 ± 120 radiocarbon years B.P., where it became established between 8,951 and 8,250 radiocarbon years B.P. At Loch Clair it was an established plant by about 7,080 B.C. and at Loch Sionascaig by about 5,930 B.C. In parts of Skye *Pteridium* became established at the beginning of the *Betula-Corylus* assemblage zone. Spores were found in Allerőd times in Loch Kinord - again indicating relative mildness of climate at that time (Vasari and Vasari, 1968).

There is a marked increase in the representation of the colonial algae *Botryococcus* and *Pediastrum*. These occur in lakes of a wide range in base status, either as plankton or associated with macrophytes in shallow water.

Comparative Pollen Zones

The Assemblage Zone designated V at Muir Park Reservoir (Vasari and Vasari, 1968) and zone V at the same site (Donner, 1957) are very similar to DL-2. Zone V at Gartmore (Donner, 1957) is also very similar. The Regional Pollen Zone NWS III, where the beginning of the *Betula/Corylus* zone has been radio-carbon dated at 6,900 B.C. shows also a pollen spectrum like that at Dubh Lochan, and like zone LME-2 at Loch Maree.

Macrofossils of zone DL-2

In pollen zone DL-2 *Betula* continues to be present locally. *Chara* and *Nitella*, which are abundant during this zone, *Chara*, in particular, indicating more eutrophic conditions than at present. It is of interest that *Nymphaea alba* seeds are present in considerable quantities, while later these are fewer in number. From the diagram it would appear that there is no *Nymphaea alba* in the lochan today, but this plant grows relatively abundantly round the margin. The reason that it is not seen on the diagram is that the site where the core was taken was overgrown just below where the last fruits were found. *Potamogeton natans* (Aalto, 1970) is present during most of the Flandrian.

Naias flexilis seeds have been found at level 544 cm in a core immediately adjacent to the site. As zone DL-2 extends from 500 - 575 cm it is a reasonable assumption that *Naias* was present during this period. It has been found fossil in Ayrshire (Durno, 1958b), in Aberdeenshire (Vasari and Vasari, 1968), in Inverness-shire at Abernethy Forest (H.H. Birks, 1970) and in Skye. It appears that its frequency is restricted today. This may be as a result of climatic deterioration (Godwin, 1956) though H.J.B. Birks feels that its restriction today is due to increasing competition (H.J.B. Birks, 1973). It is not known to be present today in the area round Loch Lomond.

Zone DL-3; *Betula* - *Pinus* - *Corylus* zone

There is rapid increase in *Pinus* pollen at the beginning of this zone. The *Pinus* curve at lower levels is undoubtedly due to long distance transport, as values are low. *Pinus* must have migrated into this area just as *Quercus* and *Ulmus* trees were also increasing in number. It is presumed that *Quercus* and *Ulmus* occupied most of the lower ground when the soils were richer, while *Pinus* probably occupied the better drained hillsides. Edaphic conditions for the spread of *Pinus* must have been favourable. These conditions are incomplete ground cover and reasonably open ground (Carlisle and Brown, 1968), and the spread appears to have been quite rapid. *Pinus* remained an important member of the forest for only a comparably short time. Perhaps with climatic change to rather wetter conditions as appears to have happened at the time of the alder rise (Pennington *et al.*, 1972), the hillsides became rather too water-logged for natural regeneration of Pinus. Whatever the reason Pinus gradually ceased to play much part in the local vegetational history.

There is a similar though rather more extended pine zone at Loch Maree (H.H. Birks, 1972) where at about 8,250 radiocarbon years B.P. pine pollen values rose very rapidly - pine becoming a dominant member of the pollen spectrum within 100 radiocarbon years. Pinus obviously played a more important role in that area, than in the Loch Lomond area, and native pinewoods are still present. There appears at Loch Maree, as in other Scottish sites - e.g. in Galloway (H.H. Birks, 1972) and in N.W. Scotland (Pennington et al., 1972) to be some correlation between the increase in Alnus pollen and a decrease in Pinus.

