An investigation into changes in composition and distribution of the vegetation of Widdybank Fell, upper Teesdale, during the last twenty years

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AN INVESTIGATION INTO CHANGES IN COMPOSITION AND DISTRIBUTION OF THE VEGETATION OF WIDDYBANK FELL, UPPER TEESDALE, DURING THE LAST TWENTY YEARS.

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usage of the area, the Cow Green Reservoir and the various management activities carried out on the habitats present.

- The findings of the survey are also discussed briefly with regards to the unique Teesdale assemblage of plant species and communities and implications for future management are discussed.

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Abstract

- A survey of some areas of the Widdybank Fell area of Upper Teesdale was carried out over a single summer to attempt to detect any changes which may have occurred in the distribution and composition of communities in the twenty-five years since an original survey was carried out during the construction of the adjacent Cow Green Reservoir (Jones 1973).

- A vegetative survey concentrated on the species composition of six of the 30+ communities originally defined (Jones, 1973) and the results were compared with those of the original survey using multivariate analysis techniques. Several areas of the fell were also mapped in terms of the vegetative community distribution. This mapping utilised both computer enhanced aerial photographic images and ground surveys and validification. The results of this mapping are compared with the community distributions produced from the original survey (Bradshaw and Jones, 1976). Further studies were also carried on the effects of different grazing regimes on the limestone grassland.

- An analysis of the original data set was carried out using a multivariate technique and the resultant classification compared to the Zurich-Montpellier method used in the original analysis. The communities are also classified in terms of the NVC vegetation communities and their fit into this system of classification is discussed.

- The changes detected are discussed in relation to several environmental factors operating on the fell which were considered as possible causes of the changes.. Such factors include grazing pressure, changing atmospheric deposition and pollution, global warming and associated atmospheric changes, anthropogenic effects, effetcs of the Cow Green Reservoir and the various management activities carried out on the habitats present.

Chapter 1

Aims and Introduction

1.1 Introduction to Teesdale and its Flora

Before describing the study which was carried out it is appropriate to "set the scene" , in terms of the flora of the study area, its origins and importance.

The national and international importance of the flora of Teesdale has long been recognised. Ever since the initial discovery of *Potentilla fruticosa*† by Ray and the tales of the miner John Binks discovering *Dryas* and *Gentiana verna* (Graham 1988), Teesdale has been known as a place of rare and unusual plants. This collective grouping of disjunct types of vegetation has been noted and studied in the past on numerous occasions. The unique mixture of Alpine and Arctic-Alpine species growing alongside more typically southern species has earned the vegetation of this area the title of "The Teesdale Assemblage". Nowhere else in Britain can arctic and arctic-alpine species such as *Gentiana verna, Dryas octopetala* and *Minuartia stricta* be found growing alongside continental species such as *Hippocrepis comosa* and *Carex ericetorum.*

This flora has been recognised as being of great importance for a long time both in terms of the relict semi-natural vegetation, such as occurs on Widdybank Fell and also because of areas with a history of more intensive man-management, such as the Teesdale hay meadows (Godwin and Walters 1967; Bradshaw 1965, 1966.) . These areas have now been recognised in terms of their national importance (e.g. Ratcliffe 1977; Pigott 1956) and the most important areas designated as SSSI's along with the creation of the Upper Teesdale National Nature Reserve.

The importance of the flora of Upper Teesdale lies in the fact that it incorporates species both at the northern and southern extremes of their ranges as well as species with extremely disjunct distributions in the British Isles (e.g. see Graham 1988; Bradshaw 1970). Many of the species are present in very few sites in the British Isles, and several are considered to have an early post-glacial origin, hence there is an historic continuum in the flora of the area. As well as these important elements of the flora, the area also contains characteristic vegetation of both northern upland limestone grassland and various upland bog, heath and mire communities.

† - Vascular plant nomenclature follows Stace (1991). *Musci* follow Smith (1978). *Hepaticae* follow Watson (1968). Lichens follow Dobson (1992)

Photograph 1- *Getiana verna*, an Alpine component of the Teesdale Assemblage of plants.

Photograph 2- *Bartsia alpina*, an Arctic-alpine component of the Teesdale Assemblage of plants.

Photograph 3- *Hippocrepis comosa*, a continental southern component of the Teesdale Assemblage of plants.

Photograph 4- *Thalictrum alpinum*, an Arctic-alpine component of the Teesdale Assemblage of plants.

1.2 Introduction to the Studies

Some of the most important latter-day effects on the Teesdale assemblage have been due to the construction during the 1970's of the Cow Green Reservoir. This scheme, despite ardent fighting by conservationists, led to a direct loss of a large proportion of the unique Teesdale plant communities (Jones 1973). Other communities were also partially altered as a result of subsidiary processes connected with the dam such as road creation etc.. As a result of improved access, and also due to a growth in the popularity of the Teesdale area in general to holidaymakers, there is also now a growing threat of increased human disturbance to what have essentially remained semi-natural habitats since the start of the Holocene. One potentially even more serious worry is that the extant plant communities may possibly be altered as an indirect result of the presence of the dam. Changes in the climatic and environmental conditions as a consequence of the presence of the dam could have much more far reaching consequences than the initial direct loss of some areas of communities. Indeed these processes could potentially lead to the complete extermination of the Teesdale assemblage. Partly for this reason the Teesdale Trust was formed, and before the flooding of the dam a three year research project was funded to study and map the unique vegetation communities of the area. As a result of this work we now have a good baseline data set of the vegetation structure and distribution before the valley was flooded. This initial work was carried out largely by Dr. Margaret Bradshaw and Miss Alison Jones of Durham University and culminated in 1973 in the production of a series of five 1:2,500 scale vegetation maps of the most important areas of plant communities and one 1:10,000 scale map showing the distribution of the broad vegetation types over the whole of Widdybank Fell. These maps were accompanied by a booklet describing the phytosociological units on the map and a Ph.D. thesis was produced describing the communities in more detail. This Ph.D. also included details of how the vegetation study was carried out as well as a more detailed study of the ecology of the communities and how these communities fitted in with other vegetation classifications available at that time.

The initial study was set up largely to provide information about the vegetation (as opposed to the flora) of the area, and Widdybank Fell in particular. This study was largely initiated as a result of the proposal to create Cow Green reservoir which would flood some of the vegetation of Widdybank Fell. The objectives of the initial investigation were therefore as follows:

- to provide vegetation maps of the whole fell at a scale of 1:10,000 and of those parts of particular phytogeographic interest at a scale of 1:2,500

- to incorporate the vegetation units distinguished into the system of plant community classification used throughout Europe
- to relate the Widdybank communities to comparable vegetation described in other British studies.

The aims of the current study are twofold. One being to re-map areas of the vegetation which were mapped in the initial survey to ascertain if there has been any change in the boundaries of the various vegetation units from the time when they were initially mapped. The second is to carry out phytosociological analysis of the vegetation within areas of selected vegetation communities to try to determine whether there has been any long-term change in the species composition and abundance in the various communities. This may would allow factors which causing the changes in the vegetation to be identified, and hence recommend changes in management etc. which may help to rectify the situation. Influential factors may include the dam scheme, changing farming practices over the period, increased public amenity usage and possibly also extraneous factors such as global warming and atmospheric deposition of pollutants and nutrients. Furthermore entirely natural changes such as shifts in the boundaries of the communities and processes of vegetative cycling and succession may also have occurred.

A comparison of the two studies provides an example of the discrepancies which can occur in classifying areas of vegetation by hand as opposed to the modern multivariate data analysis approach.

1.3 Location

Upper Teesdale is a relatively small upland area situated in County Durham in northern England, the boundaries of the Upper Teesdale N.N.R. including Widdybank Fell to the north of the River Tees and encompassing the areas of Cronkley Fell and Mickle Fell to the south of the river (see figure 1.1). Much of the Upper Teesdale N.N.R. lies at an altitude of 500-625 m above sea level, reaching 790 m on the summit of Mickle Fell. Widdybank Fell itself rises to 527 m at its summit. The N.N.R. is on the eastern side of an area of high ground of the northern Pennines which rise to 893 m at Cross Fell further to the west and which in turn is separated from the Lake District by the Eden Valley to the west. The River Tees runs through the centre of the N.N.R. before progressing to the lowlands of South Durham and discharging into the North Sea at the industrial port of Teesmouth. It is primarily for the industrial developments on Teesmouth and the growing population of the lowlands that the building of the Cow Green Dam, which now forms part of the boundary of the NNR, was commissioned.

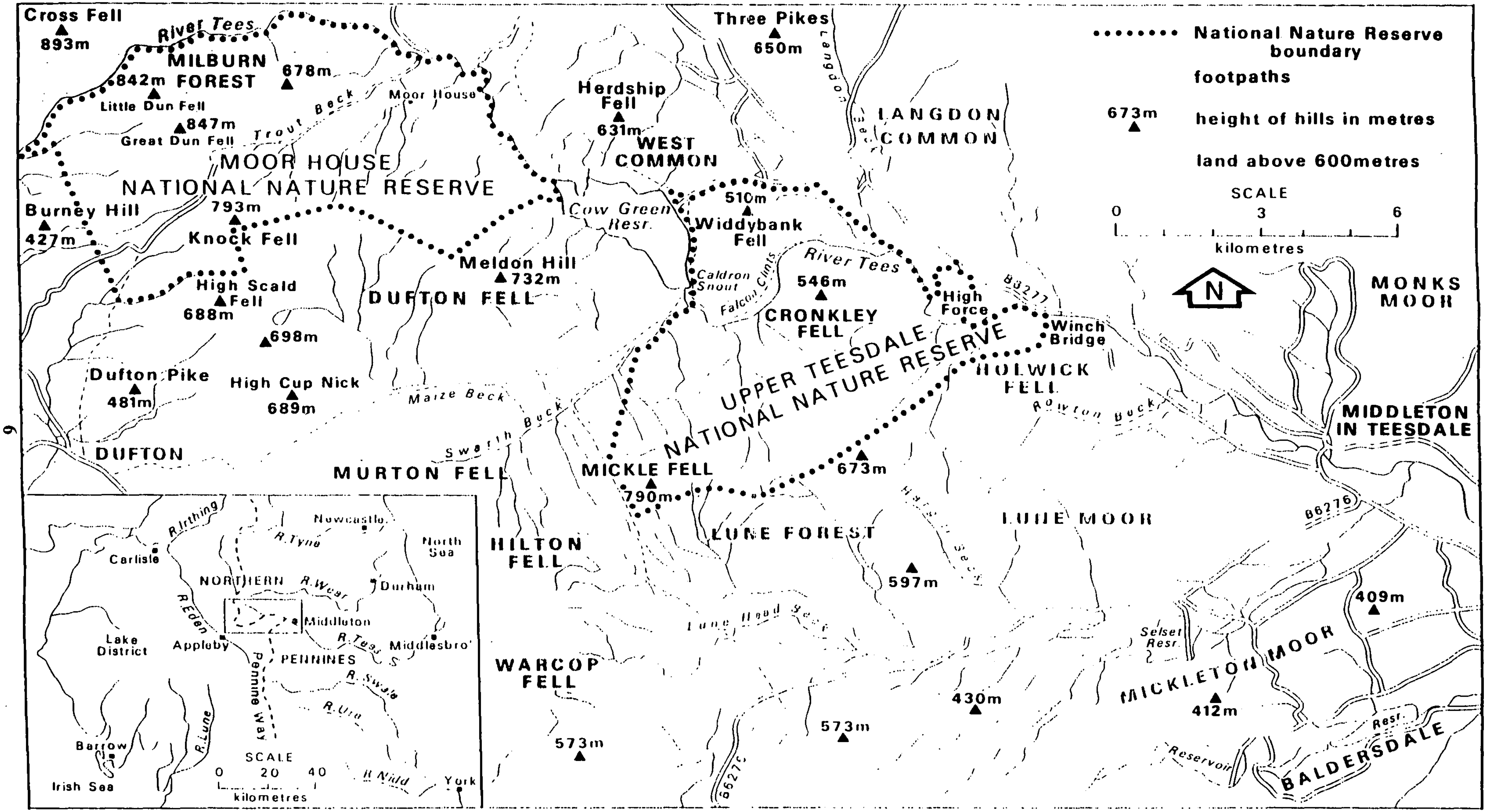


Figure 1.1 - Upper Teesdale National Nature Reserves, general relief and a location diagram (taken from Clapham, 1978)

1.4 Climate

The altitude of the Upper Teesdale NNR results in low temperatures and a high rainfall with high snowfall in winter (Clapham 1978). The altitude of Upper Teesdale is sufficient to offset the oceanic influence on temperatures in winter but exaggerate it in summer (Pigott 1978). Average monthly temperatures for Widdybank Fell are shown in Figure 1.2, alongside similar figures for the nearby Dun Fell and the more lowland site of Newton Rigg. This depicts a scenario for Widdybank Fell with monthly mean temperatures reaching a maximum of about 12° C in July and August and falling to a minimum of approximately 1° C or below between the months of December to February. The following brief account of the Teesdale climate is largely abstracted from Pigott (1978).

During the period 1968-1975 the highest daily maxima occur during August and September only just exceeding 16° C; the highest temperature recorded in this period was 25.8° C. Air frosts were recorded in every month except July and August with minima as low as -17.8° C in January. Ground frosts may occur in every month although are usually present on only one or two days in August. At a depth of 30 cm in the soil the mean temperature in the coldest months of February and March is above freezing (1.7°C) yet rarely exceeds 12° C in the warmest month of the year (August). The highest rainfall over the north Pennines is over the western escarpment with a general decrease with distance eastward, the average on Widdybank over the period 1968-1975 being 1523 mm per year. The wettest months are November and January, and the driest May and June although there is still over 100 mm of rain in both months. There are approximately 240 days with some rain every year and no month with less than half of the days having rain. Snow lies on the ground on approximately 50 days of every year, though May to September are almost free of snow. Windspeeds on Widdybank are highest in winter, with a December average of 7.2 m/s, and lowest in summer, with an August average of 4.3 m/s. The overall yearly average of 5.5 m/s is much less than that of about 10 m/s estimated for the higher summit of nearby Great Dun Fell.

1.5 Geology

The following brief geological description of the area is a brief summary of information given in Johnson (1978), Dewdney (1970) and Graham (1988).

The bedrock that underlies Upper Teesdale consists of a folded Palaeozoic basement overlain by the complete stratigraphic succession of the carboniferous rocks of the northern Pennines. Above the basement group is the Lower Limestone Group, composed mainly of a light-coloured limestone. There are also a sequence of sandstone and shale bands dividing the limestone near the top of this group and a repeated cyclic succession of this banding is characteristic of the Middle Limestone Group. The top of this Middle Limestone Group coincides with the top of the Lower Carboniferous.

The Upper Carboniferous begins with the great limestone, but above this band the limestones become thin and the bulk of the succession is composed of sandstone and shale. These beds are restricted to the tops of the fells of Upper Teesdale.

The Great Whin Sill igneous intrusion is present within the carboniferous succession. The heat from this intrusion, along with the particular chemical properties of the limestone layer, caused some parts of the limestone layer to be "baked" to produce the characteristic sacchoroidal limestone known as the "sugar limestone". The areas where this sugar limestone is exposed at the surface on Widdybank carry many of the unique plant communities for which the area is so well known. Mineralization of the carboniferous rocks also produced rich ore veins which could be mined for lead, zinc, fluorspar and barytes. The deposits from such mining operations now carry a distinct plant community composed of species which are tolerant of the minerals present and the associated harsh environmental conditions.

1.6 Vegetation

The vegetation of Widdybank Fell was studied in some detail by Jones (1973). In this work she divided the vegetation into 33 distinct noda as shown below and assigned each of these noda to their most appropriate classification group using the Zurich-Montpellier technique (See figure 1.3). The class/order titles to which the noda are allocated in Figure 1.1 follow the conspectus of Jones and Bradshaw (1976) and are used throughout the text to describe the groups of noda.

The vegetation is basically composed of calcareous grasslands (noda 1-7 and 19-22), short sedge marsh and calcareous sedge marsh (noda 8-18), acid grassland and heath (noda 25-27, 29, 31-33) and wet heath and obrogenous bog (noda 23, 24 and 28). As well as these major components of the vegetation there are also smaller areas of vegetation such as areas of spring heads (nodum of Cratoneurion commutatum), vegetation on soils rich in heavy metals (nodum V), Whin Sill scree vegetation and *Carex rostrata/Juncus effusus* dominated mires.

Mapping Unit	Nodum name	Class/Order	Quadrat Numbers used in text
1	Nodum with *Kobresia*	Festuco -Brometea	337-343
2	Nodum with *Rhytidium*	Festuco -Brometea	344-355
3	Nodum *typicum (Min.verna)*	Festuco -Brometea	356-366
4	Nodum with *Calluna*	Festuco -Brometea	367-399, 585-602
5	Nodum with *Plantago*	Festuco -Brometea	400-411
6	Nodum *typicum (Kobresia)*	Festuco -Brometea	412-428
7	Nodum with *Primula farinosa*	Festuco -Brometea	429-439, 4350-51
8	Nodum with *Sesleria*	Tofieldietalia	259-286
9	Nodum with *Juncus Triglumis*	Tofieldietalia	287-294
11	Nodum with *Molinia & Erio. lat.*	Tofieldietalia	295-309
12	Nodum with *Nardus & C.demissa*	Tofieldietalia	310-317
13	Nodum *typicum*	Tofieldietalia	318-326
14	Nodum with *Gymnostomum*	Tofieldietalia	327-336
15	Nodum with *Crat. Filicinum & Equisetum*	Parvocaricetea	146-164
16	Nodum with *R. Flammula & C.echinata*	Parvocaricetea	165-187
17	Nodum with *Viola palustris*	Parvocaricetea	188-196
18	Nodum with *Trifolium repens*	Parvocaricetea	197-202
-	Nodum with *Potamageton*	?	203-207
19	Nodum with Cardemine	Molinio-Arrhenatheretea	58-66
20	Nodum with *Sesleria*	Molinio-Arrhenatheretea	46-57
21	Nodum with *Carex caryophyllea*	Molinio-Arrhenatheretea	38-45, 525-543
22	Nodum with *Galium saxatile*	Molinio-Arrhenatheretea	35-37
23	Nodum with *Erica & Trichophorum*	Oxycocco-Sphagnetea	6-11, 605-619
24	Nodum with *Narthecum & Trichophorum*	Sphagnetalia magellanici	208-231
25	Nodum with *Erica & C.dioica*	Nardo-Callunetea	67-81
26	Nodum with *Empetrum & Erica*	Calluno-Ulicetalia	110-118
27	Nodum with *E. vaginatum*	Nardo-Callunetea	82-90
28	Nodum with *Empetrum & S. recurvum*	Sphagnetalia magellanici	232-258, 501-517
29	Nodum with *Galium saxatile & S.papillosum*	Nardo-Callunetea	91-109 565-580
31	Nodum with *Polytrichum & Deschampsia*	Calluno-Ulicetalia	119-131
32	Nodum with *Viola rivinialis*	Calluno-Ulicetalia	132-139
33	Nodum with *Danthonia decumbens*	Calluno-Ulicetalia	140-145,1400 545-560
-	Nodum of Whin Sill scree	Asplenietea rupestris	1-2
-	Nodum with Crat../Cardamine	Montio-Cardaminetea	12-20
-	Nodum with Min. Verna & T.repens	?	27-34
-	Nodum with *Sax.aiz & Crat.comm*	?	3-5
-	Nodum with C.rostrata/J.effusus	?	21-26

Table 1.1 - The noda described by Jones (1973) as occurring on Widdybank Fell with associated mapping units and quadrats numbers used to refer to these noda in the text, those quadrats with numbers between 500-600 being from the present survey (see Appendix IV)

1.7 Soils

A detailed analysis of the soils present beneath the various communities on Widdybank Fell is given by Jones (1973) and these findings have been used to provide the following brief description of soil types.

