A comparative study of higher plant diversity and communities on opencast sites of varying age and adjacent undisturbed areas

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A Comparative Study Of Higher Plant Diversity and Communities on Opencast Sites of Varying Age and Adjacent Undisturbed Areas

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ABSTRACT

A survey of three habitat types (woodland, hedgerow and pasture) on opencast sites of varying age and adjacent undisturbed sites N,W. of Durham was undertaken. Time since disturbance seems to be the primary influence on the development of organic content of the soils on opencast sites and the corresponding reduction in pH; soil water content is variable but is generally lower on recently restored and thus more consolidated soils.

The quality of soil on the opencast woodland sites selected stress-tolerant ruderal plants as constant members of the community, the troughs in the plantations provided a suitable niche for bryophytes and liverworts. The plant diversity of pastures was comparable both on and off opencast sites due to similar farming practise (eg. ploughing and re-seeding). The ground flora of hedgerows was influenced also by aspect and was more diverse when protected from grazing by livestock by a fence.

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1. Introduction

The aim of this study was to investigate the hypothesis that former opencast sites have an impoverished flora and consequently a simpler community structure than comparable habitats that have not been disturbed. Opencast mining has been carried out in Britain since the second world-war. Coal removed from the ground by this method has been consistently cheaper than deep-mined coal (Arguile, 1973) and the increase in production levels from these mines predicted by projected energy demands, suggests that greater areas of land will be subject to disruptions associated with the opencast workings.

The contribution of coal produced by opencast methods to the total national product has risen from 4.2% in 1952, to 11.1% in 1978 (CoEnCo, 1979). The 56 000 ha which have been restored following opencast mining before 1978 represent only a small fraction of the 18.8 million ha of agricultural land in Britain (Tomlinson, 1970). Nevertheless, the coal reserves under existing derelict and low-grade land are being progressively worked out and applications are being made to move into "greenfield sites" which are of higher agricultural and scenic quality (CoEnCo, 1979). In recent years there has been an increasing interest in the effects of opencast mining in this land "temporarily" removed from agriculture.

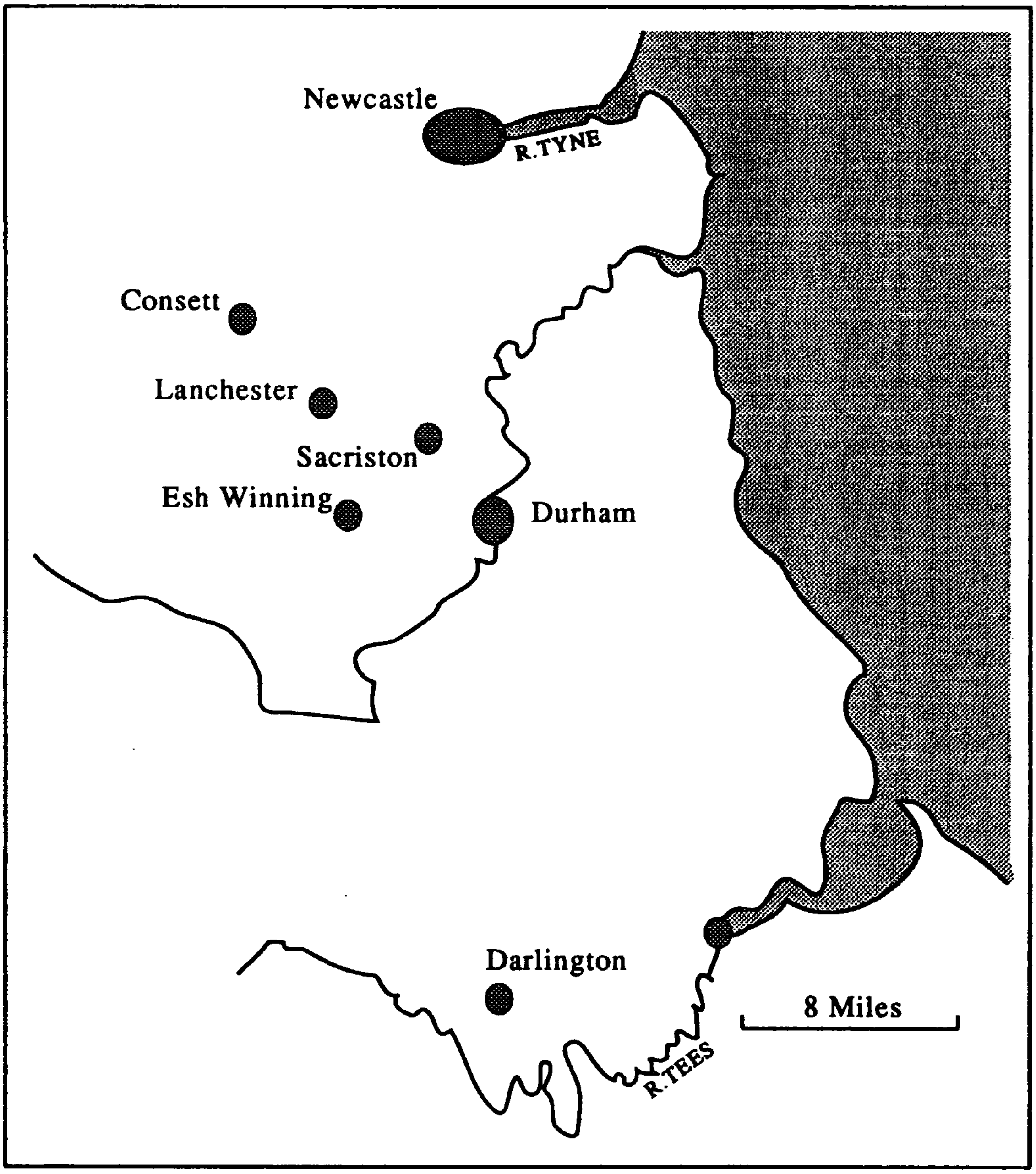
Early opencast mining was controlled under the Emergency Powers (Defence) Act 1939. This legislation continued to govern opencast operations until 1949 when MAFF assumed authority and a technical advisory committee recommended the installation of permanent field drainage to overcome surface erosion and site drainage problems. The committee also recommended the replanting of hedgerows and the rehabilitation of woodlands; the separate storing and replacement of topsoil and subsoil; and a five year period of management by the MAFF Agricultural Development Advisory Service (ADAS) (Tomlinson, 1970). This period of management involves improvement of the soil by cultivation, manuring, grazing etc. In 1958 the Opencast Coal Act was passed which requires British Coal to obtain authorisation to proceed on each site from the secretary of state for energy. This authorisation includes planning conditions for working and restoration (replacement of excavated materials), but not rehabilitation (improving soil fertility). The aim of the restoration period in the past has been to make the land 'reasonably fit' before its return to the farmer (Collinson, 1967). In recent years the demand for agricultural land has decreased because of a lower demand by the E.C. for farm produce and, since the autumn of 1988 and the intitiation of the United Kingdom Set-aside policy programme, farmers have been encouraged to allow land to develop towards semi-natural habitats.

There are various factors inherent in the restoration of opencast mining land which can influence the ground-layer communities. The increased pore space and aggregate stability within the soil makes the soil physically unstable (Curne, 1955; Jackson, 1962; Scullion, 1984 ; Evans et al, 1986) inhibiting the recolonisation by plants. Further, the recolonisation by earthworms from undisturbed areas takes a considerable time and even ten years after reinstatement of the land the earthworm biomass is still about 10% lower on restored land compared to undisturbed land. This results in low levels of readily degradable organic materials which are important factors contributing to improvement in the structure and nitrogen status of these soils, (Standen et al. 1982; Armstrong & Bragg, 1984). Organic compounds within the soil removed for opencast mining are altered by their storage under anaerobic conditions so they cannot be used by aerobic soil bacteria as a substrate (Pringle,1958). Opencast soils are very sensitive to variations in weather conditions, they often exhibit waterlogging in winter and extreme soil-cracking in the summer. Currie (1955), Pringle (1958) and Tomlinson (1970), observe that productivity decreased by 20-30% and crops were not as vigorous when grown on opencast land, mainly due to low or unavailable levels of nitrogen. Different farming practises, eg. the regularity of ploughing-in and re-seeding and stocking levels, that if too high lead to poaching of the soils (Tasker 1957; Scullion 1984; Mohammed 1986) provide different levels of competition, disturbance and stress which will influence that species may survive or subsequently colonise (Grime 1974).

The sites chosen for this survey lie in an area NW of Durham which has been intensively mined (Fig.1.). The concentration of sites in a relatively small area offers a good opportunity to compare the ground-flora communities of the habitats I have selected to study, ie. pastures, hedgerows and woodlands, in the absence of major geographical or climatic differences.

In order to detect variation in community structure between these habitat types on opencast mined land and nearby undisturbed areas a quantitative approach was used. Species lists for a representative area were compiled and species abundance was recorded using the Domin scale. The application of multivariate methods of ordination and classification to the

Figure 1. The North-East of England.



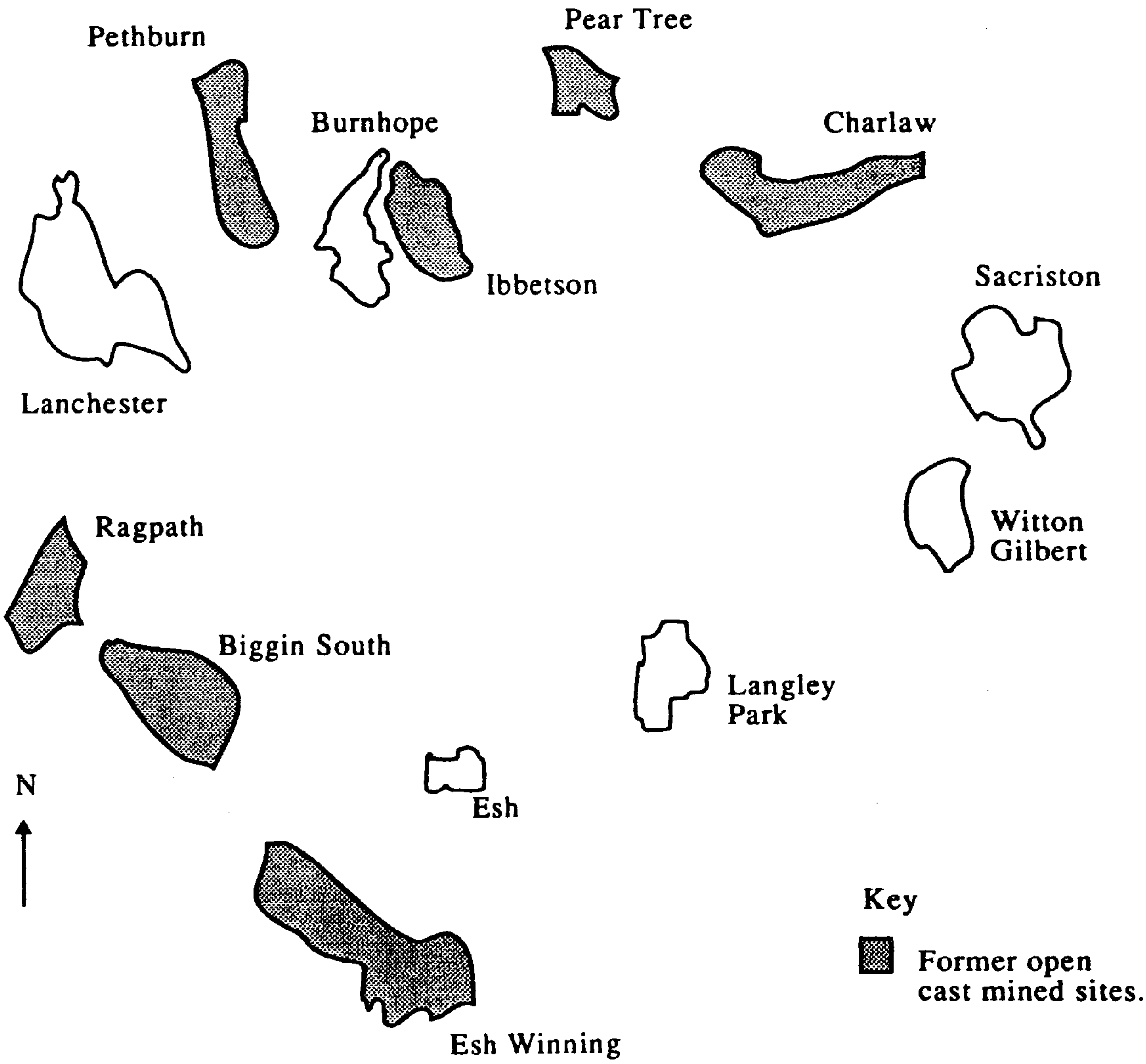


Figure 2. Diagram showing the locality of the study areas.

vegetation data has allowed the detection of the differences between plant community structure of undisturbed areas and former opencast mined areas.

2. The Study Area

2:1 Site Description

2:2 Environmental Factors

2:2:1 Geology

2:2:2 Climate

2:2:3 Soils

2:3 Biotic Influences

2:1 Site Description

The former opencast sites chosen for this survey were Biggin South, Ragpath, Pethburn, Ibbetson, Esh Winning, Charlaw and Peartree. They were all mined by British Coal and are situated in an area north-west of Durham, (Figures 1 & 2). Three habitats that are common to all of the sites were surveyed; woodland, hedgerow and pasture. In each case the habitat on the restored opencast site was compared with that on an adjacent undisturbed area (Table 2).

Biggin South lies on Weather Hill south of Lanchester (National Grid Reference NZ 1717) at a maximum altitude of about 210m. It covers a plan area of 515ha. The land was returned to the tenants in 1978.

There are three small areas of woodland on the site planted as a gesture to offer shelter for livestock and crops from the wind. They consist of a 50:50 % broadleaf and coniferous mixture at 2m spacing, planted in 1978. The species planted were *Pinus sylvestris*, *Acer pseudoplatanus*, *Fraxinus excelsior* and *Sorbus aucuparia*. A beech understorey was planted at the request of the planners, but this failed to survive. The hedgerows that are planted as field boundaries are composed of *Crataegus monogyna* with a 2 % mixture of hardwoods planted as standards. The standards planted were *Acer pseudoplatanus*, *Sorbus aucuparia* and *Fraxinus excelsior*, but because of great fluctuations of drought and water-logging, a consequence of opencast mining, these failed to survive. In more recent restorations 15-18 % of the land has been planted with trees. British Coal favour coniferous woods because they offer all year round protection but when these coniferous plantations are thinned deciduous trees are planted.

The pastures on Biggin South are very heavily grazed by sheep. The two pastures showing ridge and furrow patterns, off the opencast site, were sampled (code numbers 1 & 2, Table 2). The woods sampled (code numbers 20 & 21) on undisturbed land were *Quercus* (with *Fraxinus* as a subdominant) and *Acer pseudoplatanus* with *Crataegus* respectively.

Ragpath lies in a sheltered valley south of Lanchester on Lead Hill (National Grid Reference NZ 1645) with a maximum altitude of 210m. The site is on a steep NW facing slope and covers a plan area of around 320ha. There are two large areas of coniferous woodland that were planted in 1975; the species composition is identical to that of Biggin South, with the addition of Larch. The woodlands sampled on undisturbed land (sample code numbers 42 & 43) are *Fraxinus* (with *Crataegus* and *Betula* subdominants) and *Betula* (with *Fraxinus* and *Quercus*) respectively. There is particularly poor drainage on the SW end of the site due to poor soil quality, compaction and the absence of underdrainage. One hedgerow was sampled on this area, code number 14.

Pethburn lies NE of Lanchester above MoorLeazes Farm (National Grid Reference NZ176482). It covers a plan area of 517ha on a SW slope at a maximum altitude of 250m. No hedgerows were planted on the site at the farmers request.

Two strips of woodland on the restored land (sample code numbers 62 & 63) extend from an undisturbed coniferous plantation. These were planted with *Pinus sylvestris*, *Pinus contorta var. latifolia*, *Sorbus aucuparia* and *Acer pseudoplatanus* in a 40:40:10:10 mixture.

Esh Winning was the largest site studied with an approximate plan area of 1006ha. It was returned to the tenants in 1960. The site lies on a steep south facing slope above the village of Esh Winning, and has an altitudinal range of 125m to 190m. There was a shortage of topsoil during the restoration of the site, due to the obligation of British Coal to demolish an old mining village. Consequently areas of woodland were planted on land that did not have any topsoil returned to it and as a result the trees are extremely stunted. The tree species planted were *Pinus sylvestris*, *Acer pseudoplatanus*, *Fraxinus excelsior*, *Sorbus aucuparia*, *Alnus incana* and *Betula pubescens*. A soil survey was carried out by ADAS in 1984 on two such impoverished woodlands (sample code numbers 83 & 84) and a soil pH of 7.0-8.0 was recorded. In January of the preceding year ammonium sulphate was sprayed on the land in an attempt to lower the pH. The hedgerows were planted with *Prunus spinosa*, *Fraxinus excelsior*, *Acer pseudoplatanus*, *Quercus robur* and *Ilex aquifolium*. The pastures are grazed by sheep and cattle, whilst fields on the lower fields are left for silage production.