Today there is in this region only two small pinewoods or areas of scattered pine - one of which, at Rowardennan, National Grid Reference 26(N.S.)/358996, is considered to be either planted or natural regeneration of planted trees. The other is an area of scattered trees on the south-east of Glen Falloch at the head of Loch Lomond (National Grid Reference 27(NN)/367233). The trees are morphologically similar to native pine, and though no early historical reference has been found to them, they have been considered to be native and natural (Steven and Carlisle, 1959). However, there is a reference to a 'grant of free forestry in Glen Falloch to one Ure Campbell of Strachur on 31st March, 1568' (Anderson, 1967). There is no mention of what species was to be planted but this does raise doubts as to the native status of the pine trees in this area.

The forest cover, in this zone, must have been nearly complete, as there is little herb or shrub pollen. Plantago lanceolata pollen has been found in this zone though its presence is normally associated with human interference, and its presence at the end of the next zone, where the curve becomes continuous, is almost certainly associated with the elm decline, and man's presence. Its presence here may have been as a result of fire from natural causes. Plantago lanceolata appears in many pollen diagrams from the British Isles in small amounts before any other trace of prehistoric man's agriculture.

Comparative Pollen Zone

There is a very similar pine peak just before the alder rise at Muir Park Reservoir (Donner, 1957) at the junction between Godwin zone VI and VIIa, while at Gartmore (Donner, 1957), only a few miles away, there is no increase in pine pollen during zone VI. Pine was therefore possibly only locally present during this period in this part of Scotland.

In north-west Scotland there is a pine maximum before the alder rise, but in this area pine has persisted in limited groups in a few sites until the present day.

At Loch Maree pine is present in zones LME-3 and LME-4 after which, for some reason, there is a sharp decline in pine pollen, but pine has remained a small but persistent component of the spectrum there until the present time. Similarly at Loch Sionascaig, Loch Clair, Loch Borralan and Loch Craggie pine pollen is present in substantial amounts during chronozone NWS IV, NWS V and into NWS VI. The beginning of NWS IV has been dated at 5,900 B.C. and NWS VI at 2,070 B.C. at Loch Sionascaig.

Macrofossils of zone DL-3

In pollen zone DL-3 the macrofossils present are similar to those in DL-2 with Betula continuing to be the dominant type. Hylocomium splendens, which is present, is often associated with pine forest.

Zone DL-4: Quercus - Alnus zone

This zone is again typified by very high arboreal pollen, with Alnus increasing very rapidly at the beginning of the zone. The spread of Alnus in N.W. Scotland comes 1,000 years later than in N.W. England (Pennington et al., 1972). The alder rise in this area presumably took place before or around 6,500 B.P., since the rapid spread of Alnus at Loch Maree has been dated at about 3,500 B.P. (H. Birks, 1972). As at Loch Maree the spread of Alnus comes just after the maximum spread of Pinus. Alnus has remained an important element in the pollen spectrum until the present day - this could reflect a purely local element since Alnus is still on the site. However, it is known to be a more regional phenomenon, since the alder rise is shown on all other diagrams from western Scotland. Alnus is also present today in wet situations round Loch Lomond.

Mixed oak forest continued to expand quite rapidly at the beginning of this zone and the pollen spectrum suggests practically closed forest. Ulmus is present often on better soils than Quercus and probably pure stands of Ulmus may have been widespread. The pollen representation of Ulmus is not as high as Quercus, so it was probably quite an important element in the forest. It is of interest to note that Quercus values at Dubh Lochan are between 20 and 35% total pollen and spores at this period, while at other Scottish and north English sites Quercus pollen frequencies are rarely greater than 20% total tree pollen (Godwin and Deacon, 1974), though at Flanders East Moss Durno (1956) found Quercus values of up to 30% total tree pollen.