Soils present on Widdybank Fell are mostly directly associated with the underlying bedrock of an area. Soils which support the characteristic *Festuco-Brometea* limestone grasslands are composed largely of Rendzinas, brown calcareous and brown earth soils although one community can also grow over peaty gley soil. The class *Molineo-Arrhenatheretea* largely overlies gleys of various types. Vegetation of the class *Parvocaricetea* communities also grows over gleyed soils as well as directly over peat but here the gleyed soils tend to be peaty gleys rather than the calcareous and alluvial gleys which the former community grows on. Another group of communities which tend to grow over calcareous gleys and especially flushed gley soils are those belonging to the order *Tofieldietalia*, although some noda of this community will grow over peaty gley and even flushed peat. Vegetation of the *Nardo-Callunetea* tends to grow mostly over areas of humic groundwater gleys and peaty gleys but has also been recorded growing over flushed peat and blanket peat.

The vegetation of the *Calluno-Ulicetalia* tends to grow on a variety of typically acidic and often water associated soil types ranging through peat and peaty gleys to gleys and humic groundwater gleys as well as often growing on acid brown earth soils.

The vegetation of the class *Oxycocco-Sphagnetea* present on the fell all tends to grow over blanket peat, which itself tends to overlie either Whin Sill bedrock or impermeable clay/silt loams. The wet heath vegetation has also been recorded growing over humic groundwater gley soil.

The spring head nodum with *Cardamine* and *Cratoneuron* can develop over both drift and bare metamorphosed limestone and tends to form highly organic hummocks or tufa.

1.8 Land-Use

The effects of man upon Widdybank Fell are many-fold and are expressed in land-use such as recreation, farming and other activities carried out on the fell, as well as external factors such as pollution from further up the catchment and distant sources and even through mechanisms such as the predicted human-induced global warming.

In terms of actual land-use on the fell, farming probably has the most dominant effect on the vegetation. Grazing of sheep is carried out during the entire year on the out-by land of the fell, although the number of sheep grazed is much reduced in the winter to allow for the harsh conditions of the area, with almost all of the remaining sheep coming down to the lower areas of the out-by during the most harsh of the winter weather where additional winter food is provided. The number of sheep grazing the fell is largely determined by the changing subsidy schemes which the government provides to allow continued grazing in what would otherwise be a largely unprofitable area. The actual distribution of the sheep on the fell is largely determined by the condition of the vegetation at a particular time of the year and under particular climatic conditions, the sheep tending to favour areas with more nutritious vegetation at any time. There is also some shepherding of the sheep to maintain a more even distribution of sheep over the fell. In addition to the sheep farming there is also a sporting interest as a result of the Red Grouse which use the heather for breeding. Management to encourage grouse numbers, primarily via burning areas of the *Calluna* vegetation, will also causes changes in the vegetation of these areas as has been documented elsewhere (e.g. Rawes and Hobbs 1967, Legg *et al.* 1994).

Activities related to industrial practices which have a direct effect on the fell can be largely divided into the effects as a result of mining and those due the creation of the Cow Green Reservoir. Effects from past mining largely manifest themselves in the form of areas of the fell being contaminated with heavy metal rich waste from the mining operations and remnant gullies as a result of surface mining and possibly subsidence. The creation of the reservoir resulted in the well documented loss of large areas of the unique Teesdale Assemblage communities (Jones 1973, Bradshaw 1965, Godwin and Walters 1967) but may also have other indirect effects on the remaining communities. The creation of improved road access to the area as a result of the dam scheme may also have caused some changes in the vegetation via factors such as changed hydrology and increased vehicle emissions.

There is also a growing usage of the area of Upper Teesdale for recreational facilities due to the scenic beauty of the area and this increased human presence could also affect the vegetation via various mechanisms such as trampling, leading to localised soil compaction and erosion (e.g. Aspinall & Rye 1987).

1.9 The Origins and History of the Teesdale Flora

The origins of the Teesdale flora have been fairly well traced and are an important element in the importance of the flora. To trace the origins of the flora it is probably easiest to begin during the last glacial period, the Devensian. Early theories on the origin of the Teesdale flora (e.g. Blackburn 1931) postulated that some of the Teesdale species had survived in the region through the previous glaciation on nunataks (exposed land which was never glaciated). More recent work on the last glacial maximum (e.g. Boulton *et al.* 1977) has proposed that at the height of the glacial period the whole of the Durham area would have been under an extensive glacier of some considerable depth. These early theories therefore had to be discarded.

More recently an amalgamation of available plant fossil data from around the British Isles has shown that in the Late Glacial and early Post-Glacial periods many of the species characteristic of the Teesdale assemblage were more widespread than they are today, taking advantage of the large areas of suitable habitat becoming available as the glacial conditions receded. Hence species such as *Dryas octopetala* and *Potentilla fruticosa* have been detected at various sites where they are no longer present (Godwin 1975). The Teesdale species can therefore be considered to have survived due to the persistence of suitable conditions since the time of the widespread distribution of the rarities (Pigott 1956) or because the present habitats are of recent origin and the plants survived elsewhere (Bellamy *et al.* 1969). With the retreat of the glaciation there was an advance of vegetation and the process of succession initiated. This advance of the various species is now thought to be governed largely by climatic considerations (e.g. Huntley 1991, Huntley and Webb 1989). Palaeoecological evidence from Cronkley Fell (Squires 1971) has shown that the advance and distribution of the various tree species began in the Late Boreal period, with species being influenced by the unstable conditions of fluctuating water levels and increased temperature. The arboreal succession by the end of this period probably resulted in a scrub cover to the limits of tree growth (Johnstone 1962), hence reducing the area available for the post-glacial colonist species to survive. The Atlantic period is suggested as being characterised by an increased precipitation/evaporation ratio which caused or aided in the degeneration of the preceding vegetation and helped in the initiation of blanket peat formation. The initiation of blanket peat formation has also been attributed to varying extents to anthropogenic influences (e.g. Harris 1958; Turner, Innes and Simmons 1993).

Squires (1971) questioned whether the formation of peat in areas adjacent to the limestone outcrops would have occurred without human intervention. He also points out the continued history of instability since the late glaciation on Cronkley Fell and considers this as possibly being crucial in the continued presence of the glacial relict species. The presence of remains of these species even at the time of maximum forest development in the Teesdale area indicates that sufficient habitat was available in the area at this time so as to allow the continued survival of these species. It may simply have been that the limestone outcrops could not support anything more than a rudimentary tree cover and that the glacial relict survived in these areas.

The glacial relict species of the Teesdale assemblage can therefore be considered to have survived in the area since the glacial retreat and to have since had their extent of distribution progressively diminished as a result of the advance of an arboreal community and later the development of acidic bog conditions.

1.10 The Importance of the Teesdale Flora

The immediate features of the Teesdale flora which many people would consider important are the large number of individual rare species present in the area, including species and sub-species with their only British and English localities being in this area. However possibly more important than this is the actual assemblage of species present together in the area

As well as including species of limited distribution in Britain there are also species present with disjunct distributions throughout Europe as a whole, as well as species which find their northern or southern limits of distribution in the Teesdale area. When considering Teesdale as a phytosociologically important area it has been compared by several writers (Bradshaw 1965, Godwin & Walters 1967, Clapham 1978) to other such areas in the British Isles such as the Burren in Ireland, the Craven District of Yorkshire, Ben Lawers in Scotland, Breckland in East Anglia and the Lizard area of Cornwall. In this respect Teesdale can be considered as part of a network of similar areas and by considering these areas together theories of biogeography can be formulated and tested. Upper Teesdale is therefore of immense international as well as national biological importance. It is also worth considering that by using the present distributions of disjunct species in areas such as Teesdale, to create and test theories of past plant responses to environmental change. It may be possible to develop models to predict future responses to change and provide insight into the future effects of our current actions. Phytogeographically important areas such as Teesdale may therefore be of importance in the development of models to show possible future changes in vegetation composition and dominance as a result of anthropogenic factors such as pollution, global warming, and deposition and addition of minerals and nutrients.

The present distribution of species in Teesdale is not the only scientifically important value of the area as there is also a wealth of past plant distribution information present beneath the vegetation in the form of buried plant macrofossils and microfossils. The extraction and use of this information has provided and continued to provide evidence of past plant communities and, when assessed in conjunction with similar information from other sites, can help to provide a comprehensive account of past changes. Through such information the past changes due to anthropogenic as well as climatic factors can also be elucidated. Studies on Cronkley Fell in Upper Teesdale have also provided evidence for the continued existence of many of the Teesdale species since the early post glacial (Squires 1971).

Finally it must also be remembered that there has been a large amount of past scientific research carried out in the Teesdale area, and as a result of this the area is of large value in terms of available past data to allow temporal comparisons. Godwin (quoted in Bradshaw 1965) speaking with reference to the original dam construction scheme said that :

"It cannot be too strongly emphasised that there is already a great deal of scientific capital invested in our knowledge of the Teesdale plants and plant communities and that in a scientific sense their destruction would be intensely wasteful of past efforts as well as improvident for future scientific utilisation."

It must also be remembered that Upper Teesdale is not only a site of botanical importance but that the area also supports many species of vertebrate and invertebrate fauna. The British upland avifaunal communities of at least two habitats are considered particularly distinctive within the context of Europe and as such are of conservation value, with unique assemblies of falcons, ducks, passerines, plovers and gulls (Ratcliffe and Thompson 1988). The breeding birds of Upper Teesdale include high densities of Red Grouse, an endemic British sub-species, as well as other species which are currently declining in numbers such as the Black Grouse (*Tetrao tetrix*), Lapwing (*Vanellus vanellus*), Golden Plover (*Pluvialis apricaria*), Dunlin (*Calidris alpina*), Snipe (*Gallinago gallinago*), Woodcock (*Scolopax rusticola*), Redshank (*Tringa totanus*) and Dipper (*Cinclus cinclus*) (Tucker and Heath 1994, Gibbons *et al.* 1994).

The scientific importance of the invertebrate fauna of Teesdale is more difficult to assess than that of the flora due to the difficulties in identification and the relatively small number of studies carried out on the invertebrate species. Never-the-less there have been several rare insects and spiders recorded in Upper Teesdale (Coulson 1988) many of which have been found to be first British records or even new to science. These rare invertebrate species however do not have the same affinity for the limestone areas as do most of the rare plant species (Coulson 1988) showing that different habitats in Teesdale can be important for different groups of scientifically important species. Indeed the mosaic of communities present is important for many animal species.

In terms of affinities of the invertebrate fauna it has been found that the limestone grassland invertebrates are similar to a depauperate lowland British assemblage whilst the species of the more acidic habitats are better described as having affinities with faunas of northern Scandinavia and Iceland.

It can therefore be seen that the Teesdale plant communities and their associated faunal component are an important scientific asset; as such, attempts should be made to retain the area in as natural a state as possible with all of its associated rare species and communities.

Chapter 2

Methods

The initial aims of this project allow the method to be divided into two distinct techniques of analysing the vegetation as follows:

1. determining whether the species composition and individual species abundance in any particular community have changed since the initial survey, and;
2. determining whether the vegetation community boundaries have shifted.

Further studies examining the effects of grazing are also described here along with an attempt to describe the communities present within the context of a British framework.

2.1. Match Analysis of the Vegetation Data

By using the Match program within Vespan on both the communities as defined by Jones (1973) and the communities produced using a standard Twinspan analysis, it is possible to determine which of these two types of classification gives the best fit of the vegetation groups produced with those vegetation communities as defined by the NVC method.

Furthermore the community data which were collected during the present survey could also be analysed to determine whether the noda studied have changed in their composition by either increasing or decreasing their fit to the best fitting NVC community as calculated from the original data. This analysis potentially would show if any of the noda are shifting their vegetation composition towards a different NVC community or sub-community. Any changes which have been found in a particular nodum could then be interpreted in terms of the ecological affinities of the communities as defined in the British Plant Communities volumes (Rodwell 1991, 1992a, 1992b, 1995).

The Match analysis output included discrepancies between the communities recorded and the NVC communities closest to the vegetation, and also produced constancy/abundance tables for each set of nodum data. A comparison of these tables allowed the production of lists of increasing and decreasing species within each nodum since the initial survey. These lists are included in Chapter 3.

2.2 Seed Production of *Gentiana verna* in Several Different Vegetation Types

In order to assess the affects of a reduction in the grazing pressure as a result of enclosure a brief survey was carried out to determine the seed production of plants of *Gentiana verna* in the various enclosed areas as well as in several of the unenclosed communities to see if there was any difference in seed production. Bradshaw (1978) states that one of the worries with regard to this species is the lack of successful reproduction by seed which serves to maintain genetic variation, something which vegetative reproduction does not. She also noted that in areas where grazing was excluded more losses were as a result of natural death and assumed that there was a higher number of losses outside these areas as a result of grazing.

In order to assess the relative amounts of successful seed production, it was decided to count 200 plants of *Gentiana* in each of the chosen areas and to record the number of seedheads produced by those 200 plants. Here a plant was considered as any single rosette and the rosettes which were counted included both juvenile and adult rosettes. Two-hundred rosettes were counted as this seemed to be an achievable number to locate in any one area and almost exhausted the total population of plants in some of the smaller enclosures.

2.3. Grazing Effects: Densities

In order to assess the differences in grazing pressure between the various communities a simple survey was carried out to allow calculations of the grazing regime on several of the various community complexes. In each of the areas the total number of sheep (including lambs) on an area was noted, whether they were grazing or not. It was assumed that this would give a rough indication of the grazing intensity in any area. This of course is not entirely true as sheep have complex social and behavioural patterns and may just be using one area as a route to other feeding areas or taking advantage of a particular complex to rest or because of its available shade etc. (Eddy, Welsh & Rawes 1969). This for example could lead to over-estimations of density on the *Calluna* heaths when sheep are simply sheltering in the *Calluna* or utilising the sheep walks through the *Calluna* to reach other areas of grassland. Similar the sheep could possibly have a diurnal pattern with respect to their grazing and as all of the surveying tended to be carried out towards the middle of the day perhaps there was some bias against areas which were utilised early in the morning or late at night. It must also be remembered that the surveys were carried out in the middle of a particularly hot summer and there would no doubt be variations in any of the densities calculated at different times of the year (there are few sheep on the fell at all in the winter anyway) and during different climatic and related environmental conditions. For example it has been suggested that the best conditions in which to find *Saxifraga hirculus* flowering on the fells is during a very wet summer (Ian Findlay *pers. comm.*) as the sheep tend to graze more on the heath areas reducing the grazing pressure on the calcareous flush areas where *S. hirculus* occurs. However despite these shortfalls it was still considered that the survey would give a reasonably good idea of the different summer grazing intensities.

The total number of sheep on any one of the areas studied was counted on three occasions and from this the mean number utilising the particular area was calculated. It was then possible by utilising the detailed vegetation maps of the fell to calculate the exact extent of any one of these areas and a further simple calculation then determined the grazing density.

2.4 Grazing Effects: Enclosures

A study was carried out to assess the effects of enclosure on the limestone grassland areas, the theory:being that, grazing of areas by sheep, at the high densities currently encouraged in the uplands, affects the community composition. It is therefore possible that the enclosures may have vegetation more similar to that which would occur in a more natural grazing situation. It must also be borne in mind that sheep grazing, albeit at lower densities than those currently advocated, has been an integral part of the upland for a long period. Welch suggests that they were probably introduced by the Norse in the 10th century and Eddy *et al* (1969) state that sheep have been present in the nearby Moorhouse N.N.R. for at least the last 600 years.. Prior to that they found that *Cervus elaphus* was present until about 250 years ago and *Bos* remains have been found in earlier deposits. Rabbits are also present on the fell as a result of their general spread throughout Britain following introduction. Therefore there must always have been grazing to some extent in these areas with the exception possibly of areas such as deep ravines, very steep slopes and cliff ledges. In this respect entirely ungrazed areas on the open fell probably represent an unnatural situation but may still be more akin to the original vegetation if this was only grazed at low levels.

To determine any changes in the unenclosed and enclosed communities a series of quadrats were carried both within and around the perimeter of the enclosed areas. This would compare vegetation which would otherwise have been of very similar composition, as the enclosures were all on areas of quite similar grassland.. As the vegetation of the fell changes over short distances (as can be seen from the maps of Bradshaw and Jones) it was necessary to ensure that the vegetation compared within and beside enclosures was of the same type. The sample size of quadrats taken was to some extent limited by the small areas on the fell which were enclosed. For this reason only five quadrats were carried out in each of the four enclosed areas and a further three quadrats were carried out around the perimeter of each of these enclosures. Quadrats were not carried out along the perimeter of enclosure 4 as the fence line seemed to mark a natural vegetation boundary. It would be possible to further compare these quadrats with those carried out in similar communities throughout the fell to see if there is any further differences between the various vegetation compositions. The four enclosures on the fell were fortuitously under four separate types of management allowing further comparison of the effects of management on the community. All the enclosures have been in place for less than thirty years so it may be that the communities are still in a successional transition stage and have not fully reached a steady pseudo-climax community with respect to the current climate and management. All enclosures were deemed to be both sheep and rabbit proof. The four enclosure management regimes and communities are as follows :

Enclosure 1 - Community of 5/33; continually enclosed; ungrazed and unmanaged
Grid Ref - 81453026

Enclosure 2 - Community of 5/21; continually enclosed; ungrazed but cut once a year in late summer
Grid Ref - 81762985

Enclosure 3 - Communities 5 and 21: seasonally enclosed from approx. May to August, ungrazed through this period
Grid Ref 81722973

Enclosure 4 - Various communities, those examined being communities 3 and 5; seasonally enclosed from approx. May to August though there is still some grazing through this period as a result of rabbits and occasional sheep
Grid Ref - 81273046 to 81433023

The results of the quadrat surveys of these areas were then ran through a standard Twinspan analysis to determine whether there were any differences between the enclosed and unenclosed areas. Any similarities between the enclosed communities, despite them being in different areas of vegetation, should also show up in the analysis. Similarly a Decorana analysis was carried out on the data to determine any environmental gradients in the vegetation.