Ibbetson lies on an east facing slope in a small valley NW of Burnhope. It has a plan area of about 96ha. The woodlands and hedgerows sampled were planted with the same species composition as Biggin South. Again there was a shortage of topsoil during the restoration procedure, in this case because of the large amounts of shale that surrounded previous deep mines on the site.

Charlaw lies on Charlaw Fell NW of Sacriston. It covers a plan area of approximately

375ha and has a maximum altitude of 375m. The undisturbed woodlands surveyed (sample code numbers 114, 115 & 116) were *Betula pubescens* with *Acer pseudoplatanus* and *Alnus* as co-dominants; *Betula* (with an *Ilex aquifolium* and *Fraxinus* component) and *Fraxinus* co-dominant with *Betula pubescens* and *Quercus* (with *Sorbus aucuparia* and *Ulmus glabra* as sub-canopy components) respectively. These woodlands were felled during World War II and the trees now have a coppiced growth form. No hedgerows were sampled on the site because the protective fences had not been replaced in 39 years and bare ground was underneath the *Crataegus*.

Peartree lies east of Burnhope above Peartree Cottages (National Grid Reference NZ 486207) on a gentle SE facing slope. There is a maximum altitude of 175m. The pastures were heavily grazed by cattle and sheep. A ridge and furrow field (sample code number 122) was surveyed behind Holmside Hall (NZ 497507) at a distance of 700m from the restored area. All the fields on the opencast mined land, except the arable fields, were reploughed and seeded at regular intervals, approximately every 3 years.

The sites at Biggin South and Ragpath were sampled in June; Ibbetson and Esh Winning in July and Charlaw and Peartree in early August.

2:2 Environmental Factors

2:2:1 Geology

The geology of the study area is relevant to the plant communities at the surface due to its importance as the parent material for soil formation. They study sites lay on a coal measure which overlies millstone grit. This implies that the soil will be relatively free draining and have acidic tendencies.

2:2:2 Climate

The ability of a particular plant species to colonise a particular area and how well that species can survive and regenerate, is dependant on the species adaptations and the local climate. My study areas were located at similar latitudes and are therefore subject to similar climatic conditions. In the present study meterological measurements were supplied by Durham Observatory (pers.comm. 1990). County Durham has a relatively low mean annual temperature of 8.3°c (Dewdney, 1970), this is exacerbated by the cooling effect of the north-sea to the east and an increase in altitude to the west but as the study areas are approximately 200m higher than Durham City a somewhat lower daily temperature and higher rainfall can be inferred. Sunshine levels are reduced as far as the Pennine foothills in the west due to the effect of sea fog and low stratus caused by the north sea.

June 1990 was a cool month, the mean daily maximum temperature was a little below average at 12.7°C with 113.6 hours of recorded sunshine, which is 65% of average and 52.1mm of rainfall were measured.

July recieved 61.8% of the average rainfall for the month, it only rained on 7 days. There were 223.3 hours of sunshine which is 40% above the monthly average and the mean daily maximum temperature was slightly above average at 15.5°C.

August was a hot, sunny and fairly dry month with a mean daily maximum of 22.3°C, three degrees above average. There was only 52.8mm of rainfall, or about three-quarters of the monthly average. The sunshine levels were high with 214.2 hours recorded, 50% above average.

2:2:3 Soils

The soils of the study areas are very variable in terms of colour, moisture content and depth.A typical restored site opencast soil has a loamy topsoil of variable thickness, depending on the amount of topsoil preserved, over a slowly permeable compact clay loam, silty loam or clay subsoil. This passes at depth to dark grey rock waste, mainly of coal measure mudstone. Recently restored profiles show little structural development in the subsoil but on some earlier sites a horizon similar to that in undisturbed soil has developed. The degree of stoniness varies greatly and even fragments of coal, bricks, slag and even discarded mining equipment may be found in the soil. The compact slowly permeable subsoil in most restored opencast soil severely impedes water movement and leads to lengthy periods of winter water-logging, wetness class IV or V, (Jarvis,R.A.et.al. 1984).

2:3 Biotic Influences

No evidence of rabbit burrows was seen nevertheless the effect of their grazing on the farms cannot be discounted. Grazing by cattle, sheep and horses is widespread on the pastures and on a number of woodland sites. Poaching (disturbance and compaction by stock) is particularly prevelant around the gates and hedgerows.

Humans undoubtedly have the most dramatic effect. Pastures are reploughed, seeded and manured at regular intervals, heavy machinery exacerbates consolidation of the topsoil and repeated cropping removes organic content and nitrogen from the soil.

3. Methods

3:1 Methodology

3:2 Methods

3:3 Soil Analysis

3:4 Other Environmental Variables

3:5 Data Analysis

3:1 Methodology

Since the aim of this study was to compare the effect of opencast mining on plant communities each site was paired with an adjacent undisturbed area of comparable size, topography etc. Three releves of each habitat type (pasture, hedgerow and woodland) were taken using the Domin scale, a possible total of 18 relevés being recorded for each site.

Table 1. The Domin and Braun-Blanquet Scales.

Domin Scale	Braun-Blanquet Scale	Percent Ground Cover
10 }	5	90-100 %
9 }		75-90 %
8	4	50-75 %
7 }	3	33-50 %
6 }		25-33 %
5 }	2	10-25 %
4 }		4-10 %
3	1	< 4 % frequent
2 }		< 4 % occasional
1		< 4 % 1 or 2

(Kershaw,K.A. & Looney,J.H.H., 1985)

Braun-Blanquet (1865) originated the Zurich-Montpelier (Z-M) system of European vegetation analysis which is the method used in this investigation. Within each site several relevés are made. These are complete plant lists within a given sized quadrat, each plant being given a subjective cover score. Methods of classification (to outline the vegetation units) and ordination (which bring the most similar releves side by side along an ecological gradient) are used to identify constant species (ie. in 80% of releves). The Z-M method can compare data from many sites easily and successfully observes differences in floristic competition and habitat of the same successional graded communities. Table 1 shows a comparison between the Braun-Blanquet and Domin scale, which is a modification of the Braun-Blanquet system of rating (Braun-Blanquet, 1927; Poore, 1955).

3:2 Vegetation Survey

An overall assessment of species abundance was made by compiling a species list using randomly placed quadrats 10.0m square on each sample location on a pasture or within a woodland. For hedgerows, an area 30.0m long and 0.5m from the mid-point of the hedge was used to compile a species list. The community composition and structure of each quadrat was visually assessed using The Domin Scale (see Table 1) in a smaller quadrat of 2.0m square or for hedgerows, an area 4.0m long and 0.5m from the mid-point of the hedge was used to assess species abundance on both sides of the hedge.

3:3 Soil Analysis.

The composition and character of a plant community is related to the characteristics of the soil. The pH of the soil can be related to soil properties such as base status, soil development and topography of the soil and is modified by biological successions in soil and of vegetation (Pearsall 1952).

Soil samples were initially taken from each quadrat using a 1cm soil corer, but due to dry summer conditions this proved to be impossible and soil samples were taken just below the root zone of the herb layer using a trowel. The sample was returned to the lab. for analysis. This was carried out by adding 10g of soil to 25ml of distilled water. This 1:1.25 suspension was allowed to equlibrate for one hour. The pH was measured using a 7020 meter made by Electric Instruments Ltd., buffered with buffers of pH 7.0, 4.0 and 9.0 (Hesse, 1970). A sub-sample of soil (5-10g) was oven dried at 105°C for 14 hours in order to estimate the percent loss of weight on drying; then ignited at 550°C for 5 hours in a muffle furnace and reweighed. This provides an indication of the organic content of the soil (Hesse 1970), See Table 2.

3:4 Other Environmental Variables

Other environmental variables that used in the analysis were age of the restored site, aspect, slope and altitude. The study sites were within a small geographic area so that climatic variations can be assumed to be small. Additional information from pastures was also noted, including the maximum height of the sward and whether the site was grazed or ungrazed.

For hedgerows, the number of standard trees in the quadrat was recorded, the accessibility of the ground-layer to grazing by livestock, the presence of a drainage channel and distance from the nearest woodland or other potential colonising source. For woodlands, the dominant (canopy) trees were recorded and the number of trees standing in the quadrat in order to assess the density of the woodlands and the degree of shading by the canopy onto the ground was also noted.

3:5 Data Analysis

The following variables were recorded for each releve sampled and used in the multivariate analysis:

1. Ground flora community data (abundance values).

2. Species lists.

3. Environmental variables (Table 3 & Appendix D).

The community data was subject to classification and ordination using three FORTRAN programs; detrended correspondence analysis (DCA, Hill 1979b; Ter braak 1988), Two-way indicator species analysis (TWINSPAN, Hill 1979a) and canonical correspondence analysis (CANOCO, Ter Braak 1988).

Detrended Correspondence Analysis

This an ordination method which allows communities to be organized in a system of coordinates so that the most similar appear closest together, (Davis 1986). Detrended correspondence analysis (DCA) was developed by Hill and Gauch (1980) to correct faults of correspondence analysis, ie. that the ends of the first axis are often compressed relative to the axis middle and the arch effect which is considered to be "a mathematical artifact with no real structure in the data", Ter Braak 1988.

Hill and Gauch (1980) overcome the compression problem by rescaling the species scores to equalise the mean-within sample dispersion of the scores at all points upon the axis (Hill 1979a). Then the sample scores are simply derived by weighted averaging. The arch effect is eliminated by detrending. This assures that at any point along the first axis the mean value of the sample scores on the subsequent axis is zero.

The result is a two-dimensional chart where clustering of points indicate similar species or sites, (Gauch 1982; Causton 1988). The method of detrending used was that by Ter Braak (1987). This technique was used before the TWINSPAN program (Hill 1979a) in order to determine the most relevant cut-off levels on the dendrogram.

The TWINSPAN Program

Two-way indicator species analysis is a robust, polythetic divisive method of classification and is applicable for data outlining the occurrence of a set of species in a set of samples (Hill 1979a). The abundance data are first ordinated using reciprocal averaging, then those species that characterize the reciprocal averaging axis extremes are emphasised in order to polarise the sample, and the samples are divided into two clusters with the ordination axis near to its middle. A perfect indicator species is one which will occur in one group of species but not the other, there are seldom perfect indicators. The best five indicators are used for the next step and indicator scores are calculated for the sample. Indicator species are those which have the highest contribution to the divisions, whilst a preferential species is one which is at least twice as likely to occur on one side of the dichotomy than the other. Only those that occur in 20 % of the samples are listed. When there is a very uneven split negative preferentials can easily occur in more samples on the positive side of the dichotomy than the negative side.

The original ordination is then redivided using species with maximum values for indicating the poles of the ordination axis. The division process is repeated on the two sample subsets to give four clusters and so on until each cluster has no more than a chosen number of members. The problem of using the actual densities of the species found in classification is that the common species tend to overshadow the less abundant but equally constant species. The use of pseudospecies has been suggested to overcome this problem, (Hill 1979). The pseudospecies cut levels used in this study were chosen to reflect typical levels of abundance, ie. 1, 4, 6, 8 and 9 on the Domin scale.

TWINSPAN is designed to construct ordered two-way tables identified by differential species. In TWINSPAN the samples are classified first and the species are classified second using the classification of the samples as a basis (Hill 1979a; Hill 1973; Gauch 1982).

The CANOCO program

Canonical correspondence analysis (CCA, Ter Braak 1988) is an extension of DECORANA (Hill 1979), it visualises the relationship between species and environmental variables. It is an extension of weighted averaging ordination, (Whittacker 1967; Hill 1973) which arranges the species along axis of environmental variables. The ordination axes are constrained to be linear combinations of environmental variables. CCA distributes the species along the axis with maximal separation, the eigenvalues produced by CCA measure this separation. The output is an ordination diagram which shows the pattern of community variation and the main features of the distributions of species along the environmental variables, hence species-environment relationships can be detected.

The environmental gradients are represented by arrows which point in the direction of maximum change of each variable across the diagram. Environmental variables with long arrows are more strongly correlated with the ordination axis than those with short axes. The position of a site or species on the CANOCO biplot in relation to the first axis and the environmental variables is assessed by its angle between and the distance between the arrows.

The data from undisturbed areas and the data from releves on former opencast sites were analysed separately and together in order to assess the effects of mining on plant communities, whether it is a primary determinant for the composition of the plant communities in relation to the other variables measured.

4. Results

4:1 Classification of all data

4:2:1 Classification of abundance data in woodlands

4:2:2 The effect of environmental variables

4:3:1 Classification of abundance data in hedgerows

4:3:2 The effect of environmental variables

4:4:1 Classification of abundance data in pastures

4:4:2 The effect of environmental variables

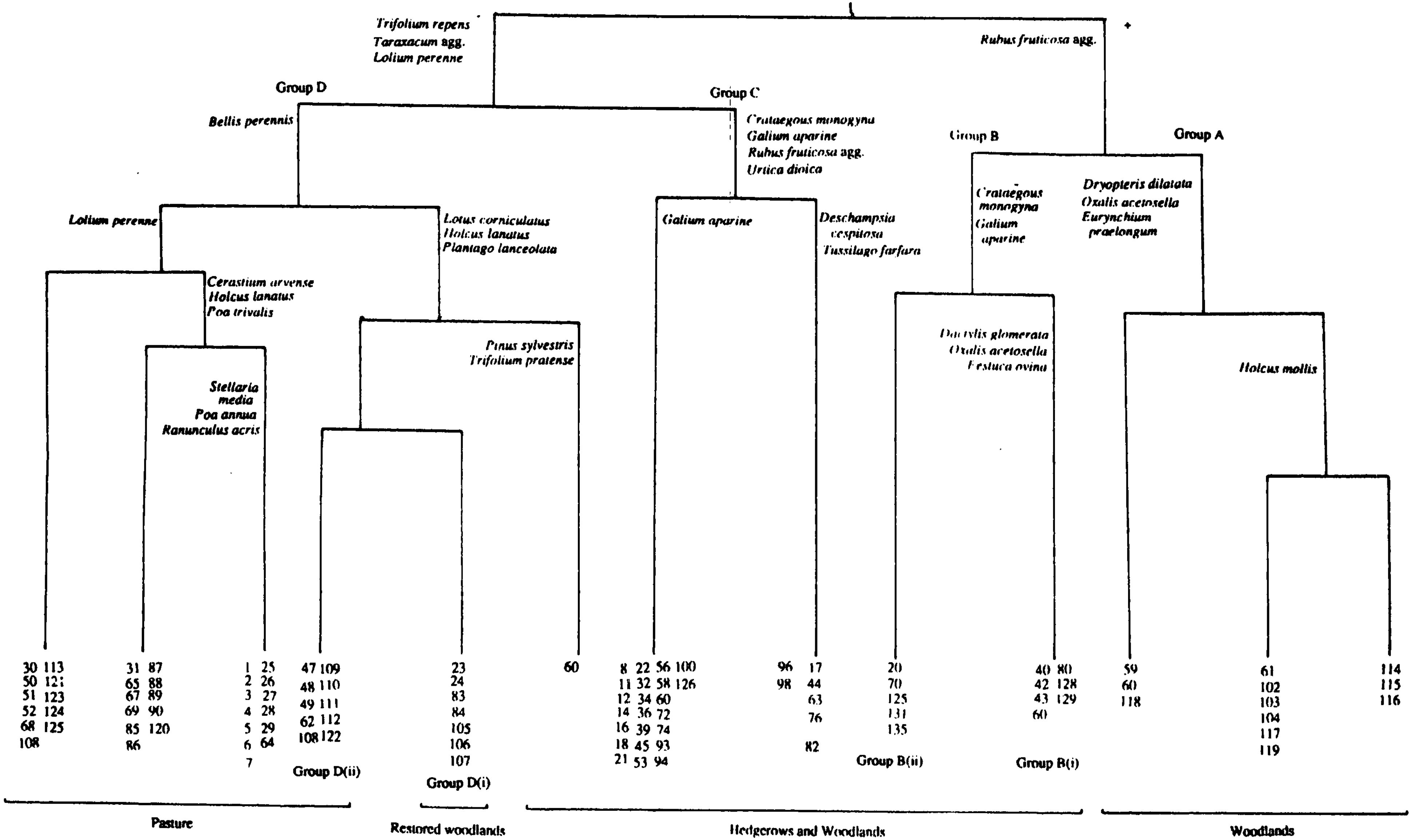
4:1 Classification of community abundance data from woodlands, hedgerows and pastures, using TWINSPAN.

The classification of all the community abundance data broadly differentiated, through consecutive dichotomies, pastures, hedgerows and woodlands on former opencast sites from similar habitat types sampled on undisturbed areas. The results were presented as a dendrogram with the length of the vertical lines representing the size of the eigenvalue (Figure 3). The sites and their corresponding sample code numbers are listed in Appendix E.