It is of interest to note that Pinus values are between 5% and 10% Σ Pollen and Spores. I consider that in an area like this where there was almost complete tree cover, these values probably mean that Pinus was still present. The presence of a single pine needle supports this hypothesis.

It is interesting to note that Polypodium reaches its highest values in this zone. This shade-loving epiphyte probably thrived in the shade of the nearly closed forest, and its presence may also reflect the increasing oceanity of the climate.

There is a very large representation of Isoetes mega and microspores during this period. This may merely be an indication that the depth of water at the site was at the optimal value for this plant. Isoetes lacustris still grows in the lochan on silty or stony parts of the bottom. There is a similar large maximum of Isoetes lacustris at Loch Maree, Loch Sionascaig and at Loch Clair.

Comparative Pollen Zone

There is a very similar mixed oak forest zone at Drymen (Donner, 1957). There is also a rapid increase in Alnus at the beginning of this zone at Drymen. The zone is designated VIIa and VIIb. At Gartmore (Donner, 1957) the pollen diagram ends after zone VIIa. This zone is again like that at Drymen with, as at Dubh Lochan, very few herbs present, suggesting a practically closed forest.

At Loch Maree the zone LME-4 is comparable. However, there is a difference in that there is a very high count of Pinus all through this zone at Loch Maree whereas at Dubh Lochan, Pinus, though probably present, was by no means an important element in the vegetational mosaic. The beginning of the zone LME-4 is dated 6,513 ± 65 radiocarbon years B.P. and the end of the zone is dated 4,206 ± 55 radiocarbon years B.P.

In north-western Scotland regional chronozone NWS 5 is similar but as at Loch Maree the Pinus component is higher than at Dubh Lochan.

Macrofossils of zone DL-4

In pollen zone DL-4 *Betula* continues to be the dominant local tree even though from the diagram it would appear that *Quercus* and *Alnus* are more important constituents of the vegetation. This would indicate that the pollen diagram is rather more than a local diagram. *Quercus* leaves are however present and although more are apparently present towards the top of the diagram this may only indicate that preservation was not as good at this time. Unidentified dicotyledonous leaf fragments are present right up to the present time. It would appear however that both *Quercus* and *Salix* have been present locally since zone 2. *Alnus* must have been growing very close to the site as both fruits and cone scales are relatively abundant.

The presence of a single needle of *Pinus* is rather tantalising. Had there been time I should have taken cores near the original zone and looked thoroughly at this level to see if another could be found. I am convinced that the presence of this single needle does indicate local presence, as already suggested in the discussion on the pollen diagram. Again I am convinced that it is unlikely to have been contamination, as there is no *Pinus* growing near the site at the present time.

A large number of terrestrial mosses are present either as isolated leaves or leafy stems, in this zone. These must have been washed into the lochan from the surrounding woodland. Many are mosses associated directly with forest trees - often growing on the trunks or on the ground in shade - viz. *Zygodon*, *Neckera pumila*, *Dicranum fuscescens*, *Antitrichia curtipendula*, *Isothecium myosuroides*, *Hylocomium brevirostre* and *Hylocomium splendens*.

The very large number of megaspores of Isoetes lacustris reflects directly the large local presence of this plant whose microspores are so abundantly present in the pollen diagram at this time.

Cristatella mucedo statoblasts, which are known from both eutrophic and oligotrophic lakes are found in rather shallow water – depth one to two metres – where it lives attached to the macrophytic vegetation (Berglund and Digerfeldt, 1970).

The Elm Decline

As no radiocarbon dates have been taken from this core the level at which the elm decline took place cannot be defined with certainty. From many Scottish and other diagrams it is apparent that after the initial elm decline there was often a temporary resurgence of elm. From this I would suggest that the initial elm decline took place at level 350 cm. From a statistical analysis of the results there is a small discontinuity at this level. The discontinuity at level 285 cm, where I have put my zone boundary, is of a larger order.