2.5 The Vegetation Survey

In order to assess if there has been any significant change in the basic species composition and abundance within the various vegetation communities, a survey was carried out on selected areas of several of the vegetation types. Six different plant communities were selected from the original α-communities determined by Jones (1973). These communities included two bog communities, two acid grassland/heath communities and two calcareous grassland communities. Within each of these communities Jones (1973) defined various distinct noda. Because of the limited time available for field surveying, only one nodum was studied from each community for the vegetation comparison. The six communities and noda which were chosen for re-analysis were determined largely by choosing the more dominant noda in terms of area for a particular vegetation community. By choosing these dominant noda it was therefore possible to detect any changes in vegetation over the largest possible area of the fell. Other advantages of using these dominant noda were that there were generally several large and easily located areas for each of the noda and also that these common noda were generally located throughout suitable areas of the fell, allowing the vegetation survey to take in as much diversity of the community as possible.

The six chosen communities and the associated nodum chosen for each community were therefore as follows:

1. Festuco-Brometea calcareous grassland, Association Seslerio-Caricetum pulicaris, Nodum with *Calluna* (mapping unit 4)
2. Molinio-Arrhenatheretea calcareous grassland, Association Festuco-Naerdetum, Nodum with *Galium saxatile* (mapping unit 22)
3. Oxycocco-Sphagnetea wet heath, Association Narthecio-Ericetorum tetralicis, Nodum with *Erica* and *Trichophorum* (mapping unit 23)
4. Sphagnetalia magellanica dry heath, Association Erico-Sphagnetum magellanici, Nodum with *Narthecium* and *Trichophorum* (mapping unit 24)
5. Nardo-Callunetea acidic grassland, Association Nardo-Juncetum squarrosi, Nodum with *Galium saxatile* and *Sphagnum papillosum* (mapping unit 29)
6. Calluno-Ulicetalia acidic grassland, *Vaccinium myrtillus* heath-*Deschampsia flexuosa* complex, Nodum with *Danthonia decumbens* (mapping unit 33)

Any references in the text to numbered noda utilise the mapping unit number of a corresponding nodum instead of the full descriptive name as a form of abbreviation. Hence the "nodum with *Calluna vulgaris* of the Association Festuco-Brometea" would be described as nodum 4. Similarly any reference in the text to nodum 4 vegetation quadrats collected during the present survey for example indicates only that the sampling was carried out in an area which Jones mapped as being nodum 4 vegetation and bears no connection to the actual vegetation currently present.

For each nodum a minimum of three different areas of the vegetation were located on the fell, preferably in areas as far apart and diverse as possible so as to accommodate as much as possible of the entire range of the nodum. At each location vegetation quadrats were collected in areas which were chosen as being typical of the vegetation of the particular nodum. The size of the quadrat used was determined by the size of those used in the initial survey so as to provide comparable results for analysis. It is worth noting that the size of quadrats which were used in the initial survey correspond well to those suggested by modern survey methods such as the standard NVC method (Rodwell, undated). It was therefore possible to analyse both sets of data using applications designed for vegetation of a similar format.

The general quadrat sizes which were used were as follows:

Short grazed grass or similar swards - 2 x 2m quadrat
Low shrub/heath communities - 4 x 4m quadrat
Moss/lichen dominated communities - 0.5 x 0.5m quadrat

One possible error which could arise from the method of locating areas for the quadrats is that by purposefully choosing the larger areas of a community in which to collect the quadrats it may be that small variants which occur within the community, when they occur in small or isolated areas, could be missed. In order to try to rectify this problem occasional quadrats were collected in smaller areas of the communities when such areas could be easily located. Another problem with the method of quadrat location is that by choosing areas of vegetation typical of a particular community some of the variation which occurs at the edge of a community may be lost. This problem was overcome to some degree by collecting quadrats in any one area so as to represent the total variation of the community in that area. This method of locating quadrats in typical areas of vegetation would not be appropriate if statistical methods were to be rigorously applied, a random system being more appropriate, but as the original survey was carried out along similar lines (Jones, *pers. comm.*) this method makes for the best comparison.

Areas of particular community noda were located by reference to the 1:2,500 scale maps produced by Jones and Bradshaw. When the area in which the quadrat was to be laid out was located a note was made as accurately as possible of the eight figure grid reference. A species list of the vegetation was then made for the area within the quadrat and any species such as mosses and liverworts which could not be reliably identified in the field were taken back to the laboratory for later determination with the aid of a microscope. Laboratory determination of mosses, liverworts and lichens was carried out with the aid of keys in Smith (1978), Watson (1968) and Purvis *et al.* (1995). The cover of each species in a quadrat was assessed using the Domin scale of cover-abundance (see Appendix II). It was not necessary to assess sociability of the vegetation, a process carried out in the initial survey, as opinion now seems to have concluded that sociability is more an indication of an individual species growth pattern than of any community-induced growth pattern.

2.5.1 The Twinspan Study

The Twinspan analysis technique (Hill 1979) was used to re-analyse the original vegetation data of Jones to see how this compared to Jones' hand-and-eye classification using the Zurich-Montpellier system.

The entire data set from the initial Ph.D. study of Jones was first transferred from relevé tables onto P.C. in standard Fortran format and then prepared for Twinspan analysis using the Prepare program available in the Vespan vegetation analysis package (Malloch 1985). The data was then analysed through a standard run of the Twinspan program using the default parameters, with five pseudo-species cut levels selected at Domin values 1, 3, 4, 5 and 7.

By studying the output of this process it was then possible to note the deviations of the Twinspan vegetation classification from the original classification produced by Jones using a hand-and-eye method. By examining the indicator species at each division of the dendrogram it was possible to manipulate the indicator species chosen so as to allow for divisions of the data which produced groupings which were more akin to the communities produced by Jones. This was achieved by eliminating some species as potential indicator species at a particular division in the hope that more meaningful indicator species were chosen. Other factors which were manipulated included the maximum number of indicator species which could be used, the relative importance of the different pseudo-species within the species and even whether the analysis was calculated on simple species presence/absence rather than the pseudospecies levels present. The idea being that if the vegetation had not changed then new relevés taken in an area of a known vegetation type would be classified into the same end group as the defining relevés of the initial study. Conversely if there has been a significant change in the species make-up of a community over the period, then the modified Twinspan classification would assign the new relevés into a different end-group. Following the production of this modified Twinspan classification for the present study it was also possible to compare this to the standard run of the Twinspan program to see how the two classifications compare using the present study results.

Twinspan analyses were also carried out on smaller subsets of data from the two datasets. For each of the six noda chosen for detailed study the original and present data set for a nodum were amalgamated and then run through a standard Twinspan analysis in an attempt to determine whether and to what extent the original quadrats were distinct from the present quadrats. A further Twinspan analysis was also carried out on an amalgamated data set comprising all of the original quadrats assigned to a particular class of vegetation along with all of the present quadrats collected within this class. It was hoped that this analysis would show whether any of the quadrats collected during the present study within a particular nodum were now more akin to one of the other noda present within the same class.

2.5.2 Decorana

To elucidate the most prominent environmental features which were acting to distinguish the various communities of the fell, a Decorana analysis was carried out on all of the quadrats from both the present and the original study. It was expected that this would allow an interpretation of the most important environmental features which were separating the different communities. It was also hoped that if such variables could be elucidated then, by comparing the original and present quadrats from a particular noda, it would be possible to suggest factors which may be responsible for changes which have occurred over the intervening period.

2.6 The Community Distribution Survey

As well as determining whether there had been any change within the actual defined communities an attempt was made to accurately remap some of the areas of vegetation on the ground to try to determine if there had been any shift of communities. It was hoped that this particular study could identify if communities were being invaded by other communities etc. and to show which communities had fared better under the environmental and physical changes which may have occurred over the last twenty years. In order to make the results comparable to those originally produced by Jones it was necessary to undertake the present survey at a similar scale of accuracy and precision. Although an increase in the accuracy of the mapping would have been possible this would not have been useful in indicating changes, as very small scale areas of vegetation were ignored by Jones in her original mapping.

In order to carry out the accurate remapping of areas of the fell it was necessary to accurately relocate points from which grids could be drawn up. This was facilitated by using notable vegetation boundaries whose positions could be accurately determined using modern aerial photographs of the site as explained in section 2.3.

2.6.1 The Aerial Photograph Analysis

In the original thesis study of Widdybank Fell an aerial photograph of part of the study area was included from the time of the original survey (1969). As further aerial photographs of the same area taken at a more recent date (1989) were available it was possible to attempt to make a comparison of the vegetation by comparing these aerial photographs. This survey had the advantages of potentially being able to map larger areas and to map areas more quickly than the ground surveying methods especially if it proved possible to utilise some of the more modern computer analysis tools. On the ground surveying proved useful when studied in conjunction with this aerial photograph analysis as it allowed validation of boundary locations determined from the photographs in areas where both survey methods were utilised.

Attempts to analyse changes over the entire fell or even over restricted areas of the fell using methods of computorial analysis (available in the Arc-Info GIS package) were eventually abandoned, problems of different photograph quality and exposure etc. masking any trends which were present. The only areas which such analysis could distinguish as having changed were the most extreme changes such as areas of recently burnt *Calluna* or areas flooded by the dam. It was possible however to produce modified grey scale images which could subsequently be analysed by eye in conjunction with the enlarged scanned images from the aerial photograph.

A detailed description of the methods utilised and analyses attempted is given in Appendix V.

To produce images for hand analysis, several smaller areas of the fell were first chosen from the original image. These areas were chosen so as to allow analysis of different areas of the fell and also so as to allow analysis of boundary movement of as many combinations of adjoining vegetation types as possible. Printouts of the images of these areas were produced at the same scale as the original maps. These images included the original scanned image as well as grey scale images in which the range of grey-scale images has been grouped into five, eight and sixteen grey-scale bands. By overlaying the 1:2,500 images with transparent sheets it was possible to delineate the community boundaries using a fine nibbed pen. The end product of this procedure was then digitised back into Arc-Info format using a digitising tablet to trace the community boundaries produced.

2.6.2 On the Ground Verification and Refinements

The boundary maps produced from the above analysis were used in the field to validate and refine the vegetation boundaries. Boundaries were checked in the field and each community was identified using the community keys as produced and used by Jones (1973). In addition many extra communities and boundaries not visible on from the manipulated aerial photographs were also added in the field. These were initially mapped using transparent sheets overlaying the previously produced community boundaries and were subsequently digitised into computer format and added to the original boundaries. The scale was then manipulated to the same scale as the original 1:2,500 maps and keys added. In order to colour and label the maps the final outlines were imported into the Corel-Draw computer drawing package.

There were however some limitations to the amount of data which could be collected during the present study . One was that, owing to the short length of time during which field work could be carried out it was not possible to map the areas to quite the same detail as the original maps. Because of this some of the areas of very similar vegetation were mapped together into single combined units as further elucidation of the exact boundaries of such communities would have taken a disproportionately large amount of time. One disadvantage of this technique is that the more similar types of vegetation may be those which are most prone to changes and hence some changes may have been overlooked. In a partial attempt to combat this, an attempt was made to try to map areas of all the types of boundaries at least in some parts of the maps. The mapping of four different areas, albeit at a reduced precision than that which would have been possible if only one area was studied, was thought to be justifiable as it would eliminate any local changes which may have occurred in one area. Another problem of the limited period of study was that, at the time of mapping, some community boundaries were much more obvious than others as a result of character species being in an easily recognised growth stage, whereas in other communities most of the character species were less obvious later in the season. This latter group of communities included several of the calcareous grassland types. Because of these slight differences in the method of mapping the vegetation the possibility of utilising facilities on the Arc-Info GIS package to calculate changing areas of communities etc. was precluded.

Chapter 3

Results

3.1 The Match Results

3.1.1 The Original Data Set

If the Match results produced by analysing the vegetation noda as originally defined by Jones are considered (See Table 3.1), it can be seen that there is quite a range in the goodness of fit of these communities to the NVC data.

The two communities which are worst fitted to the NVC classification scheme are the nodum of the Whin Sill block scree and the nodum of community fragments with *Saxifraga aizoides* and *Cratoneuron commutatum.* However, as both of these noda are defined by less than the five quadrats suggested as the minimum number required to run a Match analysis, it is not really appropriate to attempt to discuss these low values any further. Similarly other communities which have only slightly more quadrat data than the recommended minimum and which also have fairly low match coefficients include the nodum of *Juncus effusus* and/or *Carex rostrata* dominated mires, the nodum with *Minuartia verna* and *Trifolium repens*, and the nodum with *Erica* and *Trichophorum* (Mapping Unit 23). However, in considering all of the Match analyses carried out here, it must be remembered that the NVC analysis does not classify to a similar level as the Zurich-Montpellier and therefore some of these noda may represent only a small proportion of the entire variability contained within a particular NVC community type.

The various noda comprising the α-nodal group with *Trifolium repens* and *Plantago lanceolata* (mapping units 19-22) all tend to have quite low Match coefficients, but are all similarly ascribed to the *Festuca ovina-Agrostis capillaris- Thymus praecox* (CG10) grassland community. The different noda are however ascribed to two distinct sub-communities, two being more similar to the *Luzula* sub-community and the other two being more akin to the *Viola riviniana* sub-community. They are also almost as well matched to some CG9 communities. However the match coefficients produced are quite low when compared to those produced for the other calcareous grasslands of the Festuco-Brometea (noda 1-7).

The three noda of the α nodal group with *Nardus stricta* and *Juncus squarrosus* (m.u. 25, 27 and 29) are best allocated by Match to two different NVC communities. The nodum with *Eriophorum vaginatum* (m.u. 27) and the nodum with *Galium saxatile* and *Sphagnum papillosum* (m.u. 29) are both allocated to the *Juncus squarrosus - Festuca ovina* (U6) grassland community with relatively good coefficient values (~64), although they are more similar to different sub-communities. The nodum with *Erica tetralix* and *Carex dioica* (m.u. 25) however is shown to be more similar to a different type of community altogether, that of the *Scirpus cespitosa - Erica tetralix* (M15) wet heath, and even here there is not a very good match coefficient.

The communities of the α-nodal group with *Calluna* and *Cladonia arbuscula* (m.u. 26, 31-33) are not reliably matched to any one community, all Match coefficients being quite low and three of the four noda having a second community of a different type less than five units different from the best match coefficient. The most likely interpretation of these results is that the nodum with *Empetrum* and *Erica* (m.u. 26) and the nodum with *Pteridium* and *Deschampsia flexuosa* (m.u. 31) are variants on the H12-*Calluna vulgaris- Vaccinium myrtillus* heath community, whilst the nodum with *Viola riviniana* (m.u. 32) and the nodum with *Danthonia decumbens* (m.u. 33) are more akin to the H18-*Vaccinium myrtillus- Deschampsia flexuosa* heath.

If the match outputs for the noda of the α-nodal group with *Carex nigra* and *Carex pulicaris* (m.u.15-18) are examined it can be seen that there is a range in the match coefficients produced. If the low value produced by the nodum with *Potamageton polygonifolius* is disregarded due to limited quadrat data, it can be seen that the remaining four noda fit best into two communities. The nodum with *Cratoneuron filicinum* and *Equisetum variegatum* (m.u. 15) and the nodum with *Ranunculus flammula* and *Carex echinata* (m.u. 16) fit quite well into the M10-*Carex dioica- Pinguicula vulgaris* mire community while the nodum with *Trifolium repens* and the nodum with *Viola palustris* seem to be more associated (albeit to a lesser degree) to the U5c-*Carex panicea- Viola riviniana* sub-community of the U5-*Nardus stricta- Galium saxatile* grassland community.

The two noda of the α-nodal group with *Calluna* and *Eriophorum vaginatum* seem to fit quite well into two mire communities. The nodum with *Narthecium* and *Trichophorum* (m.u. 24) being most akin to the M18-*Erica tetralix- Sphagnum papillosum* raised and blanket mire community and the nodum with *Empetrum* and *Sphagnum recurvum* (m.u. 28) fitting best the M19a-*Erica tetralix* sub-community of the *Calluna vulgaris- Eriophorum vaginatum* mire community.

All of the noda contained in the α-nodum with *Carex dioica* and *Carex lepidocarpa* (m.u. 8-14) fit quite well into several of the different sub-communities of the M10-*Carex dioica- Pinguicula vulgaris* mire community. Similarly all of the noda of the α-nodal group with *Sesleria albicans* and *Koeleria cristata* (m.u. 1-7) fit quite well into CG9c-*Sesleria albicans- Galium sterneri* grassland community.

Comparing the match coefficients of the groups produced by a standard Twinspan analysis (Table 3.2), it can be seen that despite differences in the method of classification and in the allocation of various quadrats to different end groups (see later), there are a large number of identical NVC communities produced by Match to best describe the communities present.