The first division separates all pastures and restored woodlands from the majority of the woodlands on undisturbed land. Hedgerows and woodlands have similar plant components and hence are not classified separately at this stage. Ninety one percent of the sites present on the positive side of the dichotomy are undisturbed woodlands. The species contributing most to the positive division are *Rubus fruticosa* agg. which has a high association with other stress tolerant plants that grow predominantly in woodlands, such as *Pteridium aquilinum*, *Hyacinthoides non-scripta* and *Sorbus aucuparia* (Grime 1988). Also present on these sites was *Eurynchium praelongum* which prefers shaded rocks or woods; these conditions are not present in recently planted woodlands.

At the third division sites on undisturbed ground are divided into a woodland group (Group A) which is characterised by the indicator species *Dryopteris dilatata*, *Oxalis acetosella* and *Eurynchium praelongum* (listed here in importance of their effectiveness in the classification) and a group of hedgerows and woodlands (Group B). *Dryopteris dilatata* prefers conditions of little bare soil in coniferous woodlands on acidic strata, the incomplete ground cover in woodlands on opencast mined sites accounts for the absence of this fern from such sites. *Oxalis acetosella* is mostly recorded from woodland habitats with little exposed soil and high tree-litter depositions with a soil pH of 3.3 - 5.0 (Grime 1988). These two features are characteristic of old woodlands and were not present on woodlands on former opencast areas (Group D(i)) where the 12 to 20 year old trees do not form a canopy that shades the entire ground. Of the undisturbed woodlands sampled three, (59, 103 & 104), were mature coniferous plantations. The similarity in composition of the ground flora of these three mature plantations resulted in them being associated with the undisturbed woodlands.

Figure 3. Dendrogram showing the classification of all samples taken, showing indicator species at each stage.



Group B contains a mixture of both undisturbed hedges and woodlands, indicated by *Dactylis glomerata*, *Oxalis acetosella* and *Festuca ovina*. Group B(i) includes four undisturbed woodlands 43, 42, 60 and 80, and three hedges, and is divided from Group B(ii) by the presence of the indicators *Galium aparine*, *Dactylis glomerata*, *Oxalis acetosella* and *Festuca ovina*, and the absence of the fern *Dryopteris dilatata*. Two of these woodlands were subject to grazing and the ground flora was not of the typical tall herb community. The *Quercus* dominated woodland (site no. 80) had many footpaths passing through it and it is possible that more representative areas were made impenetrable by the presence of tall shrubs and brambles. *Festuca ovina* is an important component of upland pastures and prefers open habitats rather than shaded woods. The remainder of the sites in Group B (40,128 & 129) are old hedges growing on undisturbed ground, and were divided from the other hedges in Group B(ii) and Group C because they had mature oak trees as standards which cast dense shade making the ground flora more like that of the woodlands on undisturbed areas that have a similar ground flora.

All of the pastures and some of the restored woodlands were divided from other habitats at the fourth division (Group D), which is based on the presence of the indicator species *Bellis perennis*. A group of 10 pastures (Figure 3, Group Dii) have the same ruderal indicator species at the positive division of Group 4 as the restored woodlands, ie. *Lotus corniculatus*, *Holcus lanatus* and *Plantago lanceolata*.

The fourth division separates all pastures and most restored woodlands (Group E) from hedgerows and the remaining restored and undisturbed woodlands (Group C).

4:2:1 Classification of woodland groundlayer community data

The woodland sites have been extracted from the total data set and an ordination by DCA was used as a first step in the analysis in order to visualise the relationships of the woodlands. The ordination plot is shown in Figure 4 where the end-groups of the classification are superimposed on the DCA plot. The data fall into three major groups, Group 1 is composed of all the woods sampled on former opencast sites, Group 3 consists of undisturbed coniferous and *Betula* dominated woodlands together with the oldest woods sampled on former opencast mined sites, and Group 2 contains the remainder of the undisturbed woods of *Quercus*, *Corylus* or *Fraxinus* dominance. The first axis possibly reflects the transition from established to more ruderal woodland species, going from negative to positive on the plot.

In order to summarise the characteristics of each group constancy tables were produced showing the constancy class of important species per nodum (Table 4). Constancy was calculated for those noda represented by five samples or more and only those species with a constancy of II or above were included. Constancy is expressed in roman numerals according to the following definition (Mueller-Dombois and Ellenberg 1974).

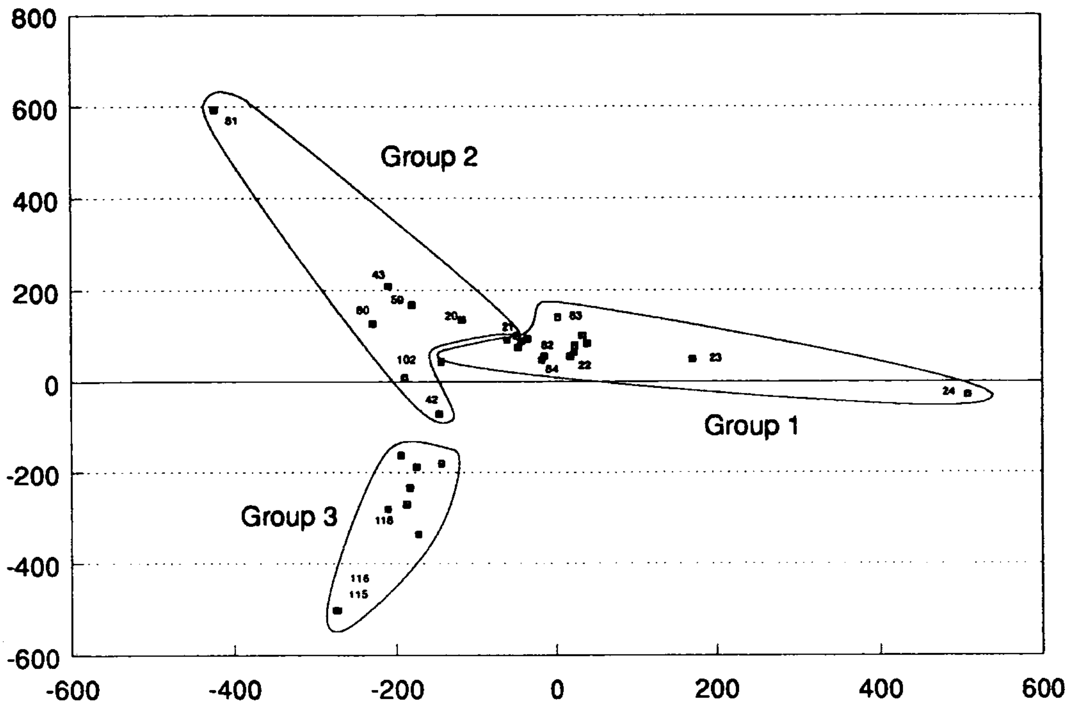
% constancy of a species between sample sites	Class
1 - 20	I
21 - 40	II
41 - 60	III
61 - 80	IV
81 - 100	V

The first TWINSPAN division was made on the presence of *Dryopteris dilatata* (Figure 6) and groups undisturbed woodlands with the oldest releves sampled on opencast mined land (ie. Charlaw) on the positive side of the dichotomy and all the young woodlands on former opencast sites and the remainder of the undisturbed woodlands on the negative side of the dichotomy.

Group 1

Group 1 lies along the positive axis of the DCA plot with samples 23 and 24 at the extreme positive end. These were the youngest woods sampled at Biggin South. A comparison of the two DCA plots of sites and species, (Figure 4 & 5), allows the plant species that favour the conditions at these sites to be elucidated. Plant species characterising the sites at the positive end of the axis are ***Anthoxanthum odoratum*** and ***Rumex crispus*** which are not usually recorded at woodland sites (Grime 1988). Sites 44, 45 and 46 (these are not labelled on the plot in Fig.4 because they are too clustered) all lie to the extreme left hand end of Group 1 and show similarity in plant associations with Group 2. These woodlands were very different from those at the other end of the group by being dense and impenetrable and containing *Deschampsia cespitosa*, *Epilobium angustifolium*, *Sagina procumbens* and *Ulex europaeus* (at the edge).

Figure 4. Woodland abundance data: DCA ordination diagram with sites shown.



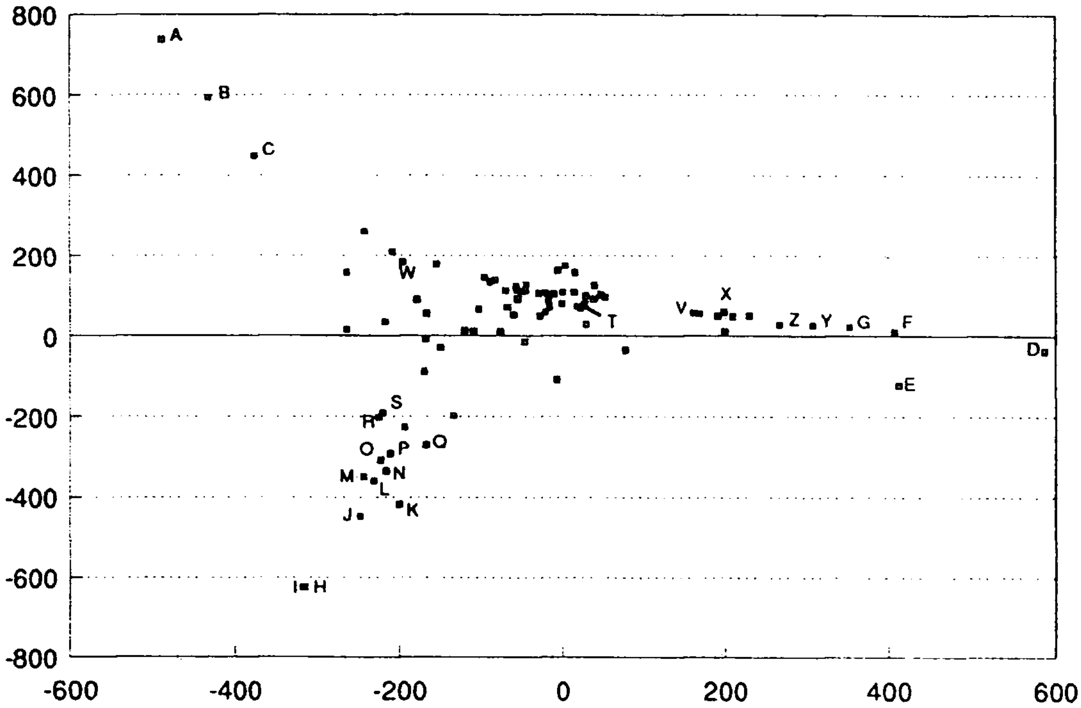
Common bent (*Agrostis*) is the dominant grass of these Group 1 woodlands and is a common grass of pasture, heath and waste places. The dominance of *Agrostis* can explained by its ability to grow in vegetation types of intermediate to low intensities of disturbance. Other grasses preferential to this group include *Dactylis glomerata* and *Holcus lanatus* which again are characteristic of meadows, pastures and rough grassland; as is *Deschampsia cespitosa* which grows in the poorly drained troughs of these plantations.

Other species present in this group are chiefly components of meadow and pasture flora, eg. *Ranunculus acris*, *Cerastium fontanum* and *Cerastium arvense*; again indicating the open nature of this group of young woodlands. *Rubus fruticosa* agg. is usually associated with scrub and hedgerows and occurs in this group on the DCA plot because of its ability to tolerate stress and compete with other ruderal plants. These plants generally favour a pH of below 5.0, although the mean pH measured for Group 1 was 6.2 (Table 3), (but the accuracy of this pH measurement as a true indication of the soil pH must be questioned as the sample was taken at about 5cm below the surface of the ground). There is no significant correlation between the soil pH and with the age of the opencast site.

Of the mosses *Brachythecium rutabulum*, which is associated with mesic conditions, has a constancy of 40-60 % in this group. The most likely cause for the low levels of moss abundance observed during the sample period would appear to be desiccation. The mosses in general show well-defined peaks of growth in the moist cool conditions of early spring and autumn. The DCA plot and the preferential species list provided by TWINSPAN shows that the highest proportions of mosses and liverworts found are components of the ground flora community on these former opencast mines. *Rhytidiadelphus squarrosus*, *Atrichum undulatum*, *Eurynchium praelongum* and *Bryum* sp. are all positioned towards the right hand side of the ordination plot. The only two liverworts recorded from all the habitat types, *Lophocolea bidentata* and *Pellia* sp., were found in this group. This relative bryophyte richness may be influenced by the deep furrows that are an element of coniferous plantations, these offer a moist and humid microclimate suitable for bryophytes.

As the canopy closes the capacity of plants to tolerate shade conditions becomes more important than their ability to compete for light (Grime 1979). In fact, shade tolerant plants such

Figure 5. Woodland abundance data: DCA ordination diagram with species shown.



The plant species shown are: **A** = *Aegopodium podragria, Centaura nigra, Brachythecium* sp. and *Thuidium tamariscinum*, **B** = *Stachys officinalis*, **C** = *Potentilla erecta*, **D** = *Bromus mollis*, *Geranium molle*, **E** = *Anthoxanthum odoratum*, **F** = *Rumex crispus*, **G** = *Agrostis* sp. **H** = *Melampyrum pratense, Hyacinthoides non-scripta & Ulmus glabra*, **I** = *Ilex aquifolium* (seedling), *Lonicera periclymenum*, **J** = *Holcus lanatus*, **K** = *Betula pubescens*, **L** = *Dryopteris dilatata*, **M** = *Rhodedendron ponticum*, **N** = *Dicranum* sp. **O** = *Oxalis acetosella*, **P** = *Alnus glutinosa & Luzula campestris*, **Q** = *Festuca ovina*, **R** = *Geranium robertianum*, **S** = *Crataegus monogyna*, **T** = *Holcus lanatus*, **V** = *Cerastium arvense*, **W** = *Deschampsia cespitosa*, **X** = *Rubus fruticosa* agg., **Y** = *Cerastium fontanum & Ranunculus acris*.

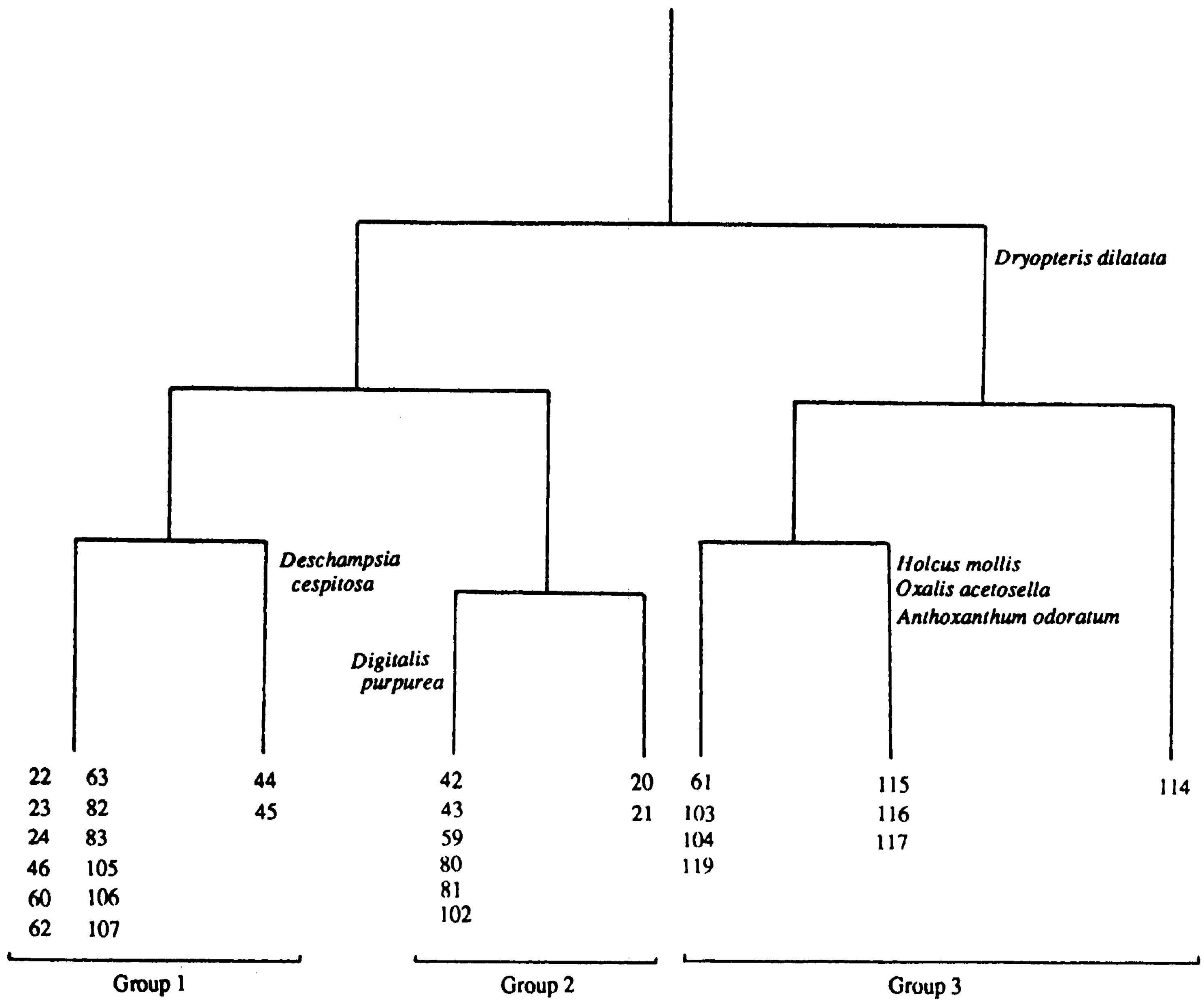


Figure 6. Dendrogram showing the results of the classification of woodlands by TWINSPAN, with indicator species shown at each stage.

as *Hedera helix, Lonicera periclymenum* and *Rubus fruticosa* agg. only flower and produce seeds at the margin of woods or beneath gaps in the tree canopy. These plants were not found in Group 1. Other abundant members of Group 1 are *Taraxacum* agg., *Trifolium medium* and *Ranunculus repens* (Table 3), which are forbs that are colonisers of bare ground but are most abundant in circumstances in which the impact of the disturbance is less immediate. Woods at Esh Winning (sites 82, 82 & 84) that had no topsoil returned to them during rehabilitation are members of this group, Figure 6.