In certain parts of north-west Scotland an increase in Calluna, Pteridium and Gramineae pollen is associated with the first discontinuity in the elm curve. There is an elm decline from Oban (Donner, 1957) which is associated with an increase in Gramineae and Cyperaceae and a slight increase in Ericaceae. The elm decline as suggested by Donner at Muir Park Reservoir is again associated with increases in Gramineae, Cyperaceae and Ericaceae. It would appear that at the above sites the pollen spectrum does not necessarily indicate local clearances but is associated with a change to a rather more open woodland, as suggested by the increase in Pteridium spores and increases in grasses and heaths.

Again the initial elm decline at Flanders Moss (Turner, 1965) may not have been associated with a local clearance, as from purely archeological evidence, it appears that there was no Neolithic occupation of the area. There are no remains of burial mounds or other features associated with a Neolithic culture (Royal Commission, 1963). Dr Turner suggests that the site at which her pollen diagram is from is too far from the nearest woodland margin for small temporary clearances in the woods on the surrounding hills to have been recorded.

The elm decline at Dubh Lochan is associated with a similarly changing pollen spectrum as at the other sites in western Scotland mentioned above. There is an increase in the pollen of Gramineae, Cyperaceae and Calluna. Note also the small peak for Pteridium at this level and the minor presence of Plantago lanceolata. An increase in Pteridium and Plantago together with an increase in Gramineae and Ericaceae, including Calluna, would suggest a pastoral economy. Plants indicating a rather more arable economy such as Rumex, Artemisia, Compositae, Chenopodiaceae, Ranunculaceae, Polygonum and Succisa pratensis enter the pollen spectrum rather later at Dubh Lochan. It is also noteworthy that, as in many Danish diagrams (Iversen, 1973) Quercus pollen increases at this point. Ulmus may originally have been cut down selectively as Neolithic farmers recognised the connection between elm forest and soil fertility. The use of elm for fodder would also result in a relative increase in Quercus pollen as compared with Ulmus pollen.

Zone DL-5; Salix - Betula zone

The continuous curve for Ulmus ended at the beginning of this zone, and plants indicative of agriculture and animal husbandry, such as Plantago lanceolata, whose curve becomes continuous at this point, *Rumex acetosa*, *Rumex acetosella*, *Succisa pratensis* and *Plantago major* began to appear. No cereal pollen has been found, but this merely indicates that cereals were not grown locally. The zone boundary is not at the elm decline, sensu stricto, but comes at a point on the pollen spectrum where more appears to be changing than at the proposed elm decline. The zone boundary has been confirmed statistically - only a minor discontinuity taking place at level 350 cm.

Deforestation appears to have taken place from this time, though the tree:herb ratio is still high. This is masked, however, by the high local count for *Salix*. *Salix* pollen production is rather low and its dispersal tends to be poor, so the high values at this point almost certainly indicate local occurrence, with the formation of willow carr at the edge of the lochan (Holm, 1970).

The paradox of the association of de-forestation with man and its apparent association with climatic change has been studied in great detail, by comparing areas where man is known to have been present with areas where man was in all probability not present. There appears to be a climatic explanation for the replacement of trees by blanket peat. In a detailed study of lake sediments in the Lake District where Neolithic man was present in considerable numbers and in Lake Sionascaig, Wester Ross, where no traces of Neolithic man has been found, it has been noted that, in both cases, associated with de-forestation, there is a decrease in the proportion of carbon and an increase in the proportion of the halogens, sodium and potassium, which are associated with increasing hilly inwash due to increased rainfall. There is also an increase in iron and manganese, indicating soil instability which appears to be associated with increasing oceanity of the climate in terms of precipitation and hence run-off (Pennington *et al.*, 1972).

Spores of Sphagnum begin to increase. This may be due to increased oceanicity of the climate.

Comparative pollen zones

There are no exactly comparable zones to this. The elm decline is an established regional event, but this zone with its increase in Salix was purely a local one.