Mapping Unit or Community	Nearest NVC Community	Match Coefficient	Nearest NVC Sub-comm.	Match Coefficient
Whin Sill	U21	30.3	U21	30.3
Sax.aizoides/ Crat. comm.	U15 (M11, CG10)	32.1	M10b (CG10b, U15)	34.4
23	M17	44.3	M16d	52.7
Cardemine	M37	53.3	M37	53.3
J.effusus/Carex	M4	43.4	M6	41.6
Minuartia/ Trifolium	CG9	47.8	CG9d	55.7
22	CG10 (U4)	37.3	CG10a (U5c)	45.3
21	CG10	53.2	CG10a	54.3
20	CG10	49.0	CG10c	55.1
19	CG10 (U15)	44.0	CG10c	48.0
25	M15 (U5)	52.3	M15d	53.8
27	U6	54.1	U6b	64.4
29	U6	58.9	U6a	64.1
26	H12	49.2	M16d (H12)	50.9
31	H12 (U3)	48.9	H12c	55.0
32	H18 (U20)	47.1	H18b (U4c)	51.5
33	U5 (H18)	48.5	H18b (U5b)	49.8
15	M10	59.0	M10b	60.8
16	M10	57.5	M10	57.5
18	M38 (CG10)	44.8	U5c (M38, CG10a)	48.2
17	M8 (U5)	46.0	U5c	54.3
Potamageton	M37	37.6	M6b	40.5
24	M18	65.6	M18	65.6
28	M18	61.7	M19a	64.2
8	M10	51.2	M10b	59.4
9	M10	51.9	M10c	61.2
11	M10	65.3	M10b	72.0
12	M10	64.0	M10b	67.6
13	M10	62.7	M10	62.7
14	M10	48.2	M10c	80.0
1	CG9	51.9	CG9d	63.9
2	CG9	51.1	CG9d	60.9
3	CG9	59.0	CG9d	70.9
4	CG9	60.6	CG9d	64.3
5	CG9	52.5	CG9d	55.0
6	CG9	59.2	CG9d	71.2
7	CG9	59.3	CG9d	68.9

Table 3.1 - Table of the matches between the communities as originally defined by Jones and NVC communities. Less highly matched communities were included in brackets when they were a different type of community (e.g. CG cf. U) and when the match coefficient was less than 5 units different from the highest ranking community

Group Number	Nearest NVC Community	Match Coefficient	Nearest NVC Sub-Community	Match Coefficient
1	U3	52.3	U20b	53.3
2	H18 (U5)	42.6	H18b	46.1
3	U5	52.5	U5c	57.0
4	U21	25.4	U21	25.4
5	CG9	57.1	CG9d	64.1
6	CG9	65.8	CG9d	70.9
7	CG9	51.1	CG9d	53.7
8	CG10	53.8	CG9e	55.2
9	CG9 (M10)	47.8	CG9d (M10b)	57.1
10	CG10	50.8	CG10c	50.9
11	M10	50.4	M10c	78.8
12	M10	70.2	M10b	73.8
13	M10	59.9	M10b	63.4
14	M37	54.2	M37	54.2
15	M10	55.3	M10	55.3
16	M37	37.6	M6b	40.5
17	M10	55.5	M10b	55.8
18	M15 (U5)	43.8	M15d (U5c)	45.7
19	M8 (Cg10, U5)	45.4	CG10a (U4d, M8)	46.1
20	H12 (U5)	52.7	H12c	59.1
21	M15 (H12)	54.8	M15d	62.5
22	M15	56.6	M17c	65.6
23	U6	59.4	U6a	66.0
24	U6 (M6)	51.4	U6a	58.8
25	M19	53.7	M19b (U6a)	57.5
26	M4	37.3	M7b	42.9
27	M18	62.7	M18a	63.7
28	M18	58.7	M18	58.7
29	M18	64.4	M18	64.4
30	M17	34.6	M16d	40.0
31	M18	57.1	M19a (M18b)	60.7
32	M18	58.4	M18b	59.3

Table 3.2 - Table of the matches between the communities as defined by standard Twinspan analysis and NVC communities. Less highly matched communities were included in brackets when they were a different type of community (e.g. CG cf. U) and when the match coefficient was less than 5 units different from the highest ranking community

There are three communities produced as best fits by Match for the Twinspan groupings which were not produced as possible communities present from the Match analysis of the vegetation as classified by Jones (1973). These three new communities produced from the reclassified data were the *Vaccinium- Dicranum* sub-community of the *Pteridium aquilinum-Galium saxatile* community (U20b), the *Juncus squarrosus* sub-community of the *Scirpus cespitosa- Eriophorum vaginatum* blanket mire (M17b), and the M7b-*Carex aquatilis - Sphagnum recurvum* sub-community of the *Carex curta-Sphagnum russowii* mire. The latter of these however has quite a low Match coefficient. In addition three sub-communities were also produced as best fits which were not present in the community matches produced from the original classification. These were the *Sphagnum magellanicum- Andromeda polifolia* subcommunity and the *Empetrum nigrum- Cladonia* subcommunity of the *Erica tetralix- Sphagnum papillosum* mire (M18a and M18b respectively), along with the *Empetrum nigrum* sub-community of the *Calluna vulgaris- Eriophorum vaginatum* mire (M19b).

If the average of the Match coefficients produced from these two different methods of analysis are calculated, there is almost no difference between the two values (average coefficient using the original classification being 57.00 and that using the Twinspan output being 56.45). Discussions of the Match results elsewhere in the text refer to those produced from the original classification of Jones (1973).

3.1.2 Match Results of the Present Data Set

If the Match coefficients produced from analysing the noda studied during the present survey (table 3.3) are compared to the Match results from the original data set (table 3.1) there are some notable differences. The vegetation of mapping unit 4 is still best fitted to the CG9d community although with a slightly lower match coefficient than the that of the original data. The quadrats collected from mapping unit 21 are again best fitted to one of the CG10 communities, the present data set having a slightly better Match coefficient than the original data. Similarly the best fitting communities for the mapping unit 28 are again the communities of M19, and the communities best fitting the vegetation from the areas of mapping unit 29 during the present study are still given as U5 and U6

One of the shifts in matching the communities of the two surveys occurs with mapping unit 23. The latest quadrats collected in areas of this nodum now being matched more closely to M18 (or even M17 and M19) than to the M16 community which was the best fit for the original data.

The communities given as best fitting the data obtained from areas of mapping unit 33 are given as U5 and H18 with the original data, but U4 and CG10 from the present data; the fit of the present data set being slightly better to its corresponding matched communities than is the original data. It is also worth noting the inclusion of a calcareous grassland community amongst the best fitting communities of the current data set. This will be discussed elsewhere.

Mapping Unit	Nearest NVC Community	Match Coefficient	Nearest NVC Sub-Community	Match Coefficient
4	CG9	55.1	CG9d (CG9, CG9c)	57.2
21	CG10	57.2	CG10 (CG10a, 10b & 10c, CG9, 9d & 9e)	57.2
23	M18 (M17)	59.0	M18 (M18a,b; M17a, b, &c; M19a)	59.0
28	M19	59.6	M19b (M19a, M19)	61.3
29	U6 (U5)	57.6	U5b (U5a, U6b, U6)	61.6
33	U4 (U5)	50.2	U4a (CG10a, U4)	54.9

Table 3.3 - Table of the matches between the communities examined during the present survey and NVC communities. Less highly matched communities were included in brackets when the match coefficient was less than 5 units different from the highest ranking community

3.2 Results of the *Gentiana* Seedhead Counts

From Table 3.4 it is initially obvious that there is little seed production at any of the studied sites; successful seed production being unusual rather than the norm. It is also noticeable that in the unenclosed areas of open grassland there were no seedheads located and likewise in the enclosed area that actually had limited access to sheep and also contained rabbits. The Festuco-Brometea nodum 4 is the community in which a calcareous grassland flora grows beneath and amongst a sparse growth of *Calluna*. Here it seems that the growth of *Calluna* actually acts to protect the flowers and/or seedheads of the *Gentiana* plants and allow some to develop successfully to the stage of producing seedheads. The possible relevance of this factor is discussed later with reference to sheep grazing of the fell. With regards to the production of seedheads in the enclosed areas, with the exception of the enclosure mentioned above all of the enclosed areas have seed production to some extent. Because of the small number of seedheads found in any of the areas of study it is not relevant to try to discuss which of the methods of enclosure management results in the most abundant production of seedheads, except to say that it seems very likely that the effects of heavy sheep and rabbit grazing is to act so as to practically eliminate the successful production of *Gentiana* seed and that even in an enclosure where there is no grazing or management, there is still some production of seedheads.

Area of Study	Percent of *Gentiana* with seedheads
Enclosure 1	1.0
Enclosure 2	1.5
Enclosure 3	0.5
Enclosure 4	0.0
Festuco-Brometea Community 4	1.0
Festuco-Brometea Community 5	0.0
Molinio-Arrhenatheretea Comm. 21	0.0

Table 3.4 - Percentage of Gentian plants with seedheads in various habitats

3.3 Sheep grazing densities on different plant communities

From Table 3.5 it can be seen that there is an enormous range in the densities of sheep in the various areas of vegetation. The lowest density in the ombrogenous bog (1) is shown as a range as a large area of this vegetation was surveyed but it proved quite difficult to accurately assess the extent of the area being surveyed. It was therefore only possible to obtain a range of densities which can be taken as the best estimate of the area being surveyed. The area categorised as ombrogenous bog (2) could be mapped more accurately but this area was close to limestone grassland areas and in general seemed to be uncharacteristic of the usual densities of sheep on this vegetation elsewhere. It is therefore probably better to consider the values obtained for the ombrogenous bog (1) area as being more characteristic of this type of vegetation. Similarly there were several areas of acidic and calcareous vegetation studied but in the case of these grasslands several areas were studied to show variations due to different communities and conditions.

It can be seen from Table 3.5 that there is a general trend of increasing sheep densities from lowest on the ombrogenous bog and bare calcareous sedge-marsh, to slightly higher numbers on the acidic grassland and highest of all on the calcareous grasslands and closed sward calcareous sedge-marsh.

One of the most interesting findings is the very low density of sheep present on the *Calluna*/calcareous grass complex of nodum 4, the initial impression being that this area was grazed by the sheep to a similar degree as other areas of calcareous grassland. However the surveying showed that much of the grazing activity was actually occurring in the small areas of open limestone grassland which occur within this vegetation type. This resulted in a quite high grazing density on these small patches of grassland (17.2 sheep/ha) which one may have expected to have been grazed to a lesser extent as a result of their isolated distribution and small size. A second anomalous result is the higher than expected densities on the riverside plain acid grassland. Possible explanations of these anomalies are given in the discussion section.

General Description of Area	Dominant communities Present	Grazing Density of Sheep no. of sheep/ha
General ombrogenous bog (1)	28	~0.1 - 0.3
Calcareous sedge marsh	8-14	2.2 ± 0.8
General ombrogenous bog (2)	28	3.2 ±1.3
Calluna/calcareous grass complex	4	3.6 ±2.8
Acidic grassland (1) slope	25-27, 29-33	7.1 ±1.3
Acidic grassland (2)	29, 33	9.2 ± 1.7
Sub-alpine calcareous pastures	21, 5	13.7 ±3.1
Calcareous grassland (1)	1-7	15.3 ±2.1
Calcareous grassland (2), patches amongst community 4	1-7, predominantly 5, 6	17.2 ±2.1
Acidic grassland (3) on riverside plains	25-27, 29-33	18.4 ±4.7
Calcareous grassland (3)	1-7	19.8 ±3.4
Mesotrophic sedge marsh and sub-alpine calc. pastures	21, 18	22.4 ±2.6
Calc. flushes and pasture, amongst community 4	8, 9, 20, 21	27.6 ±3.2

Table 3.5 - Table of calculated mean grazing densities (± standard error) during the mid-summer period on several of the community types present on Widdybank Fell.

3.4 Effects of Enclosures on the Vegetative Communities of the Limestone Grassland

3.4.1 Twinspan Analysis

There is a variety of different grazing and management regimes in the enclosed quadrats and a gradation in the severity of grazing/management.

Examining the Twinspan outcome for the enclosure quadrats (figure 3.1) it can be seen that the quadrats can be divided into three main groupings and one of these can be fairly meaningfully sub-divided into two further groups. The three initial groups which

KEY

S - quadrats from enclosure 1
M - quadrats from enclosure 2
G - quadrats from enclosure 3
R - quadrats from enclosure 4

Letters in **bold** type represent quadrats carried out within a particular enclosure.
Letters in *italics* represent quadrats carried out along the outer edge of a particular enclosure.

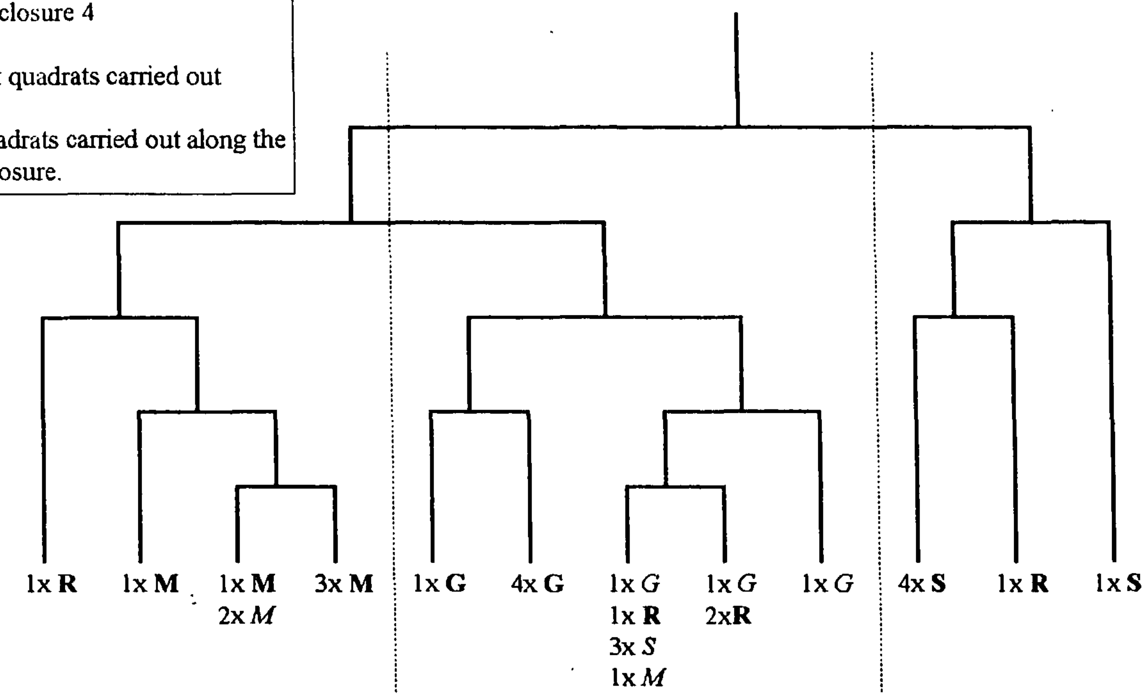


Figure 3.1 - Dendrogram showing the classification of the various enclosure quadrats produced from using a standard Twinspan analysis. An explanation of the letters listed for the end groups is given in the key.

Photograph 5 - Enclosure 2 in the centre of the picture with freely grazed grassland in the foreground. Note the taller sward and the profuse flowering of *Galium boreale, Ranunculus acris* and *Vicia cracca* in the enclosure.

Photograph 6 - Showing enclosure 1 on the left of the picture and the external grazed area on the right. Note the dense sward within the enclosure and the profuse flowering of *Sesleria albicans.*

can be picked out include most of the quadrats from enclosure two in one group, most of the quadrats from enclosure one in a second group and a mixture of unenclosed quadrats and enclosure three quadrats in a third group. At the level of the first division the areas within enclosure one are split off from the rest of the quadrats, indicating that the completely ungrazed and unmanaged areas are more distinct than any of the other enclosed or unenclosed communities. Within the remaining group of quadrats a further subdivision then separates the majority of both the unenclosed and enclosed quadrats from enclosure two quadrats. The remaining quadrats are then sub-divided again such that the enclosed quadrats of enclosure three are distinguished from a remaining group which includes unenclosed quadrats from several of the communities along with several of the enclosure four enclosed quadrats. The enclosure four quadrats are most common in the group containing unenclosed areas but odd quadrats occur in the two other groupings.

3.4.2 Decorana Plot of the Enclosure Quadrats

A Decorana analysis was carried out on all of the quadrats from the enclosure experiments to see if any gradients could be determined with respect to the various enclosure regimes. From the plot of axis one against axis two (See Figure 3.2) it can be seen that there is some separation of the various groups of quadrats. The first axis pulls out the quadrats from within enclosure one from the rest of the quadrats, indicating the vastly different vegetation resulting from a complete cessation of grazing. The second axis pulls away the quadrats of enclosure two as being most distinct, thereby showing the separation of the two least grazed communities from the rest of the data in the first two axes of the Decorana plot. It is also worth noting that the second axis seems to pull out a slight gradient in respect to the grazing pressure on each community, albeit with a reverse in the position of enclosure one and two with respect to grazing density. At the lower end of this axis enclosure three is positioned slightly above enclosure four, with the grazed areas in general lying slightly lower still.