The mean soil pH of Group 1 is 5.5 in relatively dry conditions (mean loss on drying of 20 %) and the average number of ground species per releve is 26 and the total number of different ground flora species recorded is 76.

Group 2

Group 2 is the positive group formed at the second level in the TWINSPAN dendrogram (Figure 6) and consists of the deciduous woodlands and the coniferous plantations on undisturbed areas. It contains no woods planted on opencast sites. Sample 59 is classified with this group and though it is not a typical mature plantation, it has a cover of 76-90 % by *Deschampsia cespitosa* and 33 % by *Pteridium aquilinum*. At the top left of the DCA plot is site 81, this is differentiated from the other sites in the group by a high ground cover of *Aegopodium podagraria* (50-80 %) and *Thuidium tamariscium* (75-80 %).

The vegetation type of the Group 2 sites is characterised by the constancy of *Rubus fruticosa* agg. and *Deschampsia cespitosa* which favour poorly drained, slightly acidic woodlands. The average soil pH of this group was 5.8. *Pteridium aquilinium* is abundant in this group indicating that there is a well defined leaf litter layer (leaf litter is an important factor in the competition dominance of bracken, Grime 1979). Other preferential species of this group that inhabit heavily shaded acidic woodlands with the accumulation of leaf litter include *Oxalis acetosella, Holcus mollis, Dryopteris dilatata, Digitalis purpurea* and *Anthoxanthum odoratum*. The nutrient status of these sites is relatively high, confirmed by the presence of *Eurynchium praelongum, Galium aparine* and *Deschampsia cespitosa*. The closed woodland species *Potentilla erecta, Stachys officinalis* and *Aegopodium podagraria* are characteristic of this group.

Table 2a. Soil Properties: Mean pH and percentage loss at 105°C and 550°C.
Pasture data.

Sites on undisturbed land

Mining Site	Age	pH	% Loss @ 105°C	% Loss @ 550°C
Biggin South	12	6.5	67.0	26.8
Ragpath	14	6.3	15.0	10.9
Pethburn	16	5.3	24.1	15.7
Esh Winning	30	6.4	29.0	14.7
Ibbetson	19	5.4	26.7	10.4
Charlaw	39	6.5	19.5	27.6
Peartree	38	5.6	18.4	11.8

Sites on former opencast areas.

Mining Site	Age	pH	% Loss @ 105°C	% Loss @ 550°C
Biggin South	12	6.1	31.6	14.1
Ragpath	14	6.4	16.0	8.3
Pethburn	16	6.0	23.7	7.6
Esh Winning	30	6.8	22.0	16.0
Ibbetson	19	6.4	17.8	11.8
Charlaw	39	5.6	15.7	18.5
Peartree	38	6.7	17.4	17.0

Table 2b. Soil Properties: Mean pH and percentage loss at 105°C and 550°C.
Hedgerow Data

Sites on undisturbed land

Mining Site	Age	pH	% Loss @ 105°C	% Loss @ 550°C
Biggin South	12	6.6	20.2	16.0
Ragpath	14	6.4	20.4	13.6
Pethburn	16	5.5	19.9	16.1
Esh Winning	30	6.5	18.6	12.0
Ibbetson	19	4.4	17.2	10.6
Peartree	38	5.7	9.9	9.4

Sites on former opencast areas.

Mining Site	Age	pH	% Loss @ 105°C	% Loss @ 550°C
Biggin South	12	6.3	20.2	16.0
Ragpath	14	6.1	20.2	16.0
Pethburn	16	-	-	-
Esh Winning	30	5.5	20.9	7.3
Ibbetson	19	6.1	22.5	10.8
Peartree	38	6.1	11.0	16.1

Table 2c. Soil Properties: Mean pH and percentage loss at 105°C and 550°C.
Woodland Data

Sites on undisturbed land

Mining Site	Age	pH	% Loss @ 105°C	% Loss @ 550°C
Biggin South	12	6.7	27.7	11.5
Ragpath	14	6.0	19.7	17.9
Pethburn	16	6.1	34.1	31.1
Esh Winning	30	5.6	17.5	4.9
Ibbetson	19	3.8	21.9	20.2
Charlaw	39	4.5	22.0	29.5

Sites on former opencast areas.

Mining Site	Age	pH	% Loss @ 105°C	% Loss @ 550°C
Biggin South	12	6.2	20.7	9.6
Ragpath	14	6.0	21.1	13.1
Pethburn	16	4.7	20.3	20.4
Esh Winning	30	5.9	15.7	3.0
Ibbetson	19	6.3	20.6	4.5
Charlaw	39	3.9	23.0	37.6

Table 3. Constancy tables for the ground-layer community data in woodland.

Group 1	Releves													Constancy
	22	23	24	46	60	62	63	82	83	84	105	106	107	
Brachythecium rutabulum	7				1	7	9						7	III
Cirsium vulgare	4		2			1								II
Cerastium arvense	2	1	1						1		1			III
Rumex crispus	1		2								1			II
Dactylis glomerata	5		3	1						2				II
Vicia sepium		2									2		2	II
Trifolium medium			1					1	1	4				II
Agrostis sp.			1			6	2	3	4	2	4	6	6	IV
Holcus lanatus	7	5	2				3			6	2	4	2	IV
Lotus corniculatus	2	1			2							5		II
Ranunculus repens	2								1	1	1			II
Tarax agg.		1	3					1		1	1			I
Species Richness	31	44	40	16	25	23	18	25	23	26	33	17	22	26
pH	6.5	6.5	5.5	6.8	6.4	5.0	4.4	5.8	5.9	5.9	7.3	5.6	5.9	6.2

Table 3. cont'd.

Group 2.	Releves								Constancy
	42	43	59	80	81	102	20	21	
Rubus fruticosa	6	1	2	4	2	6	4	5	V
Deschampsia cespitosa		6	9	3	5	4			III
Pteridium aquilinum			4				6	1	II
Digitalis purpurea							1	1	II
Galium aparine							2	4	II
Dactylis glomerata	5			1					II
Oxalis acetosella	3	2		1					II
Festuca ovina	2			4			5		II
Brachythecium rutabulum		1						2	II
Agrostis sp.		1	1		1				II
Betula (seedling)	1	1							II
Betonica officinalis				1	3				II
Eurynchium praelongum		1	1					6	II
Potentilla erecta				1	1				II
Species richness	20	20	14	15	15	18	21	11	17(mean)
pH	6	6	5.8	4.7	6.8	4.4	6.6	6.7	5.9(mean)

Table 3. cont'd

Group 3.	Releves									Constancy
	61	103	104	119	114	116	117	115	118	
Rubus fruticosa	1	2								II
Brachythecium rutabulum	1	4								II
Oxalis acetosella	2			3	3	3	3	3	1	IV
Festuca ovina	7	5	5					5	8	III
Dryopteris dilatata	1	7	5	6	5	6	4	4	4	V
Holcus mollis	5					5	9	8		III
Lonicera periclymenum						3		4		II
Galium saxatile	1						2			II
Holcus lanatus		2	2							II
Species richness	19	9	6	17	20	18	17	1	17	15(mean)
pH	6.0	3.4	3.5	3.8	5.6	4.3	4.2	3.6	3.6	3.2(mean)

The mean number of ground flora species per releve was 17 with a total number of 50 species found.

Group 3

This group is formed at the first division and contains undisturbed coniferous and *Betula* dominated woodlands in addition to the woods sampled at Charlaw on opencast mined sites. The group is differentiated from the previous two groups by the presence of the indicator species *Dryopteris dilatata*, which has a constancy of 80-100 % in the relevés, Table 3. Its distribution is confined to relatively undisturbed productive vegetation (Grime 1985), particularly woodlands on acidic strata, the mean pH for this group was found to be 4.2.

The division of sample 114 from the other members of this group is made on the presence of *Cirsium arvense* which is not a typical woodland species. Preferential species of sample 114 include *Crataegus monogyna, Fissidens taxafolius* and *Geranium robertianum*. This is an anomalous plot as the species components do not favour particularly acidic strata. Its position on the DCA plot at the top of the group indicate that it may have familiarity with the plant components in other groups.

Group 3 has high associations with *Rubus fruticosa, Hyacinthoides non-scripta, Lonicera periclymenum* and *Sorbus aucuparia*, a community that is characteristic of moist, fertile, undisturbed woodlands with deep leaf litter on acidic strata. According to Grime (1988) *Hyacinthoides non-scripta* has a 80% association with both *Rubus fruticosa* agg. and *Lonicera periclymenum*, which were also present on the sites. The presence of *Galium aparine* indicates that this is a fertile undisturbed habitat and with a tall herb community.

The relevés taken in Charlaw woods (117, 118 & 119), the oldest of the woods sampled in this group, indicate that the ground flora has passed through the ruderal phase of succession and that the plants are now stress tolerant. It would appear that under these conditions the ground layer community, over a period of up to 38 years has become sufficiently established so as to resemble the plant associations of the undisturbed areas sampled. *Holcus mollis*, *Oxalis acetosella* and *Anthoxantum odoratum* have the highest contribution to the further subdivisions of the group into samples 115, 116 and 117 (Figure 6, Group 3). The average pH of this group

Figure 7. Woodland abundance data: CCA ordination diagram with species and environmental variables (arrows).

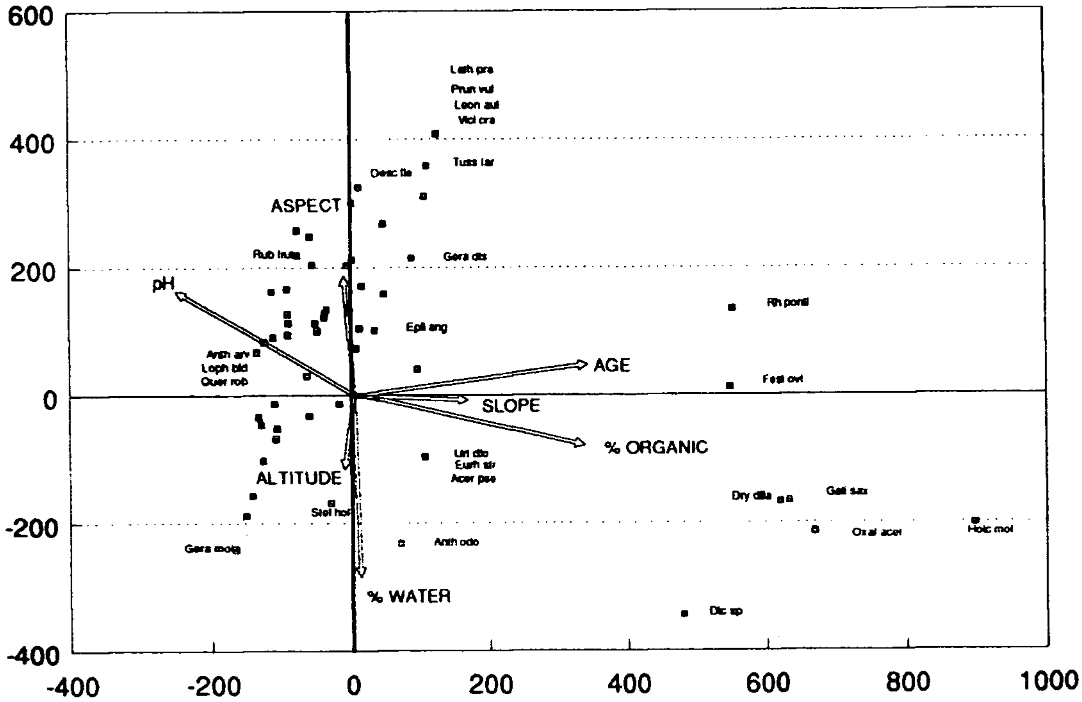
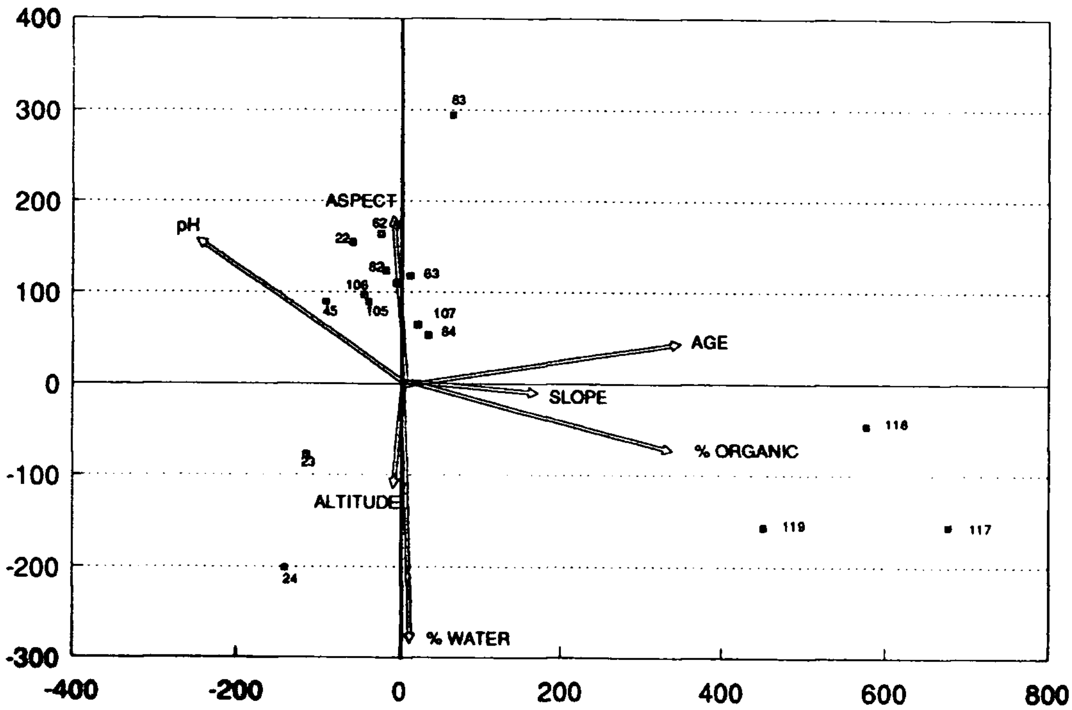


Figure 8. Woodland abundance data: CCA ordination diagram with sites on former opencast sites and environmental variables (arrows).



was 3.24, and the mean number of ground flora species found per relevé was 15 with a total number of 46 species found.

4:1:2 Influence of environmental variables on ground flora community structure in woodlands.

For the CCA analysis the woods sampled on undisturbed areas were omitted because they could not be aged. The CCA biplot (Figure 7 & 8) shows the relationship between the ground flora community data and the environmental variables pH, water content, organic content of the soil, age, aspect, altitude and slope (listed here in order of decreasing correlation with the ordination axis).

The primary axis is associated with the intercorrelated variables age, organic content of the soil and slope. The second axis is composed of altitude, water content of the soil and aspect. Rank Spearman Correlations were carried out between environmental variables in order to determine the intercorrelation; pH was found to be significantly correlated to the age of the site ($r=-0.4786$; $df=8$; $p<0.05$).

The majority of sites form an intermediate cluster along the first axis and seem to be considerably influenced by the second axis. The oldest sites sampled (sample code number 117, 118 and 119) are also those with the highest organic content and lowest pH. The species *Dryopteris dilatata*, *Galium Saxatile*, *Oxalis acetosella* and *Holcus mollis*, are all plants that favour mature woods that have a deep litter layer and a well developed earthworm and micro-flora, are consequently positioned at the end of the percent organic content axis, these species have a high constancy with sites 117, 118 and 119, (Table 4).