Macrofossils of zone DL-5

At this stage there is an expected increase in Sphagnum debris, clearly associated with the increase in Sphagnum spores. The presence of Salix catkins and leaves confirms the expected local occurrence of Salix carr. The peat at this time is a coarse telematic peat. The hydrosere has changed from lake conditions to Salix carr. Note that at the end of this zone statoblasts of Cristatella mucedo cease to be present. This would suggest that the depth of the water at the sampling site must have been approximately 1-2 metres at this time (Berglund and Digerfeldt, 1970).

Zone DL-6; Myrica - Calluna - Sphagnum zone

There is again a purely local element in this zone which is shown by the very marked increase in Myrica pollen. Myrica appears to have replaced Salix in the hydroseral succession. Myrica is still locally abundant.

The increase in Gramineae is probably due to the presence of Phragmites, which is still locally abundantly present. The size of the pollen is approximately 25 μm which is within the size range for Phragmites pollen. The Sphagnum curve continues to expand. The production of Sphagnum spores is so variable that it has not been included in the total for percentage calculation (see Table 1).

The ratio of arboreal pollen to non-arboreal pollen continues to fall, while plants of open habitats increase - note particularly the increasing abundance of *Pteridium* and *Calluna*. These are today the principal components of the vegetation over much of upland Scotland. Their continued presence is ensured by the policy of over-grazing, especially by hill sheep, and by the burning of moorland to provide young tender heather shoots for grouse.

The curve for *Succisa pratensis* becomes almost continuous. This herb favours treeless habitats (Adams, 1955).

Plants of acidophilous taxa are increasing as the treeless hillsides become more leached and acid. Local soils are schistose grits, which tend to be acid.

There is a continued expansion of plants associated with agriculture and animal husbandry.

Comparative Pollen Zones

As this zone reflects the local and regional vegetation of the area there is no exactly similar zone as man has operated differently in different areas.

It could be said to be similar to LMR-3 at Loch Maree in that in both areas the ratio of arboreal pollen to non-arboreal pollen has decreased and plants associated with de-forestation and agriculture have increased. In both areas there was a very marked increase in *Calluna*, but at Loch Maree there was no comparable increase in *Pteridium*. There was, however, a similar increase in *Pteridium* at the site in the Galloway Hills (H.H. Birks, 1972a).

There was a similar increase in *Calluna* in north-western Scotland, where the chronozone NWS 6 could be said to be comparable. The beginning of this chronozone is non-synchronous over the part of the north-west of Scotland studied (Pennington *et al.*, 1972), which is what one would expect if man had started to influence the plant structure in different parts of this area at different times.

Macrofossils of Zone DL-6

Note the continuing presence of *Calluna* and *Sphagnum*. Mycorrhizal roots appear for the first time - this might be presumed to be roots of *Myrica gale* which we are sure from the pollen and from local presence today was beginning to become established on the site around the beginning of zone DL-6.

CONCLUSIONS

This study has helped to elucidate the development of vegetation in a small area within the Loch Lomond Re-advance. That there is a regional as well as a local factor is shown by comparison with other pollen diagrams from the West of Scotland.

As no radiocarbon dates have been obtained from this site it is not possible to tell how early, relative to *Pinus*, *Quercus* and *Ulmus*, *Corylus* immigrated into this area, but it would appear that it occurred relatively early. This is consistent with the latest theory that it had refugia to the west of Scotland during the last phase of the Devensian glaciation.

It is noteworthy that here is the earliest record of *Ilex* in Scotland. There is an early record for *Hedera* at Aros Moss in Kintyre (Nichols, 1967) which came after the beginning of the *Corylus* rise, but before *Corylus* became an important component of the vegetation. In the Dubh Lochan area again *Hedera* was found before the beginning of the *Corylus* rise, and at a time when *Juniperus*, *Empetrum* and *Betula* still dominated what must have been a fairly open landscape.