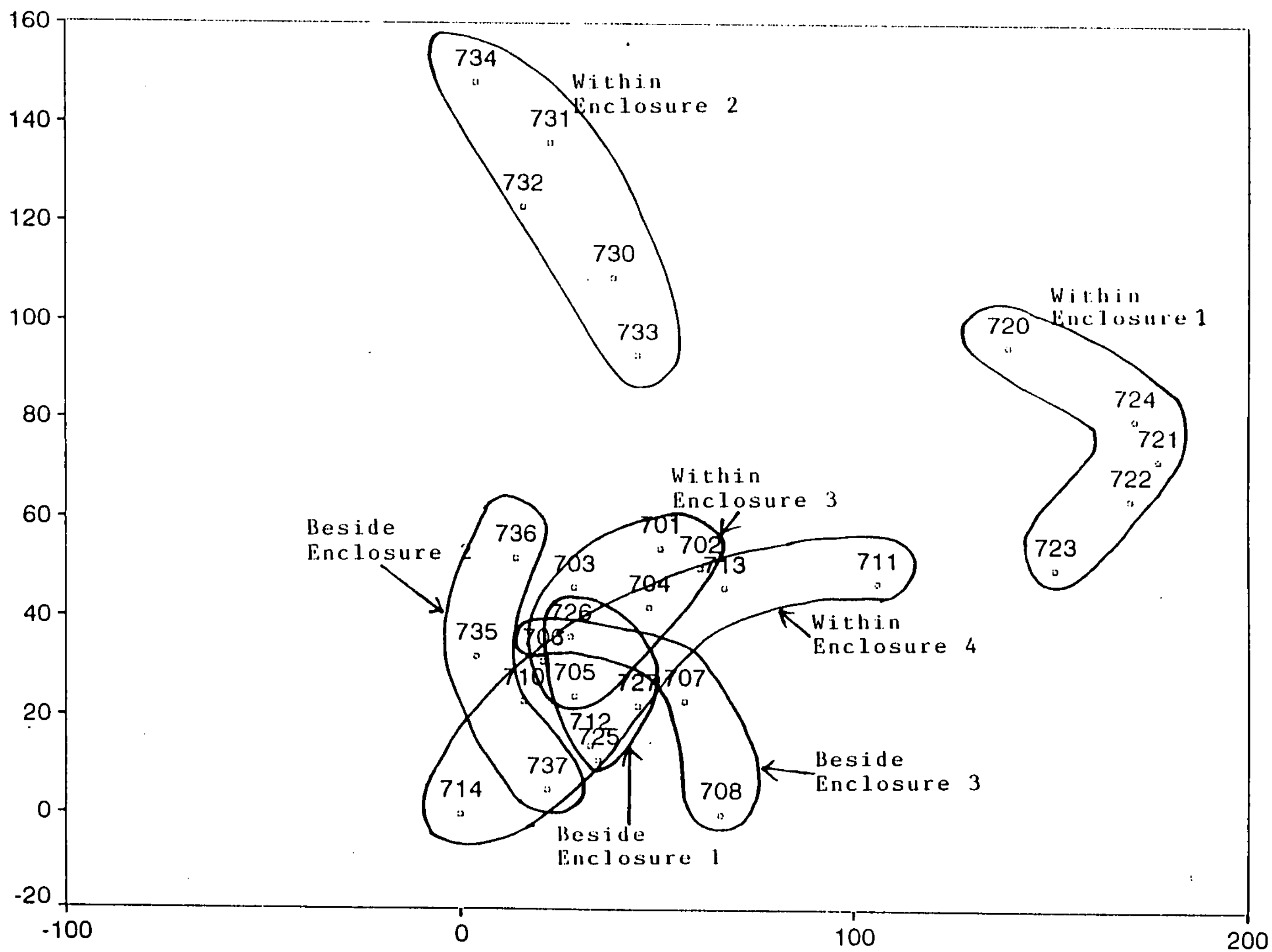


Figure 3.2 - **Decorana plot of the first two axes of variation for the quadrats carried out within and alongside the various enclosures. Numbers refer to the raw data quadrat numbers provided in the appendix. Labels show the groups of different quadrats with the numbers referringto those given in the method.**

3.5 Twinspan Classifications of the Vegetative Data

3.5.1 A Standard Twinspan Run of the Entire Data Set

If the standard Twinspan run including all of the original and present survey data (figure 3.3) is considered it can be seen that most quadrats collected during the present survey fall into end groups containing the majority of quadrats of the same nodum collected during the original survey. Included in this category are the quadrats of mapping units 28, 29, 4 and 21.

The remaining two noda do not comply to this general pattern and require some attention. The vegetation mapped in areas of nodum 33 during the present survey falls into end groups with quadrats of nodum 33 and similar vegetation from the original survey. What is also notable however is that there are also some quadrats belonging to more calcicolous noda in these groups e.g. mapping unit 21, 22 and the nodum with *Minuartia verna* and *Trifolium repens.* This has implications with respect to other results (described later) derived by analysing the data using different Twinspan analysis methods.

The dendrogram separates the quadrats of nodum 23 from the two surveys into different groups. This seems to indicate that the quadrats from nodum 23 of the present survey are more akin to the original nodum 24 and nodum 28 quadrats than they are to the original nodum 23 quadrats.

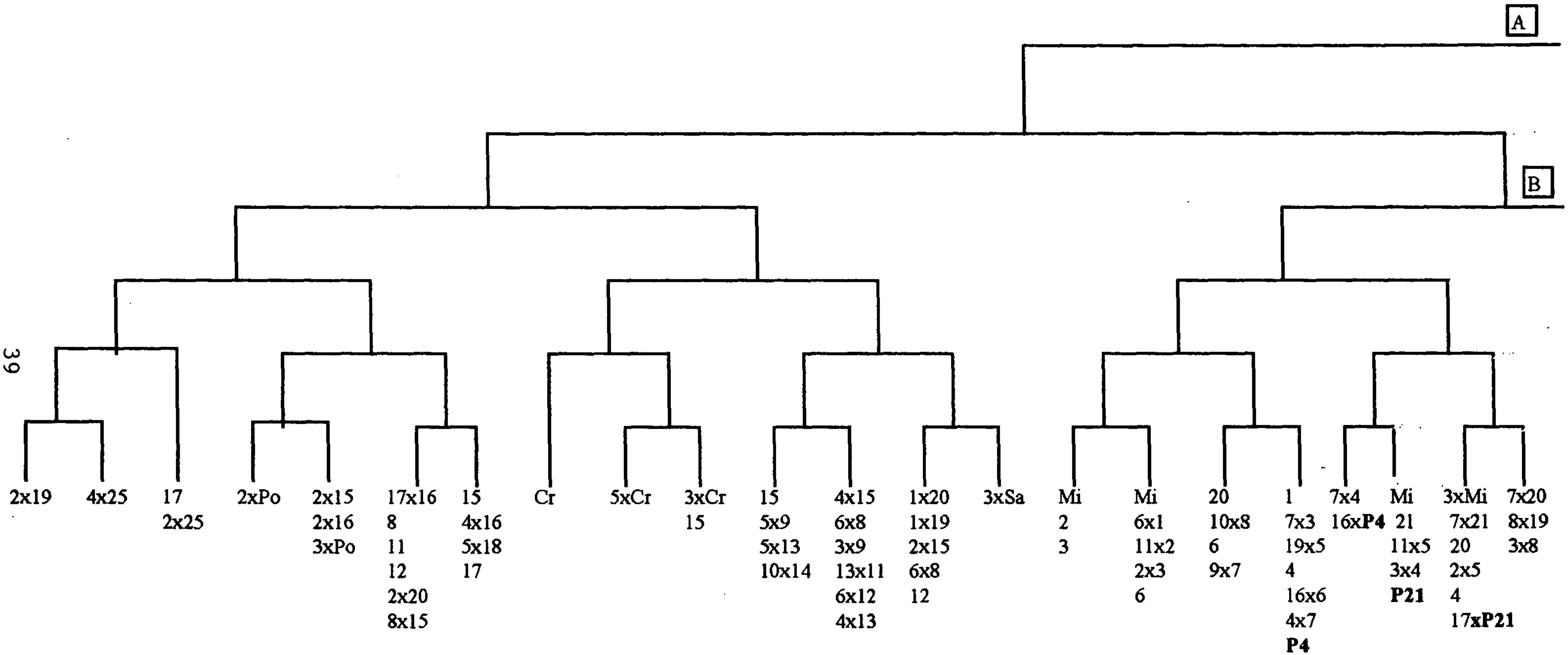


Figure 3.3 - Dendrogram depicting the Twinspan divisions produced from analysing all of the quadrats from Jones' original survey as well as all of the quadrat data collected during the present survey. Default Twinspan options were used throughout. A key to all of the end group abbreviations is provided at the end of the figure.

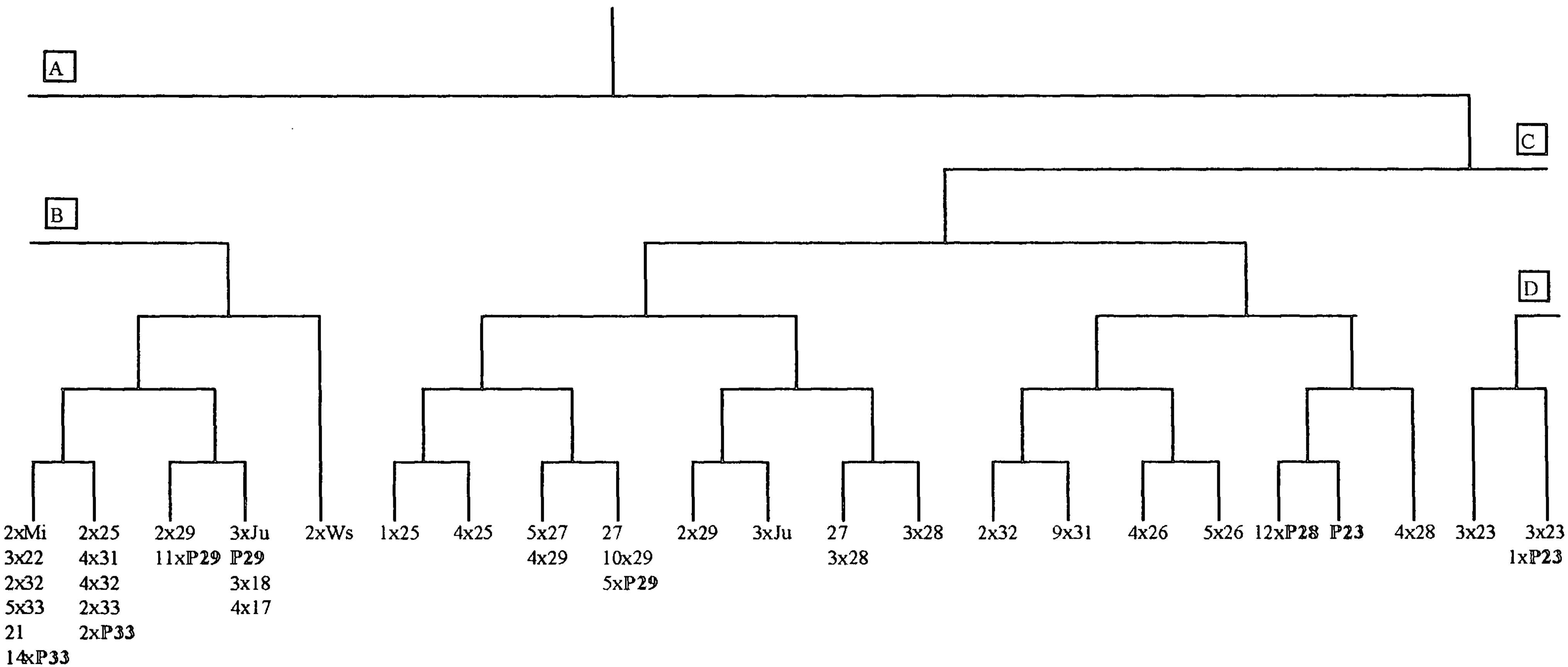
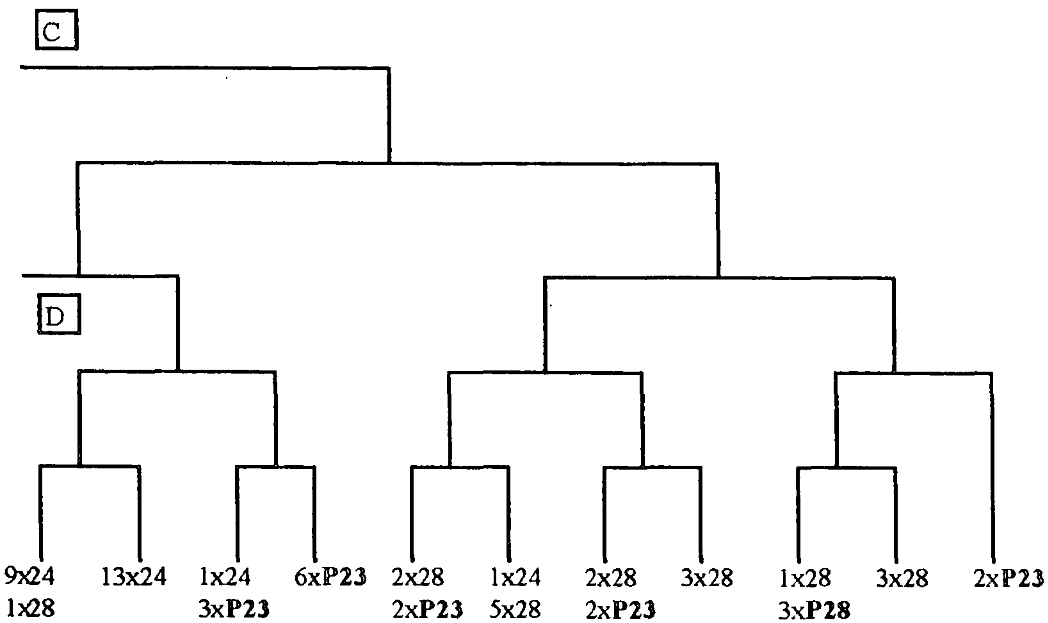


Figure 3.3 (cont.) - Dendrogram depicting the Twinspan divisions produced from analysing all of the quadrats from Jones' original survey as well as all of the quadrat data collected during the present survey. Default Twinspan options were used throughout. A key to all of the end group abbreviations is provided at the end of the figure.



Key

Numbers 1-33 - Vegetative nodum from the original survey

Number **P4** - Nodum 4 from the present study

Number **P21** - Nodum 21 from the present study

Number **P23** - Nodum 23 from the present study

Number **P28** - Nodum 28 from the present study

Number **P29** - Nodum 29 from the present study

Number **P33** - Nodum 33 from the present study

Mi - Nodum with Minuartia verna and Trifolium repens
Ju - Nodum with Juncus effusus/ Carex rostrata
Cr - Nodum with Cratoneuron Commutatum and Cardemine pratensis
Sa - Community fragments with Saxifraga aizoides
Ws - Nodum of the Whin Sill block scree

The five latter communities are all unmapped nodum from the original survey
The number preceding the multiplication sign in each of the end groups is the number of quadrats of a particular nodum which are classified together into that end group

Figure 3.3 (cont.) - Dendrogram depicting the Twinspan divisions produced from analysing all of the quadrats from Jones' original survey as well as all of the quadrat data collected during the present survey. Default Twinspan options were used throughout. A key to all of the end group abbreviations is provided at the end of the figure.

3.5.2 The Modified Twinspan Run of the Original Data Set and Hand Twinspan Classification of the Present Data Set using the Same Criteria

In terms of a method of comparative analysis of the original and present data sets this is better than the previous method, having been designed so as to assign quadrats into the same noda as those defined originally by Jones (1973) if there has been no change. A standard Twinspan run would change its indicator species at each division as a result of additional data, whilst this method retains the indicator species which provides a more robust comparative method.

Noda which seem to have changed little using this method of analysis (see Figure 3.4) include mapping unit 4 and mapping unit 28, although in the latter a few quadrats from the present survey are now classified as being more similar to noda of the *Calluno-Ulicetalia* (noda 26, 31-33). The quadrats taken in areas of nodum 29 during the present survey are all classified into an end group with about half of the original nodum 29 quadrats, the rest of the original quadrats having been split from this group at the previous level of the dendrogram. This may indicate that the present survey has only sampled a particular facies of this nodum and is not representative of the entire nodum.

A Decorana plot of the original and current data in a case like this may, with some consideration of the species in the quadrats, enable a trend of sampling a wetter facies of the nodum for example, or a general drying, to be postulated.

Half of the quadrats from mapping unit 21 of the present survey are classified with the original quadrats, whilst several of the other quadrats are classified into groups containing mapping unit 33 quadrats from the present survey and noda belonging to the *Caricetea-nigrae* (mapping units 17 and 18). Some of the mapping unit 33 quadrats from the present survey are also classified into a group containing quadrats of mapping units 19 and 20 from the original survey. Other quadrats from nodum 33 of the present survey are classified into groups containing mapping units 1-7, 21, 17 and 18. It is notable that all of these end groups are somewhat more calcicolous in nature than the end groups into which the original nodum 33 quadrats are classified.

The quadrats of mapping unit 23 are classified into several end groups, with over half being classified into groups with the original quadrats. Another third of the quadrats are classified into a group with mapping unit 28 quadrats from the original survey and only one quadrat is classified into the group which mainly includes the mapping unit 24 quadrats. This is in contrast to the results of the standard Twinspan analysis which tends to group nodum 23 quadrats from the present survey into a group with nodum 24 quadrats.

The results of this dendrogram indicate that the majority of the noda sampled have changed but not to the extent that they are now better classified within another class of vegetation. A more detailed analysis can therefore be applied by analysing the new data with only the data from its corresponding class. The only nodum which could be considered to be altering its original class affinity is nodum 33.

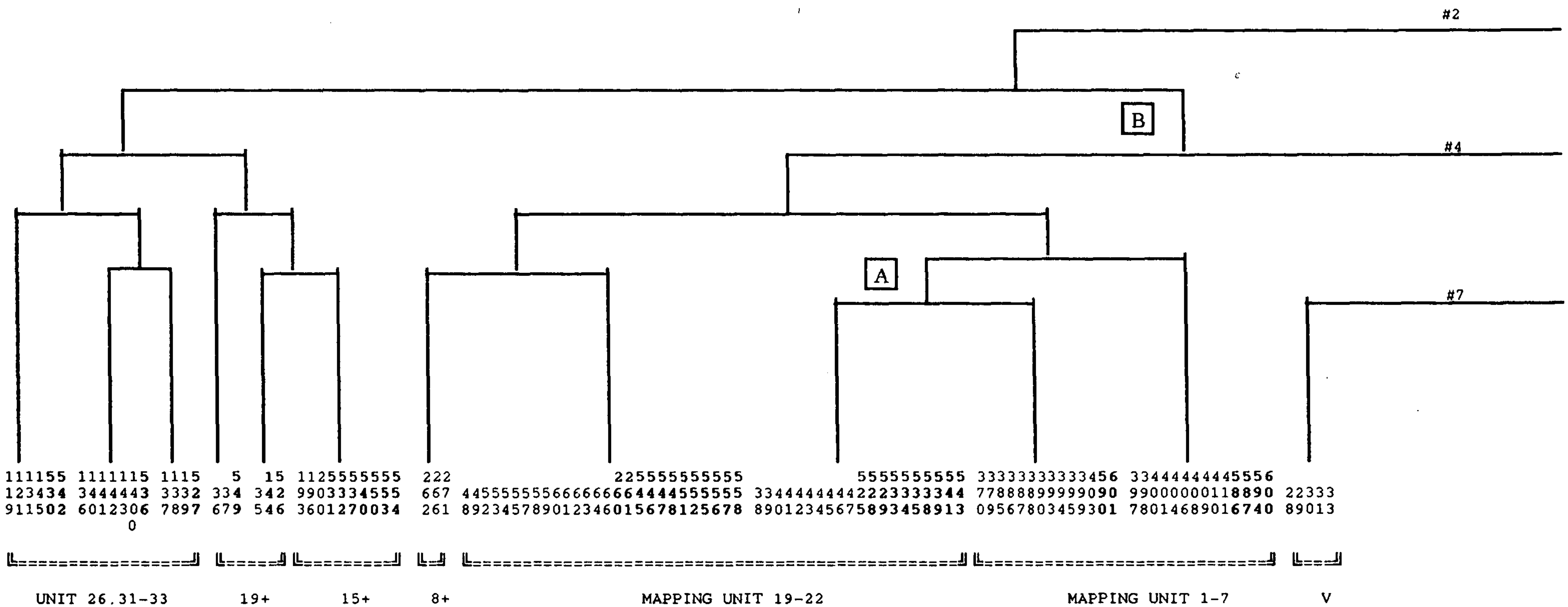


Figure 3.4 - Dendrogram depicting the Twinspan divisions produced by analysing all of the quadrats from Jones' original survey using the modified Twinspan run. Also included are the quadrats from the present survey, which were analysed by hand using the same criteria as that used by the modified Twinspan run. Numbers along the base of the dendrogram represent the quadrat number as defined inTable 1.1 and read vertically down. Mapping unit labels along the base refer to the noda of Jones data only in each end group. Letters in boxes refer to modifications explained in the key.