The sites which have most recently had coal extracted lie at the young end of the age axis, (the woods at Charlaw and also tend to be influenced by the moisture content of the soil). *Deschampsia flexuosa* lies on the negative and wetter side of the water axis whist the more drought tolerant species *Anthoxanthum odoratum*, *Stellaria holostea* and *Geranium molle* lie at the other extreme of the axis. These drought tolerant species are found predominantly in a wood at Biggin South (site 24).

4:3:1 Classification of the ground layer abundance data in hedgerows.

The classification of all the hedgerows sampled, Figure 3, failed to distinguish between hedges planted on undisturbed areas and those planted on former opencast mined sites. This may be because the ground flora of all hedges is greatly influenced by grazing of livestock who can squeeze their heads through the wire fence surrounding the hedge. Also hedges that are adjacent to pastures and arable fields are subject to the drift from herbicide and pesticide applications and seeds sown on the pastures. Consequently for the classification of hedgerows by TWINSPAN (Figure 9) the hedgerows sampled on undisturbed land were omitted.

This lack of distinction between the flora of undisturbed and former opencast sites was corroborated by a DCA of the hedges, (Figure 10) in which the majority of samples are clustered around the origin of the plot with two outliers (sites 129 & 130) situated towards the positive end of the first axis. Sites 129 and 130 lay on either side of one 38 year old hedgerow at Peartree with an east and west facing aspect respectively. Another outlier, at the positive end of the second axis, is the south facing side of a hedge sampled at Ragpath (site 34)(Appendix D). This hedge contains the species *Heracleum sphondylium*, *Achillea millefolium*, *Rosa canina* agg. and *Galium aparine* which are not found on former opencast sites and are usually associated with woodlands. Mature standards are only found on undisturbed hedges. The tree species planted by British Coal, *Quercus robur*, *Sorbus aucuparia* and *Acer pseudoplatanus* planted as standards, were not mature on the sites sampled.

Ilex aquifolium, *Lonicera periclymenum*, *Rosa canina* agg. and *Sambucus nigra* are shrubs and plants that are regularly found in old hedges. The geology and soil composition determine the presence or absence of certain shrub and tree species. Where management is absent taller plants are at an advantage, eg. *Agropyron repens*, *Holcus lanatus*, *Arrhenatherum elatius*, large umbellifers, eg. *Anthriscus sylvestris* and *Heracleum sphondylium* and other strongly growing plants such as *Ranunculus acris*. All of the hedges on undisturbed sites had either no fence, or vestigial remains, this allowed livestock to take advantage of the shade offered by the mature standard trees and to graze up to the trunks of the hawthorn

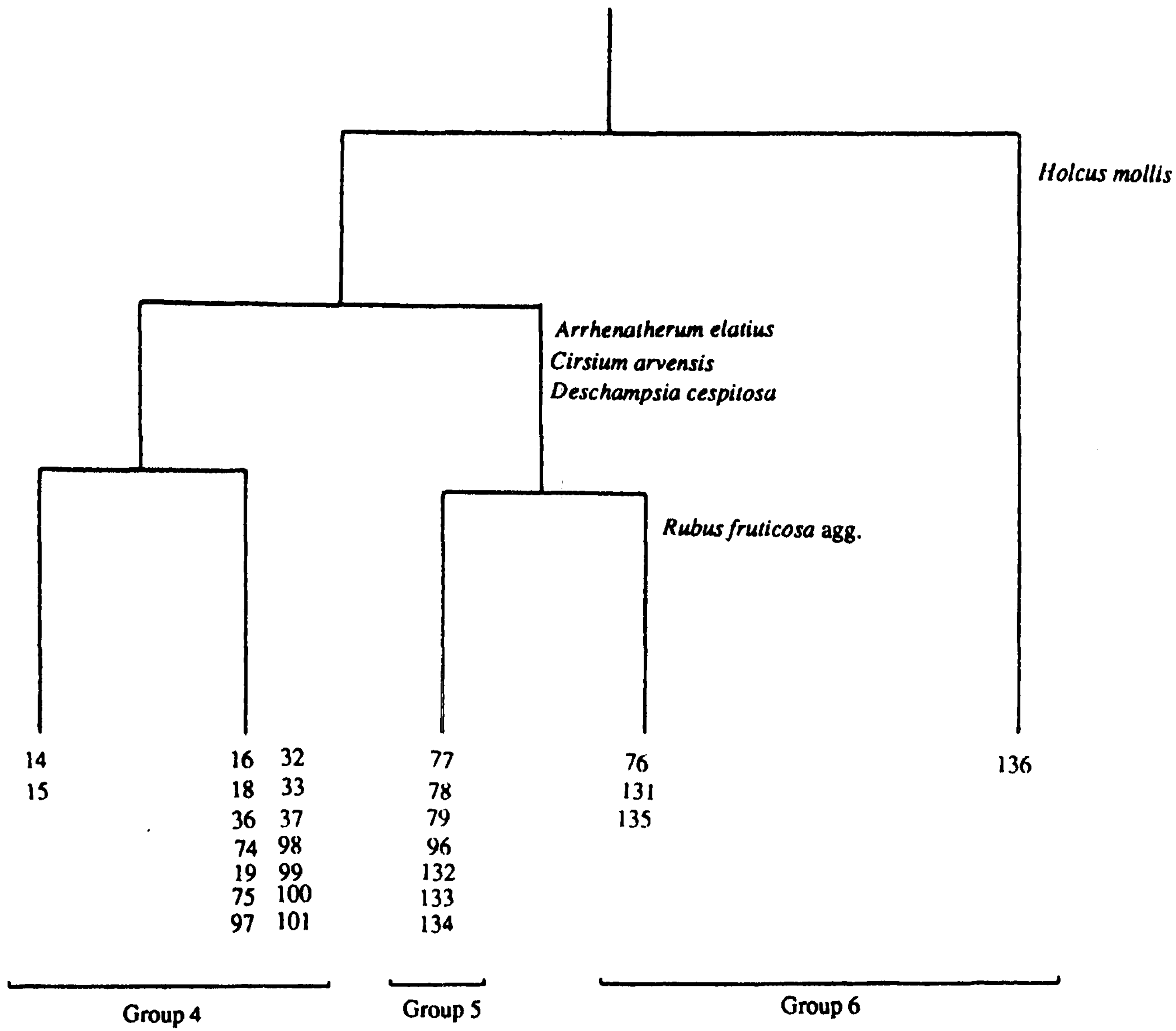


Figure 9. Dendrogram showing the results of the classification of hedgerow data by TWINSPAN, with indicators species shown at each stage.

Table 4. Constancy table for the groundlayer community data in hedgerows on former opencast land.

Group 4	Releves																Constancy
	14	15	16	18	19	36	74	75	97	32	33	37	98	99	100	101	
Crataegous monogyna	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	V
Ranunculus repens										1	1	2	3	2			III
Lolium perenne			3						2	2	6	8	3	5	5	7	III
Stellaria media												1	1	1	4		II
Galium aparine	2	1	2	2	1	3	1					2					III
Taraxacum agg	6	4		4		5						2			1		II
Holcus lanatus	3	4		4	4		6	2	2	6	4		5	3			IV
Urtica dioica				3			2	9					1				II
Poa annua	2	3	3	3									1				II
Dactylis glomerata			3	2		4	2		4								II
Poa trivalis				2	1							2					II
Species richness	19	19	19	20	20	19	17	17	32	20	20	19	22	22	19	19	20(mean)

Average age of the group=18

Table 4. cont'd

Group 5	Releves							Constancy
	77	78	79	96	132	133	134	
Holcus lanatus	1	2	3	2				III
Dactylis glomerata		2	2			2		II
Crataegus monogyna	10	10	10	10	10	10	10	V
Geranium dissectum	1	1	2					II
Cirsium arvense	1	4	1	4				IV
Arrhenatherum elatius		6	7		6	4	5	IV
Tussilago farfara	2	1	2	1		1		IV
Deschampsia cespitosa	2	1	4	4				V
Poa trivalis	1	2						II
Festuca rubra					3	9	7	II
Species richness	21	18	19	32	21	23	23	22(mean)

Average age of the group=22

Table 4. cont'd.

Group 6.	Releve				Constancy
	76	131	135	136	
Crataegus monogyna	10	10	10	10	V
Urtica dioica		3			I
Cirsium arvense	1	5	1		III
Potentilla reptans			6	1	I
Rubus fruticosa	3	5	1	2	V
Arrhenatherum elatius	5	7	8		III
Holcus mollis		4	3	6	III
Species richness	21	21	17	17	19(mean)
pH	5.8	6.4	5.5	5.5	5.8(mean)

Average age of the group=36

Also present:

Agrostis sp.,
Dactylis glomerata,
Conopodium majus,
Deschampsia cespitosa,
Epilobium angustifolium,
Equisetum arvense,
Festuca ovina,
Galium aparine,
Holcus lanatus,
Lotus corniculatus,
Rumex crispus,
Rumex obtusifolius,
Acer pseudoplatanus,
Sambucus nigra,
Rosa canina agg.,
Brachythecium rutabulum,
Eurynchium striatum.

Hedgerows are natural projections of woodlands, where the hedgerow is protected from grazing by the presence of a fence or a ditch the woodland competitive ruderal species such as *Galium aparine, Galeopsis tetrahit, Bromus racemosus. Melampyrun pratense. Digitalis purpurea* and *Poa pratensis* are present. The moss *Eurynchium praelongum* was found in the ground flora of all the groups (Appendix A). It is usually associated base-rich soil in woodlands.

The classification of the hedges on former opencast mined sites, (Figure 9), mostly grouped the opposite sides of the same hedge together. *Crataegus monogyna* was non-preferential at all pseudospecies levels because it is the principal component of all hedgerows sampled. There is one misclassified site and three groups that are dissimilar to each other. Group 4 is comprised of all sites under 20 years old, Group 5 and 6 contains hedges sampled at Esh Winning and Peartree; Group 6 contains one misclassified outlier, site 136.

Group 4.

This group consists of 16 samples, the average age of the hedges in this group is 18 years. The ruderals *Stellaria media, Stachys sylvatica, Achilles millefolium* are prevalent (Table 4) under the hedges where the shading and soil humidity are high. The grasses *Lolium perenne, Holcus lanatus* and *Poa annua* have a high constancy and are important components of the ground flora, Table 5. *Galium aparine* and *Poa trivalis* can survive in vegetation dominated by larger herbs or trees by exploiting the periods in the year when the potential impact of the dominant species is at a maximum, they reach their greatest stature in July and June (Al-Mufti et.al. 1977). The average number of ground layer species is 20 with a total of 53 species found in the group.

Group 5.

The average age of this association of seven sites (with one non-preferential site) is 28. This vegetation type was characterised by the constancy of *Deschampsia cespitosa, Tussilago farfara* and *Arrhenatherum elatius* (Table 4). The average number of ground flora species per relevé is 22, the total number of species in the group is 55. Preferential species of this group were *Geranium dissectum, Holcus lanatus, Dactylis glomerata* which are common components of rough grassland, and *Plantago lanceolata* whose seed can persist in the seedbank for a considerable period.

Figure 10. Hedgerow adundance data: DCA ordination diagram with species shown.

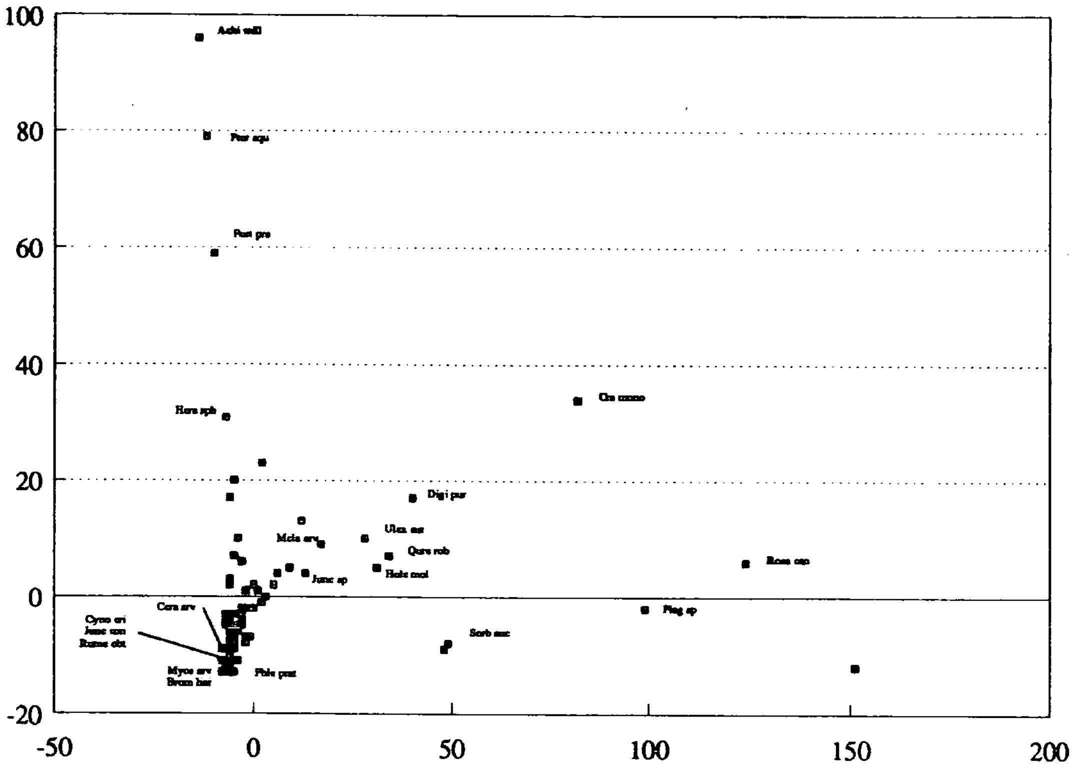
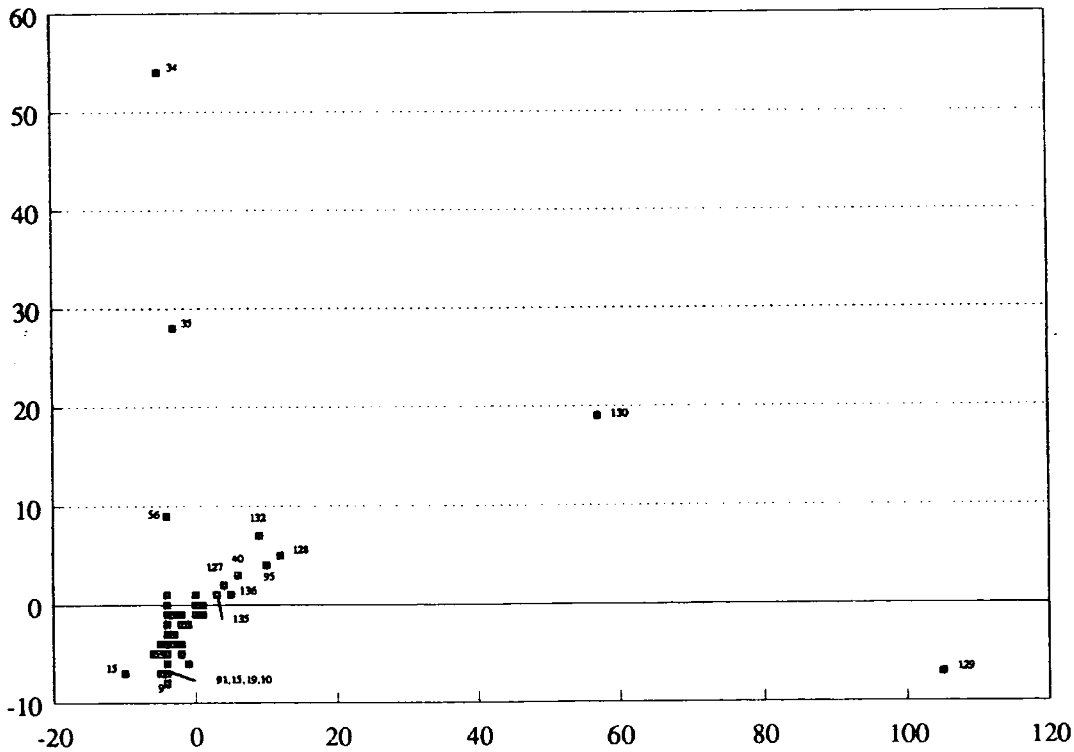


Figure 11. Hedgerow abundance data: DCA ordination diagram with sites shown.



Group 6.

This association of sites consisted of four plots. The indicator species and positive preferential for the misclassified site No.136 is *Holcus mollis*. This species was found in four hedgerows on the same site within 200m of each other. The age of these hedges 35 years and there was a mean number of species per releve of 19 and a total number of ground flora species of 32, which is lower than in the younger Groups 4 and 5. *Brachythecium rutabulum* is a preferential species for this group at all pseudospecies levels. Constant members of this group (Table 4) include *Urtica dioica*, a competitive plant which favours more established habitats; *Holcus mollis* and *Rubus fruticosa* agg. which favour south facing shaded aspects. Sites 76, 131, 135, 136 which are members of this group all have a southerly aspect (Appendix D).