It is also of interest to note that *Pinus* played only a small part at an early stage in the development of the ecosystem as it did at the site at Drymen; however, only several miles away at Gartocharn there appears to have been no *Pinus* at any stage in the ecological development. At the Dubh Lochan site the soils are probably schistose grit which must have suited an early establishment of *Pinus*, which may have only been a local component of the vegetation. That *Pinus* was growing nearby is confirmed by the presence of a pine needle .

The situation that *Pinus* was gradually replaced by mixed oak forest is similar to that at other sites in south-west Scotland, while in north-west Scotland *Pinus* has often persisted until the present day. The mixed oak forest immigrated into this area about the same period as *Pinus*, but its major expansion came just after the very sharp rise in *Alnus* pollen. Pollen values for *Quercus* at the time of the mixed oak forest may well be the highest in Scotland. The increase in *Alnus* pollen may merely represent a local growth of *Alnus* round the margin of the loch but as the alder rise is generally taken to coincide with increasing oceanicity of the climate this was probably a reflection of a more regional expansion of *Alnus*. *Ulmus* was well represented and its initial regression was associated with rising pollen values for *Gramineae*, *Calluna* and *Pteridium*, suggesting that the forest cover was becoming more open. This was followed by a resurgence of *Ulmus* before it gradually declined - a pattern typical of many Scottish and English sites. After the final decline of *Ulmus* plants directly associated with man's presence indicate that Mesolithic man was engaged in both a pastoral and an arable type of farming.

There is already much documentary evidence regarding the recent forest history of this area. A more detailed study of the upper layers of the core would add much useful information to supplement the history of this important and fascinating area.