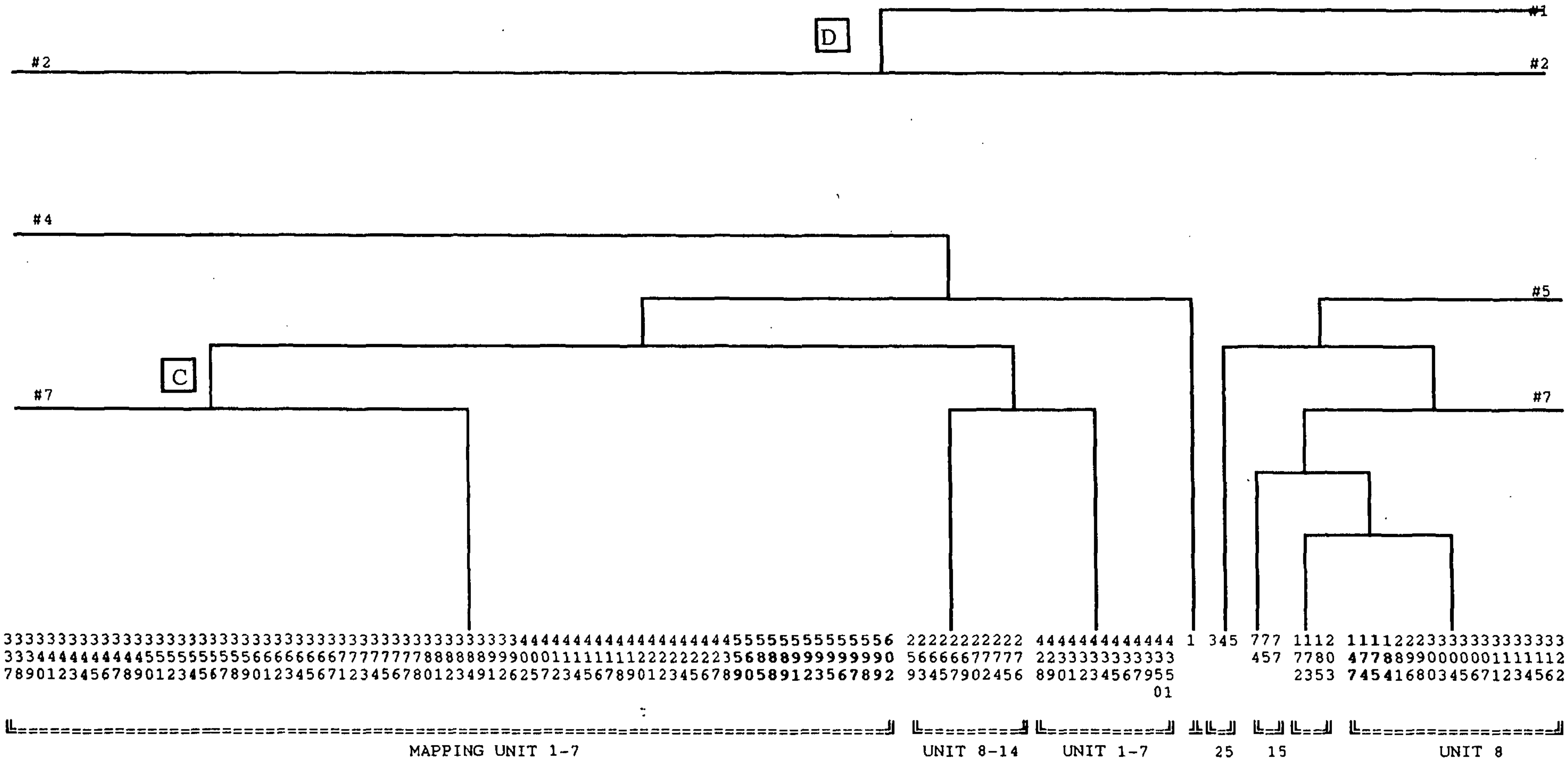


Figure 3.4 (cont.) - Dendrogram depicting the Twinspan divisions produced by analysing all of the quadrats from Jones' original survey using the modified Twinspan run. Also included are the quadrats from the present survey, which were analysed by hand using the same criteria as that used by the modified Twinspan run. Numbers along the base of the dendrogram represent the quadrat number as defined inTable 1.1 and read vertically down, and mapping unit labels refer to the noda of Jones data only in each end group. Letters in boxes refer to modifications explained in the key.

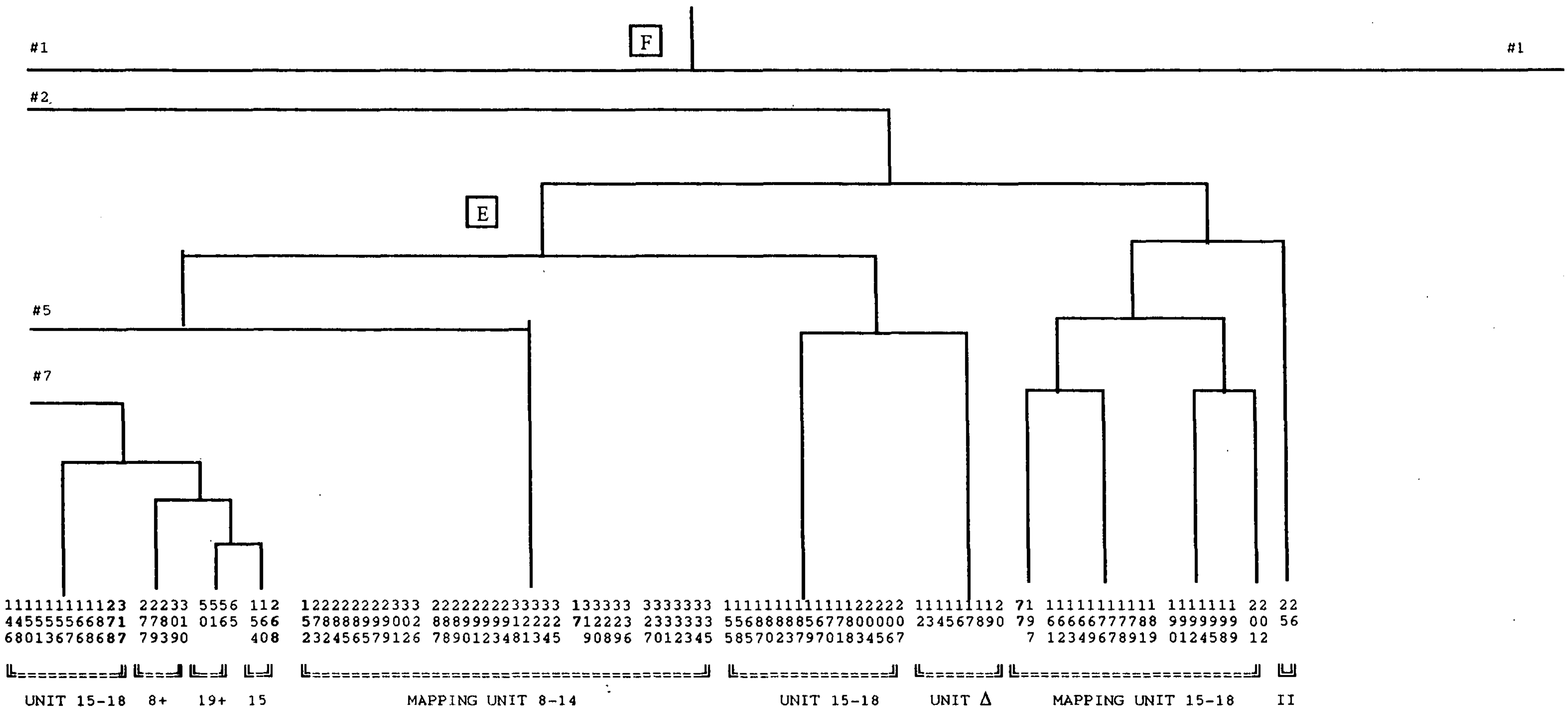


Figure 3.4 (cont.) - Dendrogram depicting the Twinspan divisions produced by analysing all of the quadrats from Jones' original survey using the modified Twinspan run. Also included are the quadrats from the present survey, which were analysed by hand using the same criteria as that used by the modified Twinspan run. Numbers along the base of the dendrogram represent the quadrat number as defined inTable 1.1 and read vertically down, and mapping unit labels refer to the noda of Jones data only in each end group. Letters in boxes refer to modifications explained in the key.

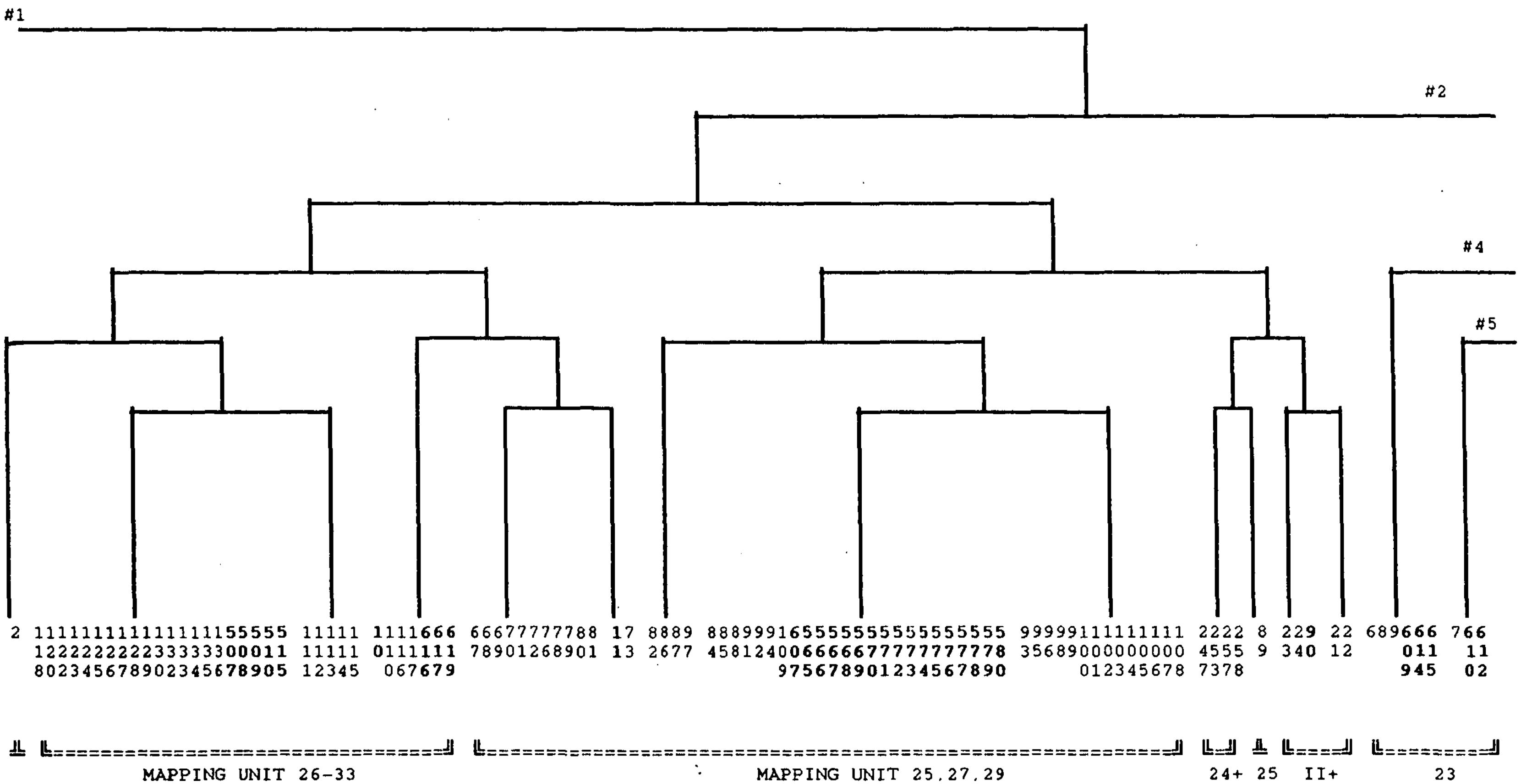
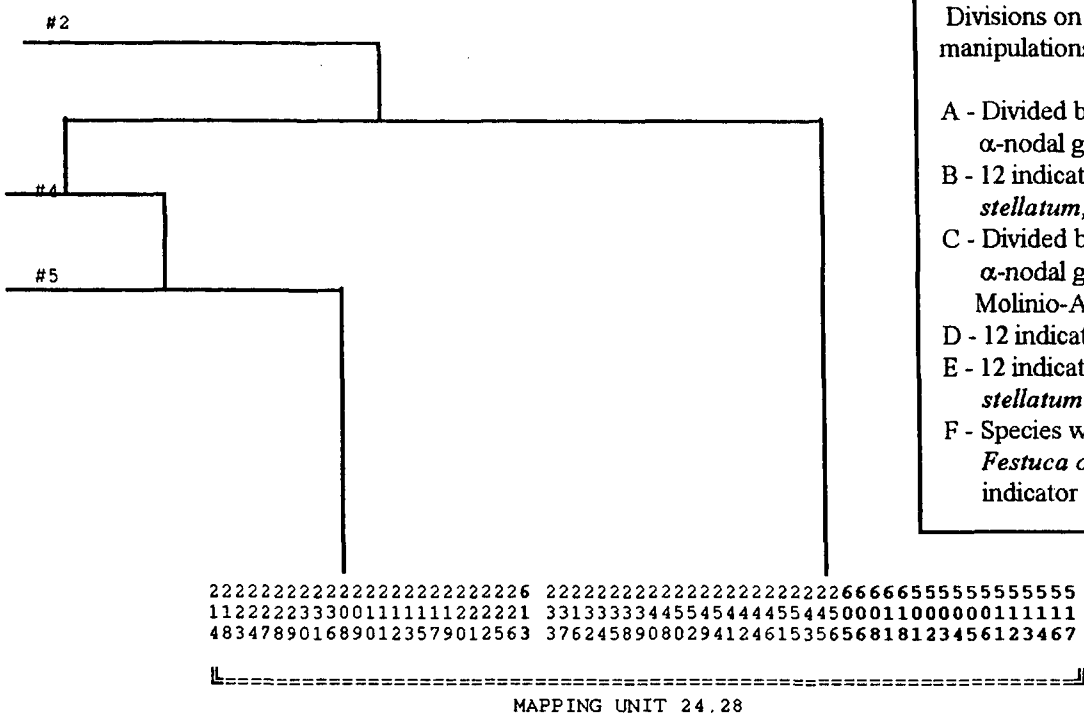


Figure 3.4 (cont.) - Dendrogram depicting the Twinspan divisions produced by analysing all of the quadrats from Jones' original survey using the modified Twinspan run. Also included are the quadrats from the present survey, which were analysed by hand using the same criteria as that used by the modified Twinspan run. Numbers along the base of the dendrogram represent the quadrat number as defined inTable 1.1 and read vertically down, and mapping unit labels refer to the noda of Jones data only in each end group. Letters in boxes refer to modifications explained in the key.



Key to Analysis Methods

Where there is no letter alongside a division on the dendrogram the Twinspan analysis was carried out using the parameters of previous divisions.. Divisions on the dendrogram with a boxed letter alongside them had various manipulations of the default parameters as follows :

A - Divided by hand on the presence/absence of character species of the α-nodal groups of the Festuco-Brometea and Molineo-Arrhenatheretea
B - 12 indicator species; omitting *Selaginella selaginiodes, Campylium stellatum*, and *Ctenidium molluscum* as potential indicators
C - Divided by hand on the presence/absence of character species of the α-nodal groups of the Festuco-Brometea, Minuartio-Thlaspeetum, and Molinio-Arrhenatheretea
D - 12 indicator species
E - 12 indicator species; omitting *Selaginella selaginoides, Campylium stellatum and Ctenidium molluscum* as potential indicator species
F - Species weightings 0,1,1,1,1; 12 indicator species; omitting *Thymus, Briza, Festuca ovina, Carex pulicaris and Ctenidium molluscum* as potential indicator species

Figure 3.4 (cont.) - Dendrogram depicting the Twinspan divisions produced by analysing all of the quadrats from Jones' original survey using the modified Twinspan run. Also included are the quadrats from the present survey, which were analysed by hand using the same criteria as that used by the modified Twinspan run. Numbers along the base of the dendrogram represent the quadrat number as defined inTable 1.1 and read vertically down, and mapping unit labels refer to the noda of Jones data only in each end group. Letters in boxes refer to modifications explained in the key.

3.5.3 Twinspan Analysis of the Quadrats from the Present Study with their Associated Nodum and Class Data from the Original Study

3.5.3.1 Nodum 4, Nodum with *Calluna*, of the Festuco-Brometea Class

A comparison of the past and present species composition and abundance in this nodum was attempted by carrying out a Twinspan analysis on the two sets of quadrat data available. The results of this analysis (see Figure 3.5) shows that at the level of the first division approximately half of the most recent quadrats are separated as being distinct from the rest of the data. On the left-hand side of the diagram it can also be seen that the majority of the remaining recent quadrats are then separated from the earlier data set at the level of the second division. This would seem to indicate that there has been a change in the vegetation community to some extent but not to such a degree as to make all of the later quadrats immediately distinguishable from the earlier ones. The quadrat of the present study which is classified as being most similar to the earlier quadrats (no. 585), was later discovered to have been recorded from an area of nodum five vegetation and should therefore be disregarded. Therefore, with a few exceptions, the later quadrats do seem to be distinguishable from the earlier ones at the level of the second Twinspan division.