4:3:2 Influence of environmental variables on the ground flora in hedgerows.

The CCA ordination diagram of the hedgerow abundance data including samples taken on former opencast sites (Figures 12 & 13) displays the relationship between the ground flora abundance data and their relationship with seven environmental variables; age, slope, % water content, % organic content, aspect, altitude and pH, (listed in order of decreasing correlation with the ordination axes).

The first axis is associated with the intercorrelated variables of age and pH, with the older sites from Charlaw and Peartree sites (131-136), which have more acidic soils positioned towards the positive ends of the axis. The second axis is composed of a combination of slope, water content, aspect, organic content and to a lesser extent altitude. Rank Spearman Correlations were carried out between the environmental variables in order to determine intercorrelations. Organic content is significantly correlated to water content ($r=-0.6094$; $df=29$; $p<0.05$) and pH ($r=-0.3829$; $df=29$; $p<0.05$). The gradient of the hedgerow is significantly correlated to its age ($r=-0.3829$; $df=29$; $p<0.05$), and water content of the soil ($r=-0.5145$; $df=29$; $p<0.05$).

Figure 12. Hedgerow abundance data: CCA ordination diagram with plant species and environmental variables (arrows).

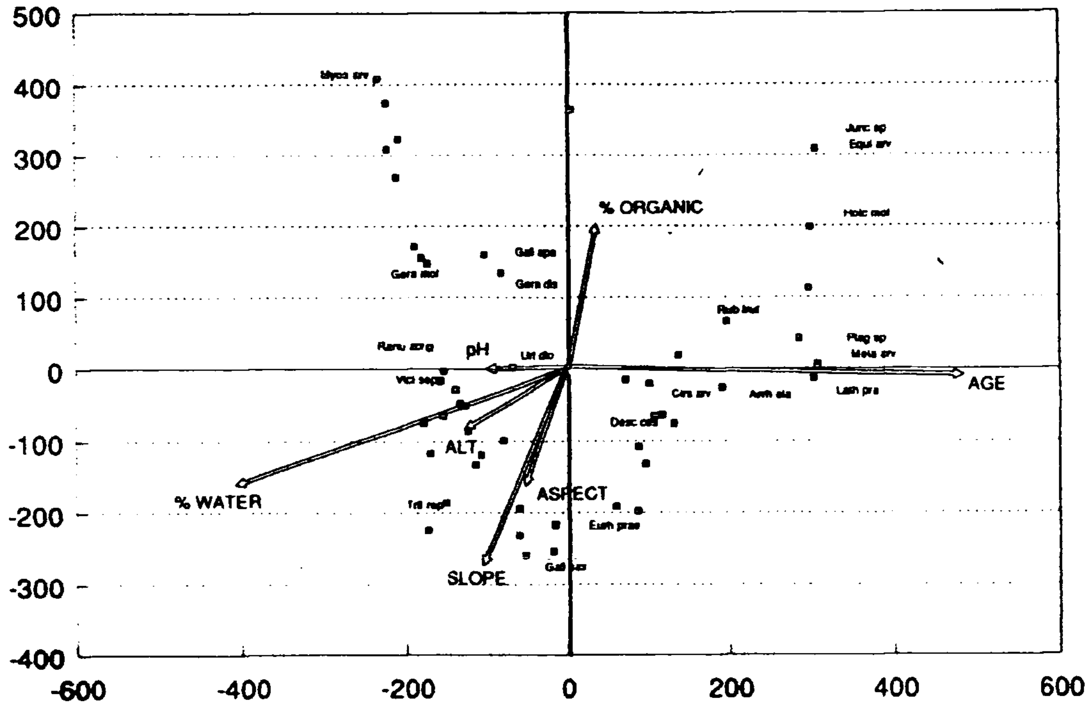
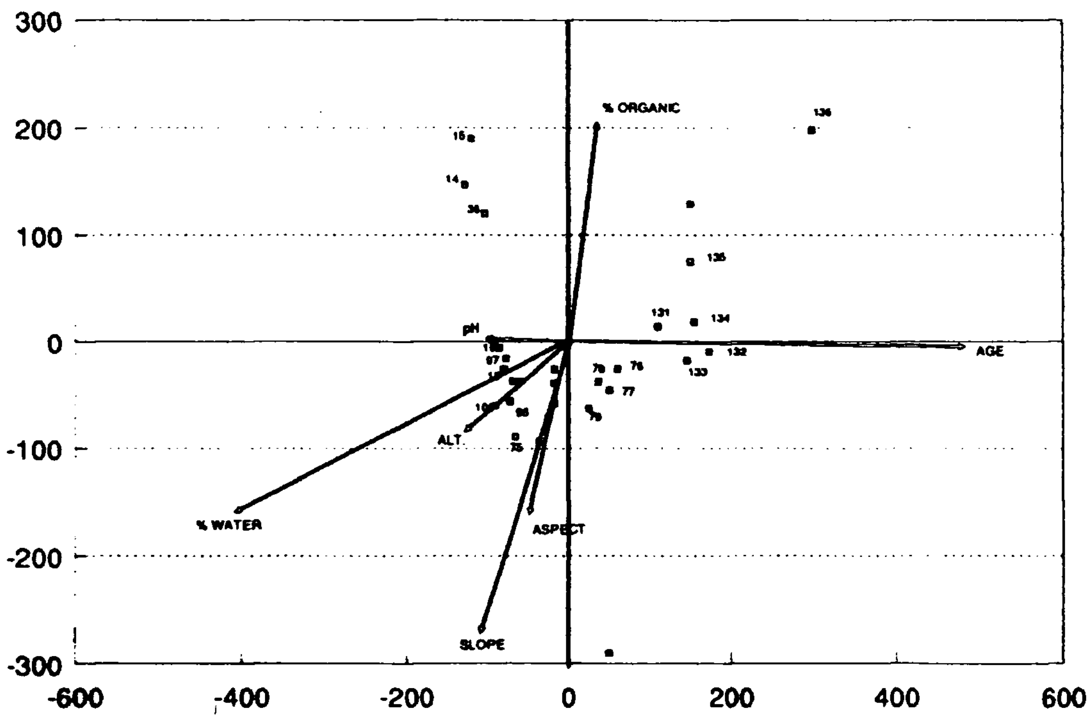


Figure 13. Hedgerow abundance data: CCA ordination diagram with sites on former opencast mined land and environmental variables.



The sites that are positioned at the negative side of the age axis are composed of sites at Biggin South, Ragpath and Pethburn. *Myosotis arvens* is positioned between the organic content and the pH axis. Woodland species such as *Melampyrum pratense* and *Holcus mollis* whose distribution is centred on undisturbed habitats lie on the positive side of the first axis. They are negatively correlated with the pH axis. *Galium saxatile* is positioned at the positive extreme of the aspect and slope axis and the negative extreme of the organic content axis, it has a distribution centred on unproductive habitats that are north facing in unshaded conditions (Grime 1988). *Vicia sepium* is positioned at the positive end of the slope and aspect variables and at the negative end of the organic content axis, and is a characteristic hedgerow species (sepium='of hedge'). *Crataegus monogyna* is ubiquitous within every hedgerow and is thus positioned at the origin of the first and second axis on the biplot. *Galium aparine* occurs on deep fertile soils (Grime 1979) and is positioned between the positive ends of the organic content and pH axes.

4:4:1 Classification of the ground layer community data on pastures.

The first division of the classification of the ground flora abundance data separated the data into a group of seven sites (Figure 12, Group 7) in the positive division and a group of 36 sites on the negative side (Figure 12, Groups 8 & 9). the negative indicator species is *Lolium perenne*. The positive indicators for this division are *Holcus lanatus* and *Plantago lanceolata*. The species and to a lesser extent the sites are spread along the first axis of the of the DCA plot, (Figures 15 & 16). On the basis of the specific requirements of the plants the primary axis can be postulated to relate to a gradient from ruderal to later successional species going from left to right across the plot (Figure 15 & 16).

The sites in group 7 (Figure 12) are positioned on the positive end of the primary axis and are composed of the three medieval ridge and furrow fields (sites 47, 109 & 122); two undisturbed fields (49 & 110) and two pastures sampled at Charlaw (111,112). These sites are characterised by the high constancy of *Holcus lanatus*, *Festuca ovina* and *Agrostis* sp. which are all associated with habitats of intermediate fertility (Table 6). Other constant species of this group include *Plantago lanceolata*, *Lolium perenne*, *Rumex acetosa*, *Leontodon autumnalis* and

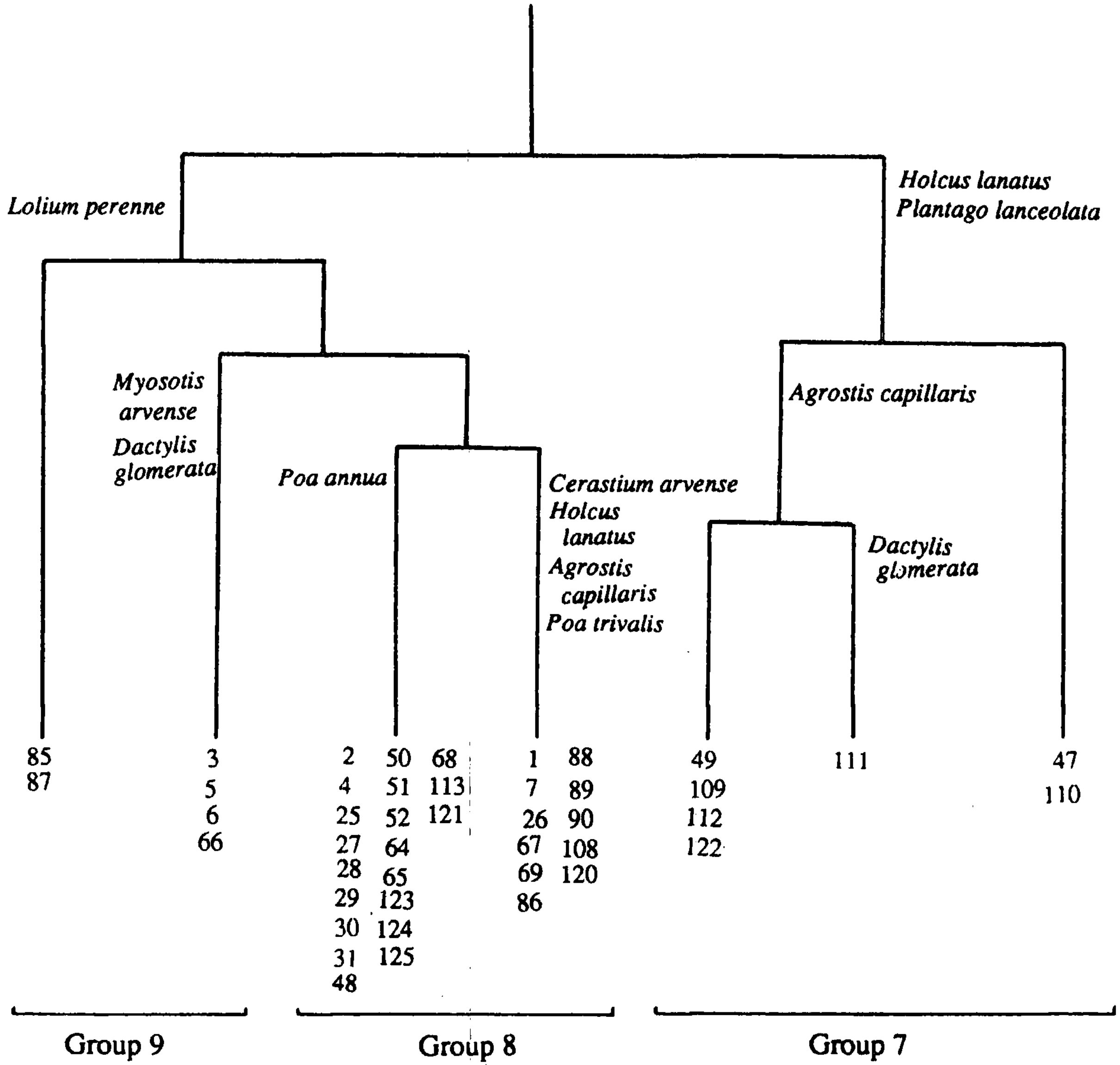


Figure 14. Dendrogram showing the results of the classification of pastures by TWINSPAN, with indicator species shown at each stage

Table 5. Constancy table for the groundlayer abundance data in pastures on opencast mines

Group 7	Releves							Constancy
	47	49	109	110	111	112	122	
Holcus lanatus		1	3	3	4	6	4	V
Plantago major		2				3		II
Plantago lanceolata			1		3	2		III
Festuca ovina	6	4			6	5	5	IV
Lolium perenne		2	4	5				III
Agrostis sp.		5	6		2	2	4	IV
Lotus corniculatus		1			4			II
Trifolium repens	5	5	5	5	5		5	IV
Trifolium medium	2				3			II
Rumex acetosa	1			1		2	3	III
Ranunculus acris	2			4	1	2	2	III
Leontodon autumnalis		2			3	2	2	III
Taraxacum agg.	1					2	2	III
Cynosaurus cristata			3	3				II
Anthoxanthum odoratum			3				3	II
Deschampsia cespitosa			1				4	II
Eurynchium praelongum					5	4		II
Species richness	26	24	17	23	14	39	21	23(mean)
pH	5.8	4.1	6.7	6.1	5.0	5.3	5.5	5.5(mean)

Table 5. cont'd.

Group 8	Releves											Constancy
	1	7	26	67	69	86	88	89	90	108	120	
Trifolium repens	2	6	4	6	6		5	5	9	4	3	V
Cerastium arvense	1		2		1	1	8		1			III
Agrostis sp.					2	2	1	5		6		III
Phleum pratense	3			5	3	2	2	2				III
Lolium perenne	6						4	4	5	8		III
Poa trivalis		5	2	3	2		2	3				III
Holcus lanatus		1	2				3			5		II
Brachythecium rutabulum	5		2				3			5		II
Taraxacum agg.	1									2	3	II
Poa trivalis		5		2	3	2			2			III
Species richness	14	22	24	15	16	6	11	10	12	18	12	14(mean)
pH	6.5	5.7	6.4	6.5	6.7	4.9	6.3	6.0	6.8	6.8	6.1	6.2(mean)

Table 5. cont'd.

Group 9.	Releves						Constancy
	85	87	3	5	6	66	
Lolium perenne	4	6	3	5	9	7	V
Myosotis arvense			2	1	1	1	IV
Dactylis glomerata			7		6		II
Ranunculus acris	5			8	4		III
Trifolium repens	4	3					II
Brachythecium rutabulum	7		4				II
Bellis perennis		6	3	2			II
Ranunculus repens			2		1		III
Poa annua			2	1		4	II
Poa trivalis		2			3		II
Stellaria media				2	2	2	III
Species richness	20	6	31	20	24	21	24(mean)
pH	5.1	6.2	6.9	6.2	6.5	6.2	6.2 (mean)

Taraxacum agg. indicating a moderately disturbed habitat of neutral pH. The indicator species *Holcus lanatus* and *Plantago lanceolata* are positioned on the positive side of the first axis, (Figure 15), along with *Equisetum arvense* and *Deschampsia cespitosa* which are stress tolerant competitors that favour moist unimproved pastures of a neutral pH. The average pH of group 7 is 6.2, the water content is 24.8 %, the organic content is 15.4 %, whilst the average number of species per relevé was 14 and the total number of ground flora species found in this group was 65.

The sites in group 8, (Figure 12), have not been subdivided further due to the similarity in composition and abundance of plant species. They are clustered towards the negative end of the primary axis, (Figure 16). Notably, two of the sites at Peartree which are regularly ploughed and seeded are of a similar age since restoration to the pastures sampled at Charlaw but are not associated with these.

Arrhenatherum elatius has its highest frequency of occurrence in productive pastures (Grime 1988). The annual grass *Poa annua* is a ruderal that can survive the damage by animals and the seasonal effects of drought better than other species and is thus positioned at the negative end of the first axis. There is a greater proportion of ruderal species on the negative side of the first axis on the DCA plot, (Figure 15), eg. *Myosotis arvensis*, *Capsella bursa-pastoris* and *Geranium molle*; possibly constant disturbance of ploughing, scorching by urine and adverse weather conditions prevent succession progressing beyond the ruderal stage. *Plagiothecium* sp. was located in high abundance (75-90 %) at site 110. This site was within 30m of a wood which had a deep turf which supported this predominantly shade tolerant bryophyte.

4:4:2 Influence of environmental variables on the ground flora community in pastures.

The pastures sampled on undisturbed areas were omitted from the CCA analysis because they could not be aged. The CCA biplot, Figures 17 & 18, shows the relationship of the ground flora community data and the environmental variables organic content, age, slope, aspect, altitude, pH and water content of the soil (listed in order of decreasing correlation with the ordination axes).

Figure 15. Pasture abundance data: DCA ordination diagram with plant species on former opncast mines shown.