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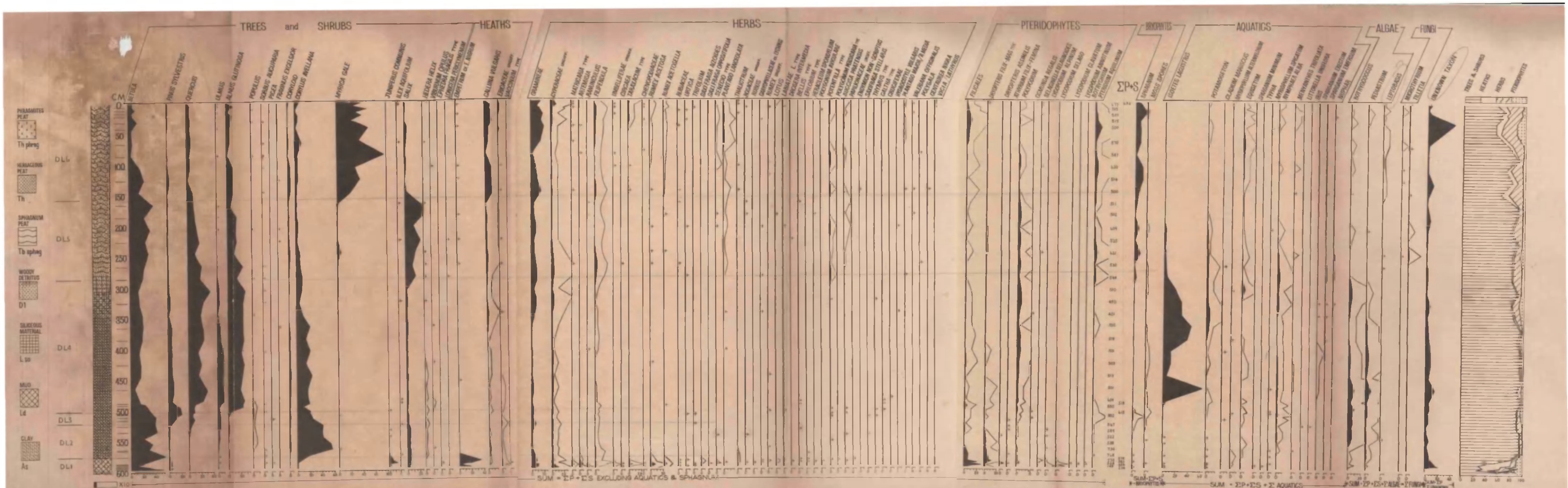
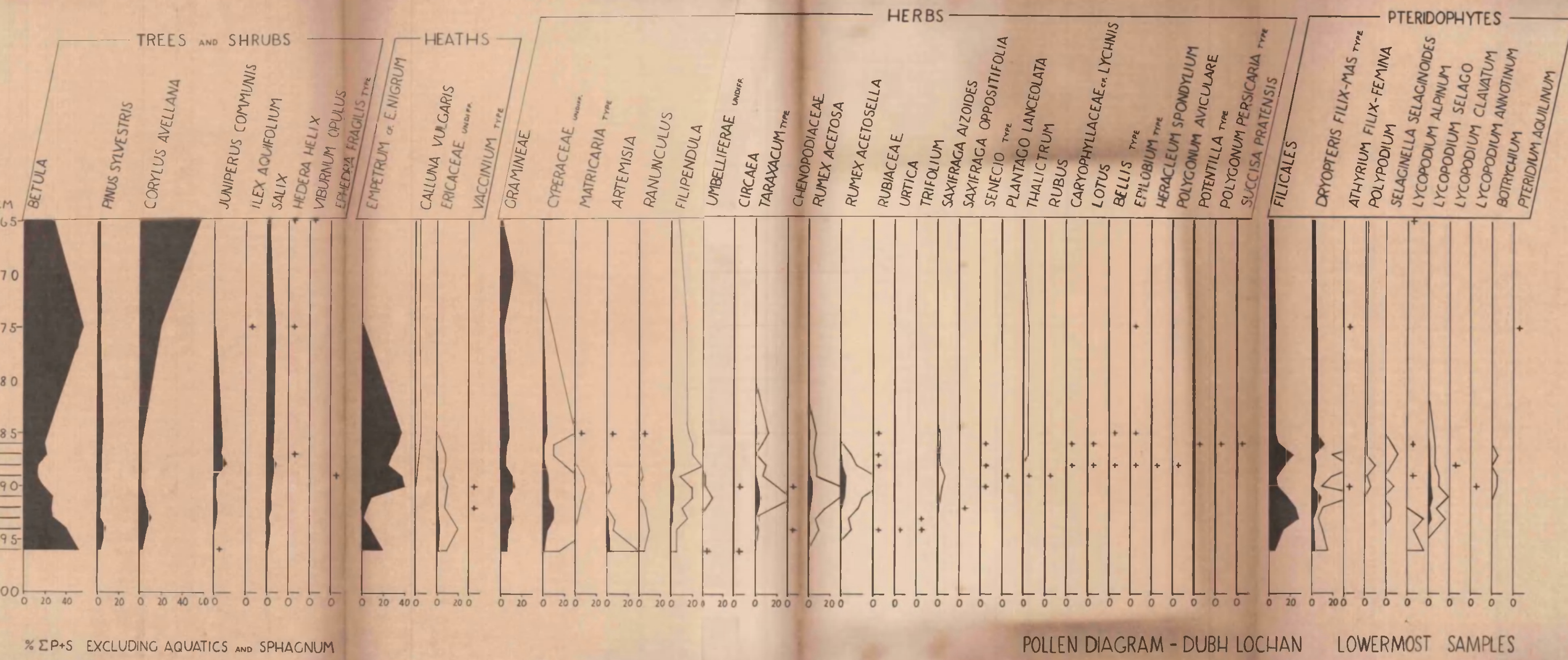