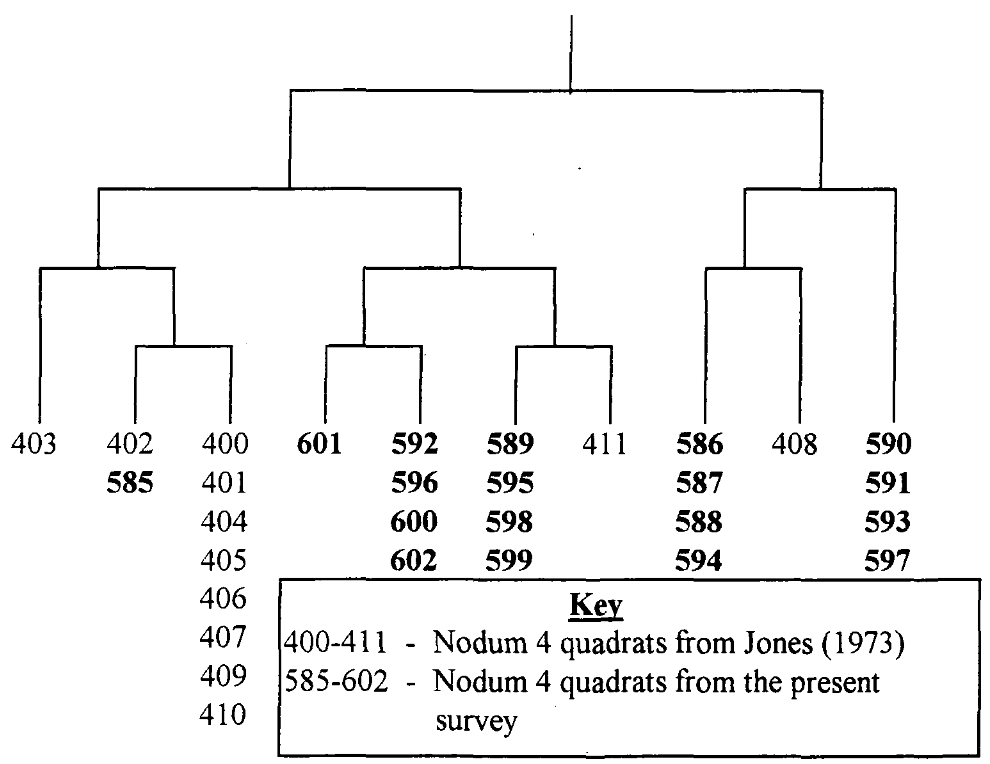


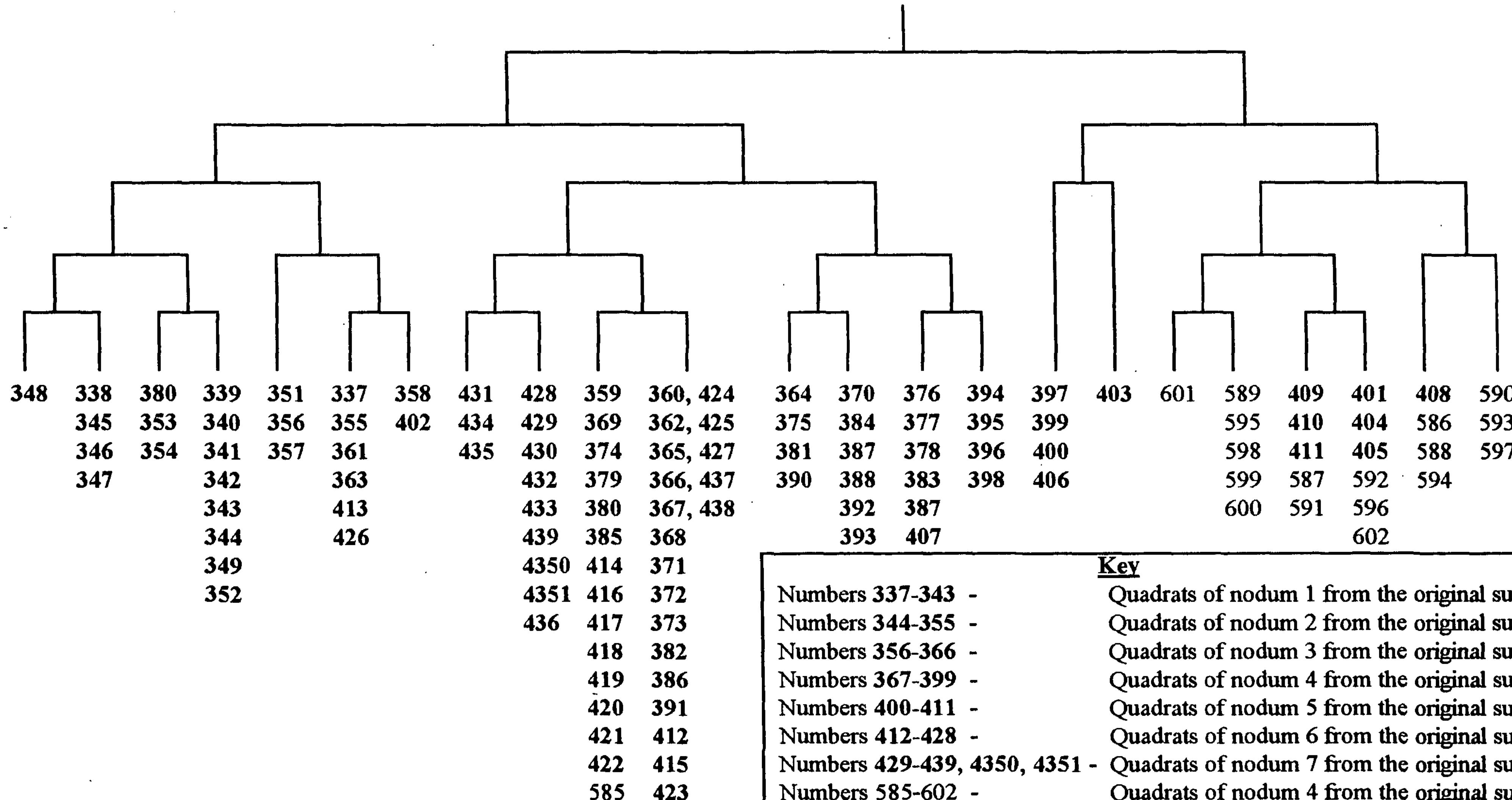
Figure 3.5 - Dendrogram depicting the Twinspan divisions produced from analysing the nodum 4 quadrats from both the original and present survey. See key for explanations of the numbers used in the dendrogram.

If these two sets of data are then compared to the remainder of the noda of the Festuco-Brometea from the original study using a standard Twinspan analysis (Figure 3.6), it can be seen that the majority of the two sets of data are divided from the rest of the Festuco-Brometea noda at the level of the first division. Subsequent divisions of the nodum four communities then fail to effectively split the original and present data sets. It can be deduced that at the level of the association, the community of the present study can still be classified as belonging to the nodum with *Calluna* but within this community there do seem to have been some changes since the original survey.

The mismapped area of nodum 5 vegetation is here differentiated entirely from the nodum 4 vegetation and is classified into an end group containing other quadrats of nodum 5 vegetation, the vegetation type from which it was accidentally collected.

Changes occurring with respect to increasing and decreasing species as well as new species and species lost from the community between the two studies are shown in Tables 3.6 and 3.7. Although these show changes in a considerable number of species, the gains and losses seem to almost balance each other out. Notable losses, in terms of the formerly most constant of the lost species, are *Plagiochila asplenioides* and *Potentilla crantzii* whilst the most notable gains are by *Ctenidium molluscum* and *Agrostis canina*. There seems to be no noticeable ecological trend in these changes, with gains and losses of calcicoles and more mesotrophic species although a large proportion of the missing species are mosses and liverworts.

In terms of increasing/decreasing species (Table 3.6) all, save *Viola lutea,* are only slight changes, most also only being present in one or two quadrats. This therefore seems to indicate a community which has only been slightly altered over time.



Key

Numbers 337-343 -	Quadrats of nodum 1 from the original survey
Numbers 344-355 -	Quadrats of nodum 2 from the original survey
Numbers 356-366 -	Quadrats of nodum 3 from the original survey
Numbers 367-399 -	Quadrats of nodum 4 from the original survey
Numbers 400-411 -	Quadrats of nodum 5 from the original survey
Numbers 412-428 -	Quadrats of nodum 6 from the original survey
Numbers 429-439, 4350, 4351 -	Quadrats of nodum 7 from the original survey
Numbers 585-602 -	Quadrats of nodum 4 from the original survey

Figure 3.6 - A dendrogram depicting the Twinspan divisions produced from analysing all of the *Festuco-Brometea* communities See key for explanations of the numbers used in the dendrogram.

Species lost since the Original Survey	New species detected in the Present Survey
Scapania aspera (2)	*Carex lepidocarpa (1)*
Frullania tamarisci (3)	*Ctenidium molluscum (1/3)*
Fissidens adianthoides (1)	*Trifolium repens (2)*
Plagiochila asplenioides (4)	*Achillea millefolium (3)*
Peltigera leucophlebia (1)	*Cladonia rangiformis (1)*
Potentilla crantzii (4)	*Carex pilulifera (2)*
Bryum pseudotriquetrum (1)	*Festuca rubra (1)*
Barbilophozia floerkei (1)	*Agrostis canina (5)*
Cerastium holostioides (1)	*Veronica officinalis (1)*
Luzula campestris (1)	*Anthyllis vulneraria (1)*
Lophocolea bidentata (2)	*Primula farinosa (1)*
Ptilidium ciliare (2)	
Galium verum (1)	
Baeomyces roseus (2)	
Botrychium lunaria (1)	

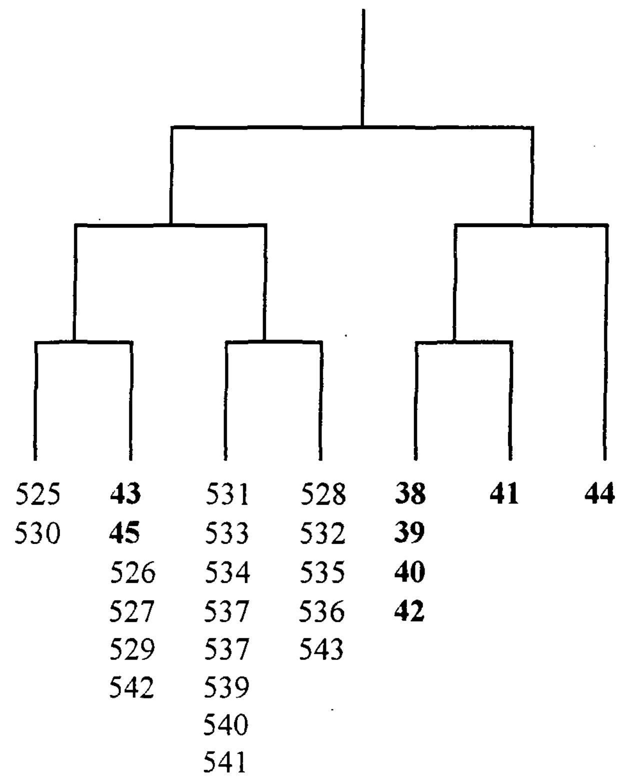
Table 3.6 - Table of changes occurring in vegetative nodum 4, showing species lost or gained since the original survey. Numbers in parentheses refer to the number of occurrences of the species, or when represented in fractional form indicate an approximation of the percentage of quadrats containing the species; those in the left-hand column referring to occurrences in the original survey and those in the right-hand column referring to the present survey.

Species increasing since the original survey	Species decreasing since the original survey
Danthosia decumbens (Sl)	*Cladomnia arbuscula (Sl)*
Helictotrichon pratensis (Sl)	*Cladonia pulicaris (Sl)*
Hypnum jutlandicum (Sl)	*Pleurozium schreberi (Sl)*
Thuidium tamariscinum (Sl)	*Rhytidiadelphus loreus*
Viola lutea	*Agrostis stolonifera (Sl)*
Empetrum nigrum (Sl)	*Briza media (Sl)*
Polytrichum formosum (Sl)	*Rhacomitrium lanuginosum (Sl)*
	Agrostis tenuis (Sl?)
	Ranunculus acris (Sl?)
	Sanguisorba officinalis (Sl)

Table 3.7 - Table of changes occurring in vegetative nodum 4, showing species which have either increased or decreased in abundance or distribution since the original survey. Where the letters "Sl" are included in parentheses after a species this indicates only a slight change

3.5.3.2 Nodum 21, Nodum with *Carex caryophyllea* of the Molinio-Arrhenatheretea Class

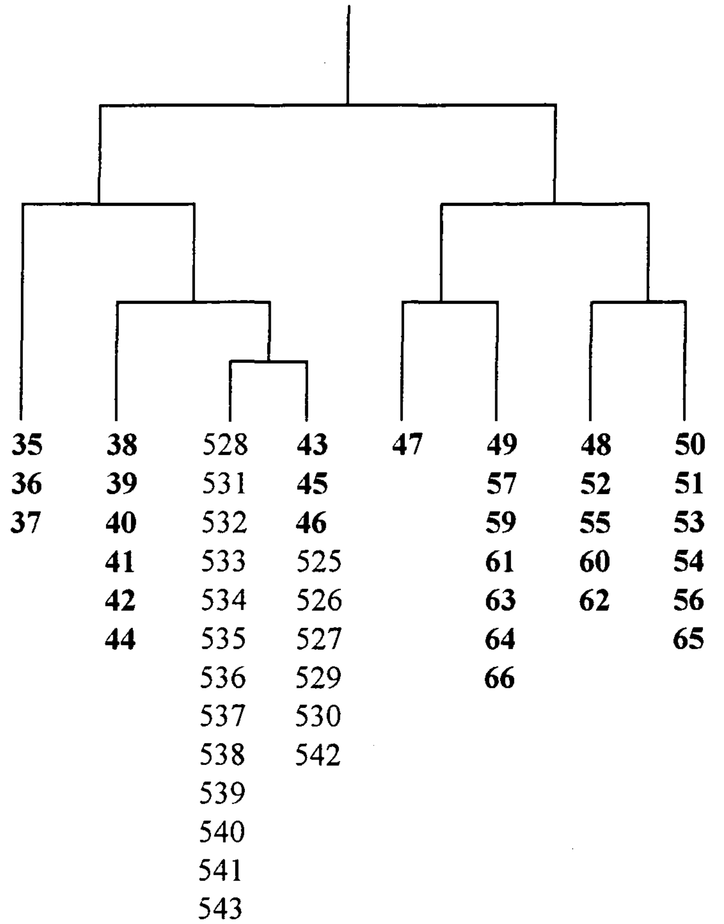
The Twinspan analysis carried out on the quadrat data of the present and original study (Figure 3.7) shows that at the level of the first division there have been changes in the sward to such an extent as to allow a fairly distinct separation of the present survey data from that of the original survey.



Key
Numbers 525-543 - Quadrats from the present survey
Numbers 38-45 - Quadrats from the original survey

Figure 3.7 - A dendrogram depicting the Twinspan divisions produced from analysing the nodum 21 quadrats from both the original and present survey. See key for explanations of the numbers used in the dendrogram.

If the data are then compared in the context of all of the Molinio- Arrhenatheretea noda present on the fell (Figure 3.8), both sets of nodum 21 vegetation are classified together down to level three of the classification and only then is there some partial but incomplete separation of the two groups of samples. It would seem that again any differences occurring within the studied nodum are subtle changes within the nodum and not significant enough to cause the quadrats from the present survey to be classified as being more akin to another nodum of the association or as being entirely distinct.



Key	
Numbers 35-37 -	Quadrats of nodum 22 from the original survey
Numbers 38-45 -	Quadrats of nodum 21 from the original survey
Numbers 46-57 -	Quadrats of nodum 20 from the original survey
Numbers 58-66 -	Quadrats of nodum 19 from the original survey
Numbers 525-543	Quadrats of nodum 21 from the present survey

Figure 3.8 -A dendrogram depicting the Twinspan divisions produced from analysing all of the Molinio-Arrhenatheretea communities. See key for explanations of the numbers used in the dendrogram.

Table 3.8 and 3.9 display the changes which have occurred in nodum 21 and seem to show no loss in the species richness of the community. They show a community where there seems to have been little change and the few losses have been matched by gains of other species.

There again seems to be no real ecological trend with respect to the changes in species, new species including calcicoles (*Carex capillaris* and *Ditrichum flexicaule*) and more calcifuge species (*Galium saxatile* and *Agrostis canina*), although some of the newly colonising species are now quite common in this nodum. In terms of species losses several liverworts are amongst the list, although none of these were frequent even originally. These losses of liverworts in this and the previous nodum studied may be indicative of a factor related to the dry summer which may affect such a hydrophilic group on habitats over quite shallow soil and in such low swards, or maybe under such conditions they dry up and are overlooked. The absence of several easily recognised liverworts would however seem to suggest otherwise and that this could be a real longer scale trend.

Of the increasing species all four are calcicoles, three of which are mosses. Decreasing species include *Agrostis tenuis* and *Atrichum undulatum*, which are species more often associated with moderately acidic soils.

Species lost since the Original Survey	New species detected in the Present Survey
Poa pratensis (1)	*Galium saxatile (~1/2)*
Scapania aspera (2)	*Agrostis canina (~1/3)*
Plagiochila asplenioides (1)	*Carex capillaris (3)*
Barbilophozia floerkei (1)	*Asplenium viride (3)*
	Ditrichum flexicaule (~1/3)

Table 3.8 - Table of changes occurring in vegetative nodum 21, showing species lost or gained since the original survey. Numbers in parentheses refer to the number of occurrences of the species or when represented in fractional form indicate an approximation of the percentage of quadrats containing the species; those in the left-hand column referring to occurrences in the original survey and those in the right-hand column referring to the present survey.

Species increasing since the original survey	Species decreasing since the original survey
Hypnum lacunosum	*Campanula rotundifolia (Sl)*
Lotus corniculatus (Sl)	*Atrichum undulatum (Sl)*
Ctenidium molluscum (Sl)	*Agrostis tenuis*
Rhytidiadelphus triquetrus	*Koeleria cristata*
	Lophocolea bidentata

Table 3.9 - Table of changes occurring in vegetative nodum 21, showing species which have either increased or decreased in abundance or distribution since the original survey. Where the letters "Sl" are included in parentheses after a species this indicates only a slight change.