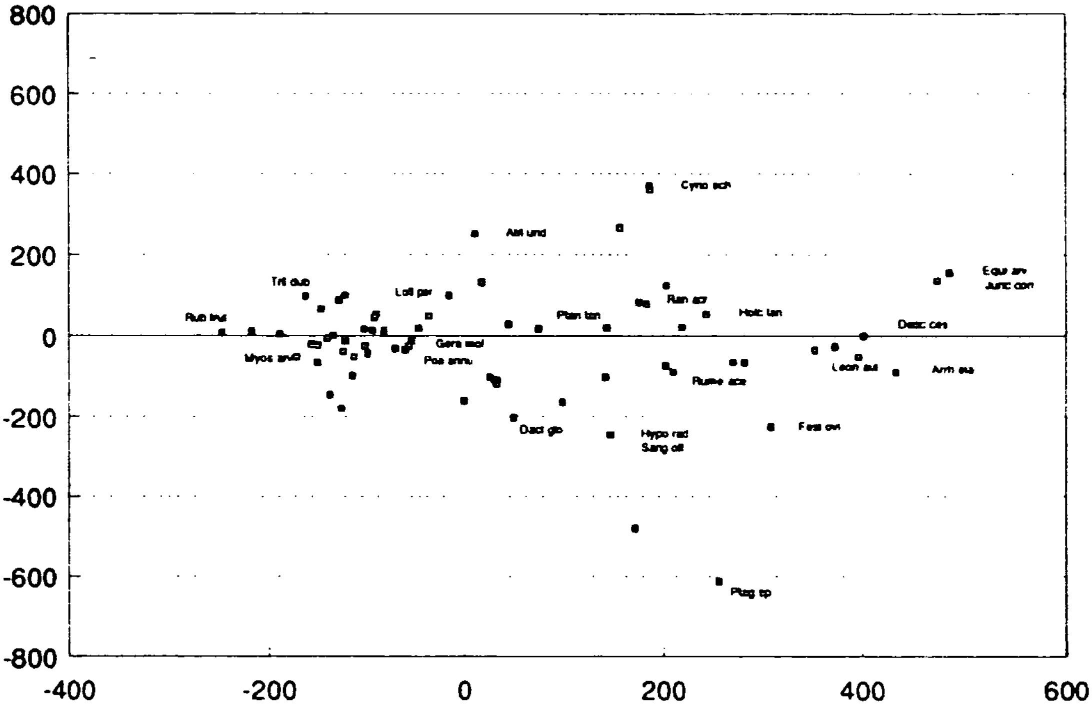
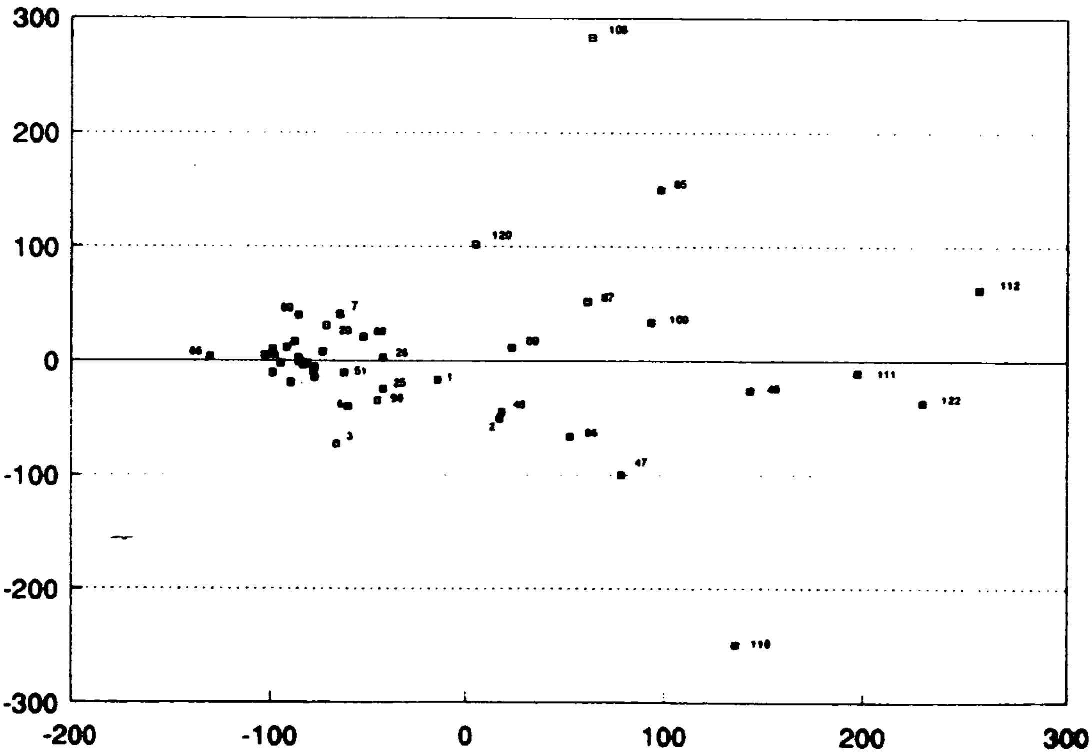


Figure 16. Pasture abundance data: DCA ordination diagram with sites on opencast mines shown.



The primary axis is a combination of the intercorrelated variables aspect, organic content and age. The second axis is a combination of altitude and slope. Rank Spearman correlations were carried out between the environmental variables in order to determine their inter-correlation. The age of a site since rehabilitation is significantly correlated to percent organic content ($r=0.534$; $df=21$; $p<0.05$). The gradient of a pasture and its aspect are significantly correlated ($r=0.7539$; $df=21$; $p<0.05$). Organic component and pH are negatively correlated, hence a soil with a high organic content is more acidic than a soil with less organic matter.

The pastures sampled at Charlaw (111, 112 & 113) lie at the right hand extreme of the primary axis. The plant species that grow on one of these sites (112) is influenced by a high water content in the soil and to a lesser extent altitude and gradient of the pasture. *Juncus conglomeratus*, *Deschampsia cespitosa* and *Equisetum arvense* prefer moist productive soils. The flora at site 113 is more strongly influenced by the second axis.

Eighty percent of the pastures are clustered at the negative end of the first axis and correspond to group 8 on the DCA plot (Figure 16) and hence are equally influenced by the environmental variables sampled. Members of Group 8 have a low organic content and are younger than the pastures at Charlaw. The pastures sampled at Peartree (123, 124 & 125) are of a similar age to the Charlaw sites and the ground flora present is influenced by a neutral to basic pH and a low soil pH and soil water content. Stress toleraters such as *Poa annua* and *Geranium molle* lie to the negative and drier end of the moisture axis. *Poa annua* and *Stellaria media* are annuals that occupy severely disturbed habitats. *Hypochaeris radicata* is positioned centrally on the first axis and has the capacity for regeneration of the shoot from buds situated near the top of the taproot, this characteristic appears to play an important role in allowing the persistence of this plant in pastures subject to close grazing by rabbits, sheep and invertebrates.

Figure 17. Pasture abundance data: CCA ordination diagram with species and environmental variables (arrows) shown.

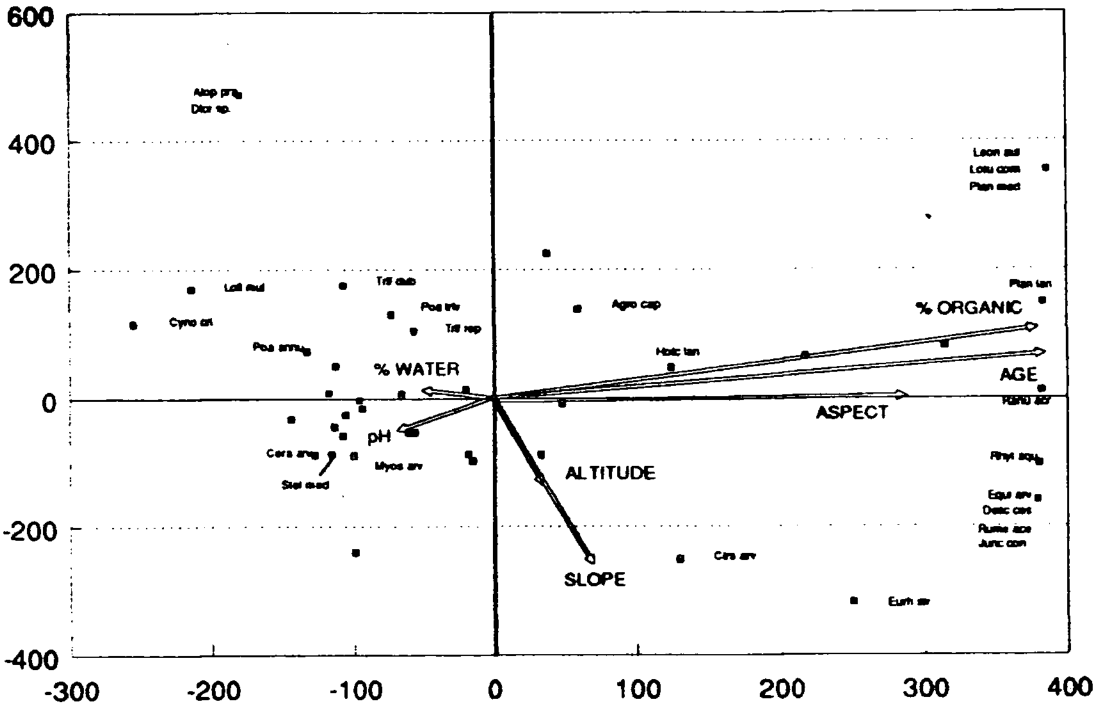
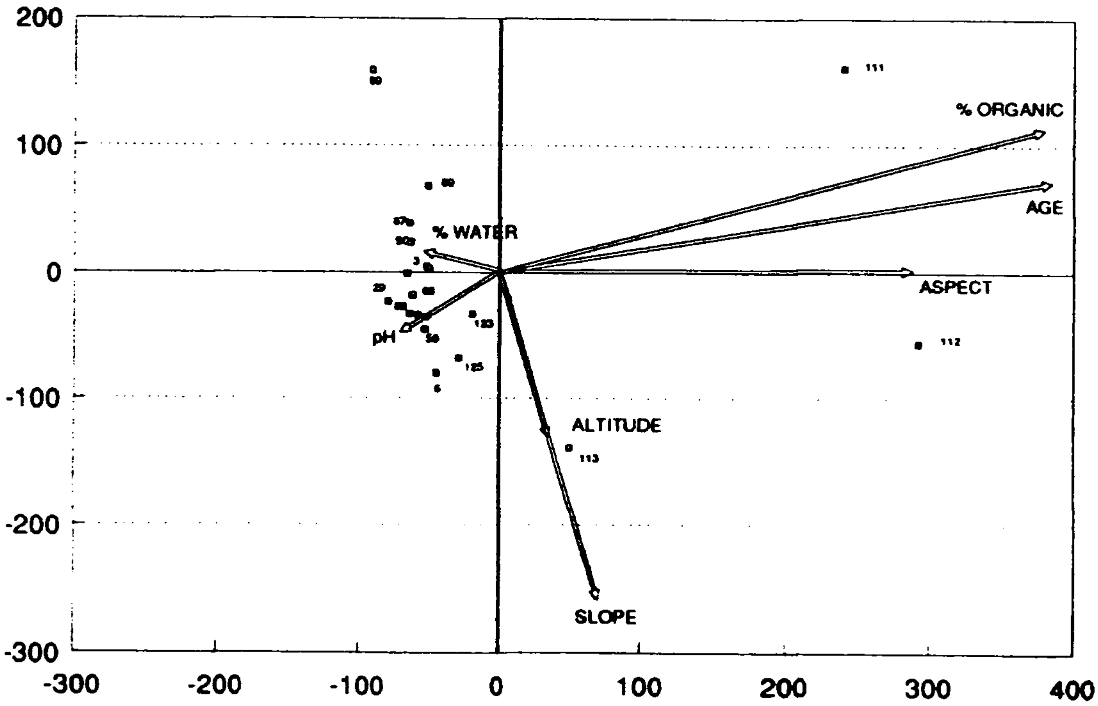


Figure 18. Pasture abundance data: CCA ordination diagram with sites and environmental variables (arrows) shown.



5. Discussion

The results of the present study have revealed the differences between the habitats surveyed on previously opencast areas and adjacent undisturbed areas and have demonstrated that the most important factors causing these differences in floral diversity in the community structure of the habitats are the physical and chemical conditions in the soil, intercorrelated with other environmental variables. The type of crops sown and the shrubs and trees initially planted during the rehabilitation period are also important within the timescale considered.

Nature of the Communities

Classification and ordination of the ground flora abundance data for each of the habitats studied differentiated pastures from hedgerows and woodlands, the latter two possess similar plant components, for example *Rubus fruticosa* agg. and *Holcus mollis*, and consequently were not so clearly differentiated from each other. The community structures of both pastures and hedgerows on undisturbed and opencast sites were insufficiently distinct for the site types to be separated. The woodlands, however, were clearly separated according to site type, possibly due to the immaturity of the trees in recently planted coniferous woods discouraging the growth of shade tolerant species characteristic of established woodlands. There is also comparatively less disturbance in woodlands than on pastures; the latter being subject to ploughing, herbicide sprays, manuring, re-seeding, grazing etc. This lower level of disturbance may allow succession to proceed more naturally in the woodlands.

When large scale disturbance of the soil occurs, as in opencast mining, succession is initiated and different species associations will replace each other through time depending upon their colonising and competitive ability and other life history characteristics. In this study, most members of the ground flora community in opencast woodlands were competitive stress tolerant grasses such as *Holcus lanatus* and *Dactylis glomerata*, wheresas the older woodlands studied contained *Dryopteris dilatata*, *Hedera helix*, *Hyacinthoides non-scripta* and *Lonicera periclymenum* as shade tolerant members of a tall herb community. A greater diversity of microclimates was, however, found in the new plantations, accounting for the relative proliferation of bryophytes, as well as for the only occurrence of liverworts and the constancy of

Deschampsia cespitosa.

The maximum species diversity was found to occur 15-20 years after disturbance. Subsequently, there is a decline in species numbers as an equilibrium community develops that is dominated by a lesser number of more strongly competitive species. 76 species were recorded in the young coniferous plantations on restored opencast land compared to 44 species in the woods on opencast land at Charlaw (35 years old) . This decrease in species richness with time since disturbance was also observed under hedgerows; 53 species were found beneath an 18 year old (approx.) hedge but only 32 species under a hedge established for 35 years.

Community variation attributable to variations in edaphic properties.

Many authors have found that the major cause of decreased productivity in crops upon opencast mines is the detrimental effects of soil storage (primarily those of consolidation) for a period of 5-6 years during opencast mining (Scullion 1984, Gibbons 1961, Tasker 1957, Evans et.al.1986, Baker & Younger 1986). It has taken millenia for the present physical and chemical properties, and the biological interactions of a soil to build up (Scullion 1984), hence it is likely to take considerably longer than the five year period of time allocated by ADAS to attain comparable fertility after mining has taken place

In this study, most of the variation of species composition in hedgerows and woodlands was explained by the organic content of the soil and by the time elapsed since it was restored. The effects of age upon the variables measured in pastures was not as great as in the other habitats, probably because of the dominant effect of the removal of nutrients by agricultural practises. In the case of pastures, the organic content of the soil in combination with slope and aspect are important secondary contributors to the variation in species composition.

The environmental variable measured that was responsible for the greatest variation in the plant communities was found to be soil organic content, but this was strongly correlated with the time since diturbance. The species of trees and shrub that are planted on an opencast site during the period of rehabilitation will themselves influence the edaphic properties of the soil and so determine the herbaceous species that will colonise. For example, conifers tend to promote greater surface organic matter accumulation, greater acidity and a higher degree of podsolisation than broadleaved species (Miles 1986). All of the opencast plantations were of coniferous (*Pinus sylvestris*), leading to the reduction in numbers of humus forming earthworms and of the microorganisms that contribute to the formation of the litter layer. In addition, compaction of the soil reduces the abundance of earthworms on restored land when compared to undisturbed areas and their slow migration into the centre of a mined area will reduce the rate of build up of humic material.in the soil. The woods at Esh Winning that had no topsoil returned to them during rehabilitation have the lowest organic matter and water content. The plant communities on these sites are composed of stress tolerant ruderal species, eg. *Dactylis glomerata*, *Lotus corniculatus*, *Holcus lanatus*, and species of disturbed soil, eg. *Ranunculus repens* and *Cirsium vulgare*.

In the woodlands studied, the pH and age of a site since rehabilitation were significantly correlated, there was a reduction from pH 5.5 on recently restored sites to 3.2 in mature woodlands. Younger woods have a poorer soil structure with less organic material and so reduced water holding capacity. This favours such drought tolerant species as *Anthoxanthum odoratum*. *Stellaria holostea* and *Geranium molle*. Miles (1986) found that there was more surface organic matter and organically bound nitrogen accumulating under conifers aged 38 to 46 than under broadleaved species; this favours species such as *Pteridium aquilinum* which exploit a cover of leaf litter in order to gain a competitive advantage over other less robust species. The amount of organically bound nitrogen accumulating under conifers up to 38 years old was nine times greater than under broadleaved species (Miles 1986). Conifer litter lies on the surface for many years prior to commutation by earthworms.