POLLEN DIAGRAM - DUBH LOCHAN



POLLEN DIAGRAM - DUBH LOCHAN LOWERMOST SAMPLES

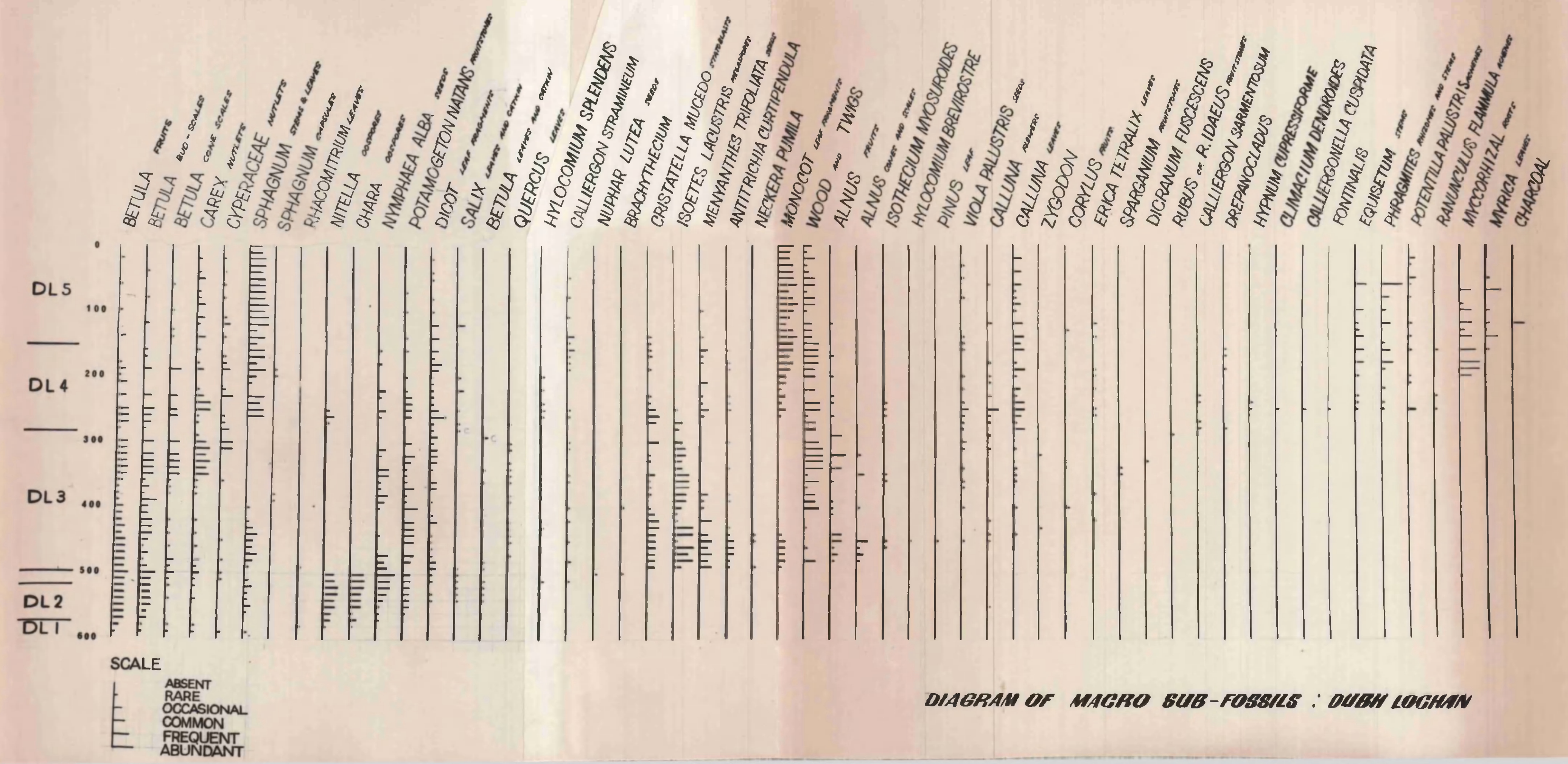


DIAGRAM OF MACRO SUB-FOSSILS : DUBH LOCHAN