The storage of topsoil is being improved by technological advances, eg.lightweight vehicles which are now used to form smaller storage mounds that reduce the pressure experienced by soil in the mound and decrease environmental impact The seedbank within the topsoil is maintained and the aesthetic appearance of the sites also improved by sowing a grass or wildflower seed mixture onto the stored soil.

Persistence in the seedbank is an advantage for most ruderal species but is also characteristic of certain pasture species that were found during this study, eg. *Agrostis tenuis*, *Anthoxanthum odoratum*, *Holcus lanatus* and *Plantago lanceolata*; this persistence is also prevalent in species colonising seasonally waterlogged grasslands, eg. *Deschampsia cespitosa*, *Poa trivalis*, *Ranunculus repens* and *Potentilla erecta*. These species were constant members of the young plantations and in all of the pastures, though further studies would have to be carried out in order to determine wether constant disturbance of the soil was favouring the appearance of these species. There was a high proportion of annual weeds found in the pastures on and off the site because of the constant disturbance caused by cultivation of the soil. The effect of the previous years crop on the subsequent years plant community was not investigated

Environmental variables that determine community structure.

One of the prerequisites for the success of multivariate methods is measuring the relevant environmental factors. It is impossible to know with any certainty if the most relevant factors were measured or if an important variable was discarded. In this study the variables considered were chosen on the basis of what other authors have suggested as being important in plant communities and the deleterious effects of opencast mining. The soil samples from which pH, water and organic content were measured are uniform between sites but not ideal, the soil was collected from just below the rootzone of the ground flora. In hedgerows the amount of water that a soil can retain and its organic content were correlated. Pastures on recent opencast sites have a low organic content which decreases as the site gets older. The proximity of a diverse habitat as a source of potential colonisers, eg. a roadside verge, is an important variable that requires further study. The Broad Helleborine (*Epipactus helleborine*) was observed in a woodland at Pethburn (site 62) within 15m of a mature woodland.

The fields with ridge and furrow patterns that were not subject to such intense disturbance as the pastures sampled were found to have a greater diversity and species richness, compared to pastures on restored land. The similarity in farming practises for the remainder of pastures both on and off the opencast sites creates equivalent communities.

Overall, the ground flora under hedgerows on restored opencast land had a greater diversity of plant species than older hedges, because the fences protecting older hedges from grazing pressures and trampling by livestock were often absent. These recently planted hedgerows should be expected to support a greater number of small mammals than the mature hedgerows. Thus, the maintenance of these protective fences is essential for an improved floral and faunal diversity and to preserve those plants that are sensitive to grazing pressures. On the whole, community diversity was impoverished on former opencast sites, ie. there are not as many niches for plants (and animals) with more exacting requirements to occupy compared to undisturbed land. After 35 years the ground flora under coniferous plantations resembles mature plantations on undisturbed land. The management practises undertaken during the five year restoration period by ADAS are targeted at providing the farmer with fields of reasonable agricultural standard, with adequate shelter in the form of hedgerows and token woodlands. They are not aimed at the conservation of uncommon habitats that may have been present on the site prior to mining. In the selection of sites to mine, small diverse communities should be given greater value and consideration and possibly conserved by transplanting areas of turf. In the future, the possibilities that a lower demand for agricultural land as a result of changing E.C. and agricultural practises andthe implementation of the Set-Aside Policy programme (1985) offer should be exploited.They should make available land that can be managed during the restoration period with the aim of maximising wildlife value and not just the more limited one of primarily pastures, hedgerows and woodlands, as British Coal have done in the past.

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Appendix

APPENDIX A

Total species list of woodland species in the groups defined by Figure 6.

Species	Group 1	Group 2	Group 3
Acer pseudoplatanus	*		*
Alnus glutinosa	*		
Betula pendula	*		*
Betula pubescens	*	*	
Fraxinus excelsior	*	*	
Larix sp.	*		
Pinus sylvestris	*	*	
Quercus robur			*
Crataegus monogyna	*	*	*
Ilex aquifolium		*	*
Lonicera periclymenum	*	*	*
Rosa canina agg.	*	*	
Sorbus aucuparia	*		
Ulex europaeus			*
Aegopodium podagraria	*	*	
Anthoxanthum odoratum	*		*
Anthriscus sylvatica	*	*	
Arrhenatherum elatius			*
Athyrium felix-femina	*	*	
Betonica officinalis	*	*	
Calluna vulgaris		*	
Carex sp.		*	
Centaura scabiosa		*	
Cerastium fontanum	*		
Cirsium arvense	*		*
Conopodium majus	*		
Dactylis glomerata	*		
Deschampsia cespitosa	*		*
Digitalis purpurea	*		*
Dryopteris dilatata			*
Dryopteris pseudomonas	*	*	
Equisetum arvense	*		
Festuca rubra	*	*	
Festuca arundacea		*	
Filipendula ulmara		*	
Galium saxatile			*
Geranium dissectum	*		
Geranium molle	*		
Geranium robertianum		*	*
Hedera helix	*	*	
Heracleum sphondylium			*
Holcus lanatus			*
Holcus mollis	*	*	*
Hyacinthoides non-scripta			*
Hypochaeris radicata	*		
Isoetes sp.	*		
Juncus conglomerata	*		
Lactuca virosa	*		
Leontodon taraxacoides	*		
Lolium perenne		*	
Luzula campestris			*

APPENDIX A cont'd.

Melampyrum pratense			*
Melampyrum sylvaticum			*
Oxalis acetosella	*		*
Poa annua	*		
Poa trivalis	*		
Potentilla erecta	*		
Potentilla sterilis	*		
Prunella vulgaris	*		
Pteridium aquilinum			*
Ranunculus sp.		*	
Rumex acetosa	*		
Sagina procumbens	*		
Senecio jacobea	*	*	
Stachys arvense		*	
Stachys offficinalis		*	
Stachys sylvaticum	*		
Stellaria holostea		*	
Stellaria media	*		
Teucrium scorodia		*	*
Trifolium dubium	*		
Trifolium campestre	*		
Trifolium pratense	*		
Trifolium repens	*		
Tussilago farfara	*		
Urtica dioica	*		
Veronica chamaedrys	*		
Vicia cracca	*		
Vicia sativa	*		
Viola riviana		*	

Brachythecium albicans			*
Brachythecium rutabulum		*	
Dicranella sp.			*
Dicranum scoparium	*		
Eurynchium praelongum	*	*	*
Fissidens taxafolium			*
Mnium hornum		*	*
Plagiothecium cuspidatum		*	*
Polytrichum sp.	*		
Polygonium bistorta			*
Pseudoscleropodium purum	*		
Thuidium tamaricians	*		
Lophocolea cuspitata	*		
Lophocolea heterophylla	*		
Pellia sp.	*		

APPENDIX B

Total species list of Hedgerow species in the groups defined by Figure 9.

Species	Group 4	Group 5
Acer pseudoplatanus	*	*
Fraxinus excelsior	*	
Sambucus nigra	*	
Sorbus aucuparia	*	*
Ulex europaeus		*
Achillea millefolia	*	
Agropyron repens	*	
Agrostis sp.		*
Alopecurus pratensis	*	
Anthriscus sylvatica	*	
Arrhenatherum elatius	*	*
Bellis perennis	*	
Bromus mollis	*	
Carex sp.	*	
Cerastium arvense	*	*
Cirsium arvense	*	
Cirsium vulgare	*	
Deschampsia cespitosa	*	
Dryopteris felix-mas		*
Epilobium angustifolium	*	*
Equisetum arvense		*
Galium aparine		*
Galium saxatile	*	
Geranium molle	*	
Heracleum sphondylium		*
Holcus mollis		*
Juncus conglomeratus	*	*
Juncus effusus	*	
Lathyrus pratensis		*
Lolium perenne		*
Lotus corniculatus		*
Myosotis arvense	*	
Plantago lanceolata	*	*
Potentilla reptans		*
Ranunculus acris		*
Ranunculus repens		*
Rosa canina		*
Rubus fruticosa agg.		*
Rumex acetosa	*	
Rumex acetosella	*	
Rumex crispus	*	
Senecio jacobea		*
Stellaria holostea	*	
Trifolium dubium		*
Trifolium pratense	*	
Trifolium repens	*	*
Tussilago farfara	*	
Urtica dioica		*
Veronica chaemydrys	*	
Vicia cracca		*
Vicia sepia	*	

APPENDIX B Cont'd

Eurhinchium striatum	*
Eurynchium praelongum	*
Plagiothecium undulatum	*
Rhytidiadelphus squarrosus	*

APPENDIX C

Total species list of pasture species in the group defined by Figure 14.

Species	Group 7	Group 8	Group 9
Acer pseudoplatanus (seedling)	*		
Achillea millefolium	*	*	*
Agrostis sp.	*	*	
Alopecurus pratense		*	*
Anthoxanthum odoratum	*	*	
Anthriscus sylvatica		*	
Arrhenatherum elatius	*		*
Bellis perennis	*	*	*
Bromus erectus			*
Bromus mollis			*
Capsella bursa-pastoris		*	*
Centaurea nigra		*	
Cerastium arvense	*	*	*
Cerastium fontanum			*
Cerastium holsteoides		*	
Chaerophyllum temulentum			*
Chamomilla suaveolens			*
Chenopodium bonus-henricus			*
Cirsium arvense	*	*	*
Cirsium vulgare	*		*
Cochlearia officinalis			*
Conopodium majus	*		
Chrysanthemum leucanthemum			*
Cynosaurus cristatus	*		*
Dactylis glomerata	*	*	*
Deschampsia cespitosa	*	*	
Equisetum arvense	*		
Euphrasia officinalis agg.	*		
Festuca ovina	*	*	
Festuca rubra	*		
Galium saxatile	*		
Geranium dissectum		*	*
Geranium molle		*	*
Heracleum sphondylium			*
Holcus lanatus	*	*	*
Holcus mollis		*	
Hordeum sp.			*
Hypochaeris radicata	*		
Juncus conglomeratus	*	*	
Juncus effusus	*		
Lamium purpureum			*
Lathyrus pratensis	*		*
Leontodon autumnalis	*		
Leontodon taraxacoides	*		
Lolium perenne	*	*	*
Lotus corniculatus	*		
Matricona perforata		*	
Montia sp.	*		
Myosotis arvense			*
Myosotis sylvaticum			*
Phleum pratense		*	*

APPENDIX C cont'd.

Plantago lanceolata	*	*	*
Plantago major	*		
Plantago media		*	
Poa annua	*	*	
Poa pratensis		*	
Poa trivalis	*		*
Potentilla erecta	*		
Prunella vulgaris	*		
Ranunculus acris	*	*	*
Ranunculus bulbosus		*	*
Ranunculus repens	*	*	*
Raphanus raphanistrum			*
Rhinanthus minor			*
Rubus fruticosa (seedling)			*
Rumex acetosa	*	*	*
Rumex acetosella	*	*	
Rumex crispus		*	*
Sanguisorba officinalis	*		
Senecio jacobea	*		*
Senecio vulgaris	*		
Stellaria media		*	*
Sysimbrium officinale		*	
Taraxacum agg.	*		*
Trifolium dubium		*	*
Trifolium medium	*	*	*
Trifolium pratense		*	*
Trifolium repens	*	*	*
Ulex europaeus	*		
Veronica arvense		*	*
Veronica chamaedrys	*	*	*
Veronica officinalis	*		
Veronica serpyllifolia	*	*	
Vicia sepium	*		*
Viola arvensis			*
Brachythecium albicans	*		
Brachythecium rutabulum	*	*	*
Cephalsea bicuspidata		*	
Dicranum fuscescens		*	
Eurynchium praelongum	*	*	*
Eurynchium striatum	*		
Lophocolea bidendata	*		
Lophocolea cuspidata		*	
Plagiothecium sp.	*	*	
Rhytidiadelphus squarrosus	*		

APPENDIX D

Table of the sample code numbers with their corresponding environmental variables of aspect, gradient and altitude.

Code No.	Aspect(°)	Gradient	Altitude(m)
1	0	0	220
2	0	2	220
3	70	9	215
4	0	1	215
5	0	5	175
6	70	14	220
7	0	11	200
8	21	0	205
9	200	0	205
10	290	7	160
11	110	15	230
12	90	11	230
13	270	0	185
14	310	0	185
15	40	0	210
16	115	14	210
17	295	14	210
18	115	12	200
19	115	12	200
20	295	27	200
21	230	16	200
22	0	0	195
23	100	12	205

APPENDIX D cont'd.

24	80	9	195
25	0	0	140
26	330	0	130
27	290	29	110
28	0	0	125
29	330	27	150
30	340	27	160
31	340	27	160
32	230	25	150
33	50	25	150
34	200	26	175
35	20	0	175
36	310	0	140
37	130	0	140
38	120	0	140
39	300	0	140
40	300	16	140
41	120	16	140
42	330	85	150
43	60	18	190
44	320	25	150
45	300	14	150
46	0	0	150
47	140	21	200
48	190	4	230
49	270	20	200
50	240	18	220

APPENDIX D cont'd

51	250	16	220
52	260	15	220
53	230	0	240
54	50	0	240
55	140	18	200
56	320	18	200
57	60	5	200
58	240	5	200
59	310	18	235
60	310	18	200
61	210	5	200
62	270	4	235
63	270	5	205
64	90	14	210
65	230	18	200
66	230	16	210
67	210	5	190
68	230	9	155
69	210	0	155
70	30	0	195
71	120	0	195
72	330	9	205
73	150	9	205
74	130	2	200
75	310	2	200
76	210	9	200
77	22	9	200

APPENDIX D cont'd.

78	310	9	135
79	310	9	135
80	230	7	145
81	250	5	130
82	220	12	185
83	230	20	175
84	10	9	130
85	0	0	205
86	0	0	230
87	90	9	230
88	140	10	210
89	0	0	200
90	0	0	205
91	340	7	205
92	160	7	205
93	140	8	230
94	80	9	235
95	260	9	235
96	310	6	205
97	130	6	205
98	340	5	205
99	160	5	205
100	280	8	205
101	100	8	205
102	0	0	200
103	0	16	310
104	250	9	220

APPENDIX D cont'd.

105	140	6	220
106	0	0	205
107	110	18	240
108	350	20	200
109	350	5	200
110	80	8	195
111	350	8	195
112	350	18	185
113	350	18	220
114	0	18	150
115	0	0	150
116	350	33	150
117	10	20	195
118	330	16	190
119	0	18	180
120	0	0	175
121	160	5	185
122	180	10	170
123	70	2	175
124	0	0	180
125	80	6	175
126	120	0	175
127	300	0	175
128	70	5	185
129	290	0	185
130	90	0	185
131	120	2	174

APPENDIX D cont'd.

132	120	2	174
133	300	2	174
134	120	2	174
135	80	0	175
136	80	0	175

APPENDIX E. Sample code numbers and their corresponding site names that were used throughout analysis.

Part 1 : Samples taken on undisturbed areas.

Mining Site	Age	Habitat Type	Sample Code Number
Biggin South	12	Pasture Hedgerow Woodland	1, 2, 3, 4 8, 9, 10, 11, 12, 13 20, 21
Ragpath	15	Pasture Hedgerow Woodland	25, 26, 27, 28 34, 35, 38, 39, 40, 41 42, 43
Pethburn	16	Pasture Hedgerow Woodland	47, 48, 49 53, 54, 55, 56, 57, 58 59, 60, 61
Esh Winning	30	Pasture Hedgerow Woodland	64, 65, 66 70, 71, 72, 73, 17 80, 81
Ibbetson	19	Pasture Hedgerow Woodland	85, 86, 87 91, 92, 93, 94, 95 102, 103, 104
Charlaw	39	Pasture Woodland	108, 109, 110 114, 115, 116
Peartree	38	Pasture Hedgerow	120, 121, 122 126, 127, 128, 129, 130.

Appendix E cont'd.

Part 2 : Samples taken on former opencast mined areas.

Mining Site	Age	Habitat Type	Sample Code Number
Biggin South	12	Pasture Hedgerow Woodland	5, 6, 7 14, 15, 16, 18, 19 22, 23, 24
Ragpath	15	Pasture Hedgerow Woodland	29, 30, 31 32, 33, 36, 37 44, 45, 46
Pethburn	16	Pasture Woodland	50, 51, 52 62, 63
Esh Winning	30	Pasture Hedgerow Woodland	67, 68, 69 74, 75, 76, 77, 78, 79 82, 83, 84
Ibbetson	19	Pasture Hedgerow Woodland	88, 89, 90 96, 97, 98, 99, 100 101 105, 106, 107
Charlaw	39	Pasture Woodland	111, 112, 113 117, 118, 119
Peartree	38	Pasture Hedgerow	123, 124, 125 131, 132, 133, 134, 135, 136.