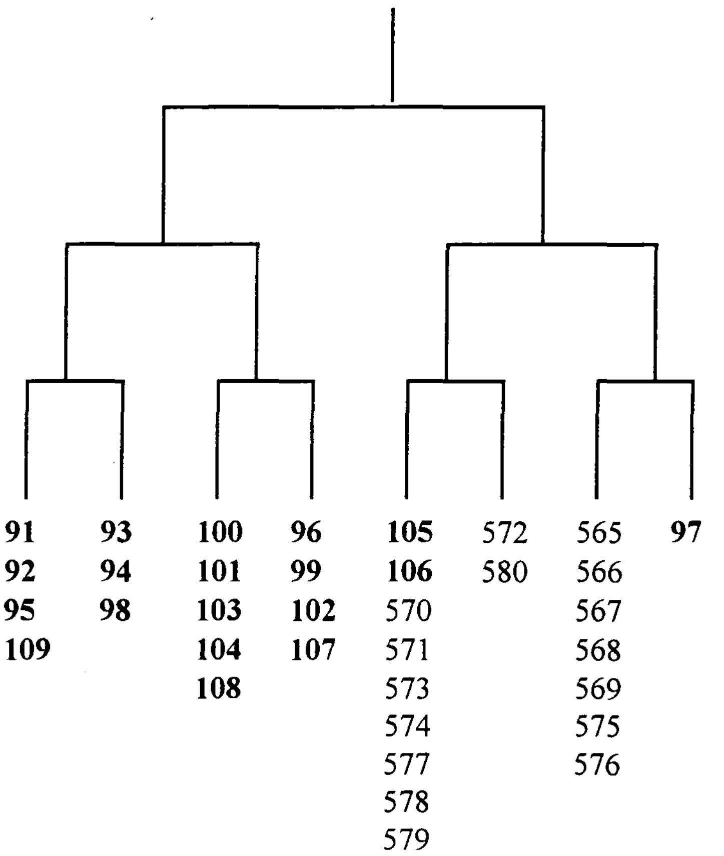
3.5.3.3 Nodum 29, Nodum with *Galium saxatile* and *Sphagnum papillosum* of the Class Nardo-Callunetea

As with the previous nodum, when the original and present data are compared in a Twinspan analysis (Figure 3.9), there is a splitting of the new and old data sets, with a few exceptions at the level of the first division. Further divisions of the right-hand sub-group however fails to split conclusively those quadrats of the original study which were classified with those of the present study. Thus there again seems to have been a significant change in this community over the intervening period between the studies. This outcome of only a few quadrats of the original study being grouped with the majority of those from the present study may support the hypothesis that during the present study only one facies of the entire community proper was sampled, i.e. the areas close to limestone.

A comparison of the two data sets alongside other noda in this association (Figure 3.10) splits the nodum 25 quadrats off from the rest of the data set at the level of the first division. There is therefore no splitting of the two nodum 29 data sets until level two. At this level all of the data from the present study, along with two quadrats from the original study are separated from the remaining data. In this respect the classification seems to indicate that there is more of a similarity between the original nodum 29 and the nodum 27 data sets than there is between the original and present nodum 29 data sets. This may indicate a notable change in the vegetation.

The tables showing how the species composition and abundances have changed (Tables 3.10 & 3.11) suggest that the present survey records a somewhat depauperate community compared to that of the original survey.

Of the species lost, seven were present in at least two of the original quadrats and most are not species which would be overlooked. There is something of a trend in the species lost as many are species associated with wet conditions, although there seems to be no opposite trend with respect to newly detected species. There are also many more species decreasing in abundance and constancy than there are increasing, again suggesting a depauperate flora. Of the two increasing species *Deschampsia flexuosa* is generally infrequent on waterlogged soil (Grime *et al.* 1995) whilst *Pleurozium schreberi* often prospers on slightly drier soils than many of the other species of this nodum, possibly suggesting a slight drying. Decreasing species however seem to show no real trend. As it is likely that Jones sampled areas of nodum 29 in wetter areas away from the limestone, this change in species may represent only the predominant sampling of a drier facies during the present survey rather than an absolute change.



Key
Numbers 565-580 - Quadrats from the present survey
Numbers 91-108 - Quadrats from the original survey

Figure 3.9 - A dendrogram depicting the Twinspan divisions produced from analysing the nodum 29 quadrats from both the original and present survey. See key for explanations of the numbers used in the dendrogram

Species lost since the Original Survey	New species detected in the Present Survey
Equisetum palustre (4)	*Polytrichum juniperum (1)*
Thuidium delicatulum (2)	*Polytrichum formosum (2)*
Agrostis tenuis (3)	*Sphagnum capillifolium (1)*
Viola palustris (3)	*Tortella tortuosa (2)*
Juncus effusus (~1/2)	*Empetrum nigrum (1)*
Polygala serpyllifolia (~1/3)	*Poa annua (1)*
Narthecium ossifragum (2)	*Cornicularia aculeata (1)*
Diplophyllum albicans (1)	*Bryum pseudotriquetrum (1)*
Aulacomnium palustre (~2/3)	
Sphagnum papillosum (~2/3)	
Ptilidium ciliare (~1/3)	
Sphagnum capillaceum (1/3)	
Sphagnum subsecundens (1)	
Acrocladium cuspidatum (1)	
Taraxacum officinalis agg. (1)	
Barbilophozia floerkei (~1/3)	

Table 3.10 - Table of changes occurring in vegetative nodum 29, showing species lost or gained since the original survey. Numbers in parentheses refer to the number of occurrences of the species or when represented in fractional form indicate an approximation of the percentage of quadrats containing the species; those in the left-hand column referring to occurrences in the original survey and those in the right-hand column referring to the present survey.

Species increasing since the original survey	Species decreasing since the original survey
Deschampsia flexuosa	*Carex echinata (Sl?)*
Pleurozium schreberi (Sl?)	*Polytrichum formusum (Sl)*
	Agrostis canina
	Agrostis stolonifera
	Potentilla erecta
	Calluna vulgaris (Sl)
	Carex panicea (?)
	Mnium hornum (Sl)
	Lophocolea bidentata
	Plagiothecium undulatum
	Calypogeia trichomanis
	Acrocladium stramineum
	Carex nigra
	Sphagnum recurvum

Table 3.11 - Table of changes occurring in vegetative nodum 29, showing species which have either increased or decreased in abundance or distribution since the original survey. Where the letters "Sl" are included in parentheses after a species this indicates only a slight change

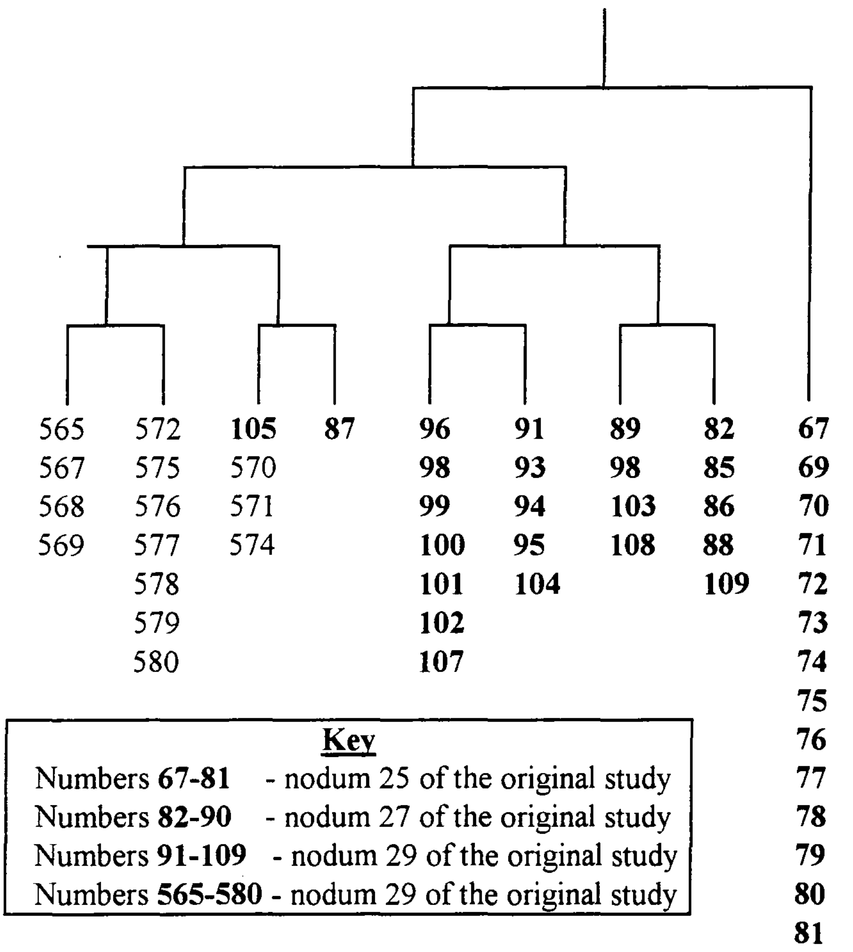


Figure 3.10 - A dendrogram depicting the Twinspan divisions produced from analysing all of the Nardo-Callunetea communities. See key for explanation of numbers used in the dendrogram.

3.5.3.4 Nodum 33, Nodum with *Danthonia decumbens* of the Class Calluno-Ulicetalia

The Twinspan analysis of the original and present data sets of nodum 33 vegetation (Figure 3.11) again splits the majority of the present data set off at the level of the first division as being distinct from the original data set (with a few exceptions). When these two data sets are compared alongside other members of the Association present on the fell (Figure 3.12), the data from the present survey is first split from its counterpart nodum from the original survey at the level of the second division. Here however, in a similar fashion to the previous example, the original nodum 33 data are classified as being more akin to the quadrats from nodum 32 of the original survey than they are to the quadrats collected in nodum 33 during the original survey.

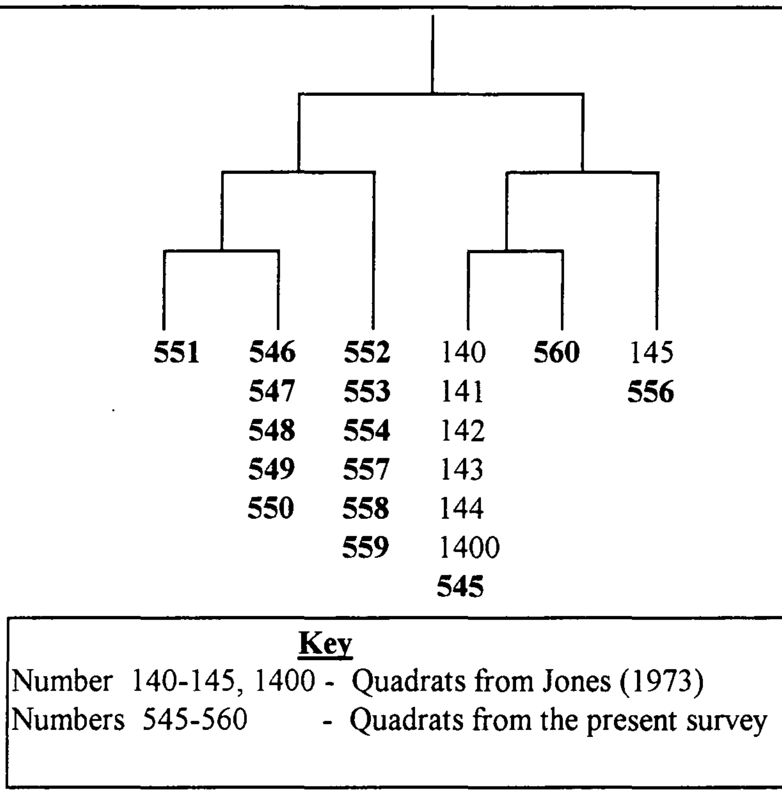
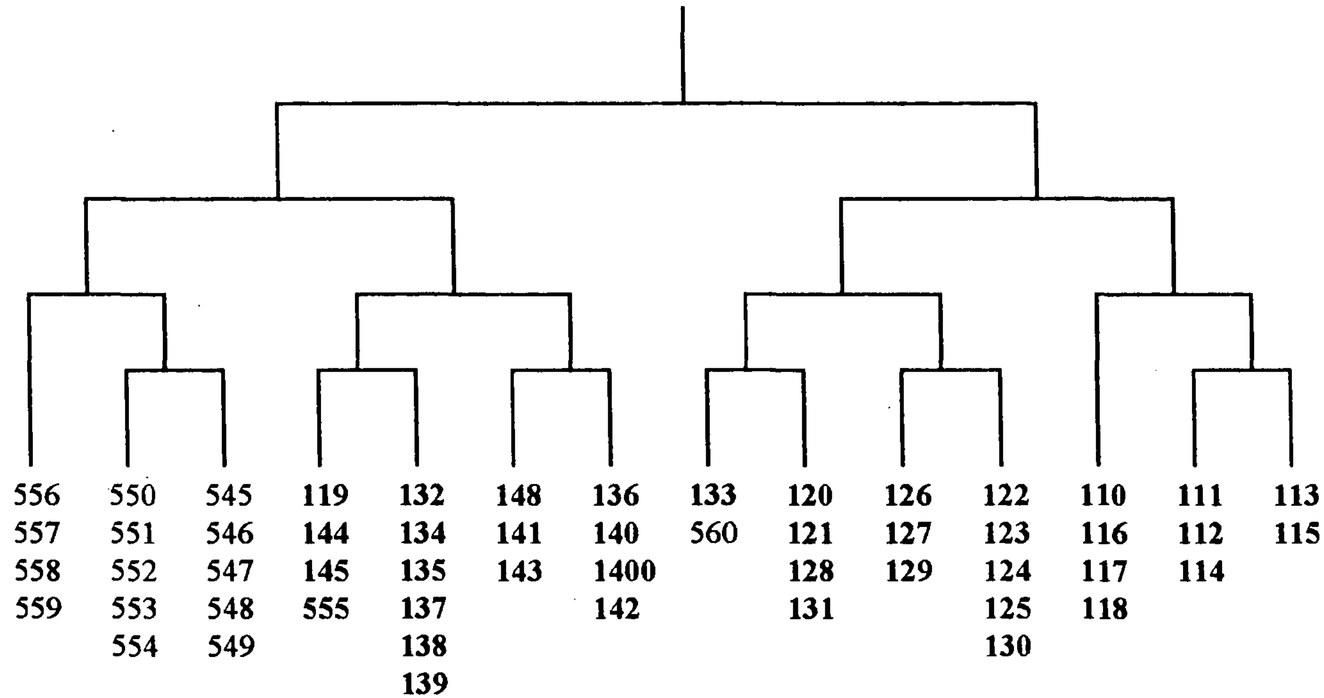


Figure 3.11 - A dendrogram depicting the Twinspan divisions produced from analysing the nodum 33 quadrats from both the original and present survey. See key for explanations of the numbers used in the dendrogram

If the changes in the species distribution and abundance are considered (Tables 3.12 & 3.13) it can be seen that although the number of decreasing species are approximately matched by the number of increasing species, there is vast increase in the number of species newly colonising the community compared to the number of species which have been lost. This was originally thought, when considering the raw data, to represent something of a directional shift towards a community more similar to the nodum 32 community, Nodum with *Viola riviniana*. The Twinspan analysis however seems to show that this is not the case and that the original nodum 33 vegetation is actually more akin to nodum 32 vegetation than is the present data set.

Increasing species include a mixture of species types, including calcicoles (*Viola lutea, Viola riviniana*), mesotrophic species (*Trifolium repens*) and acidic species (*Deschampsia flexuosa*), as well as indifferent species (*Rhacomitrium lanuginosum, Rhytidiadelphus squarrosus* (Watson 1968)). Decreasing species include both calcicoles and more cacifuge species, although generally the calcicoles tend to only decrease slightly. Most of the species lost only had one occurrence in the original survey and most are calcifuge to some extent, *Koeleria* being an exception. The observed decline in *Koeleria* may be



Key

Numbers 110-118 -	Quadrats of nodum 26 from the original survey
Numbers 119-131 -	Quadrats of nodum 31 from the original survey
Numbers 132-139 -	Quadrats of nodum 32 from the original survey
Numbers 140-145,1400 -	Quadrats of nodum 33 from the original survey
Numbers 545-560 -	Quadrats of nodum 33 from the present survey

Figure 3.12 - A dendrogram depicting the Twinspan divisions produced from analysing all of the *Calluno-Ulicetalia* communities. See key for explanations of the numbers used in the dendrogram.

explained, as in nodum 21, by the hot summer or due to heavy grazing The huge number of newly colonising species are predominantly calcicolous or at least mesotrophic and many have appeared in this habitat in some quantity. This may be indicative of a general increase in the pH of the soil of this nodum over the time between the two studies.

Species lost since the Original Survey	New species detected in the Present Survey
Calluna vulgaris (1)	*Cladonia macilenta (1)*
Carex binervis (1)	*Alchemilla glabra (1)*
Pohlia nutans (1)	*Achillea millefolium (~2/3)*
Ptilidium ciliare (~1/2)	*Lotus corniculatus (~1/3)*
Koeleria cristata (1)	*Carex flacca (1/3)*
	Hieracium pilosella (4)
	Hypnum lacunosum (4)
	Thymus praecox (~3/4)
	Cladonia furcata (1)
	Carex echinata (1)
	Carex pulicaris (1)
	Diplophyllum albicans (1)
	Rhytidiadelphus loreus (~1/3)
	Psuedoscleropodium purum
	Climacium dendroides (2)
	Juncus squarrosus (2)
	Ranunculus acris (3)
	Botrychium lunaria (2)
	Euphrasia officinalis agg. (~1/2)
	Acrocladium cuspidatum (1)
	Selaginella selaginoides (4)
	Prunella vulgaris (~1/3)
	Plantago lanceolata (4)
	Cerastium holostioides (4)
	Thuidium tamariscinum (2)
	Mnium hornum (2)
	Mnium longirostrum (1)
	Atrichum undulatum (1)
	Dicranella heteromalla (1)
	Plagiomnium undulatum (2)
	Peltigera canina (1)
	Cirsium palustre (1)
	Cirsium vulgare (1)
	Gentiana verna (1)

Table 3.12 - Table of changes occurring in vegetative nodum 33, showing species lost or gained since the original survey. Numbers in parentheses refer to the number of occurrences of the species or when represented in fractional form indicate an approximation of the percentage of quadrats containing the species; those in the left-hand column referring to occurrences in the original survey and those in the right-hand column referring to the present survey.

Species increasing since the original survey	Species decreasing since the original survey
Trifolium repens	*Cladonia arbuscula (Sl)*
Viola riviniana	*Nardus stricta (Sl)*
Viola lutea	*Agrostis stolonifera*
Hylocomium splendens	*Carex caryophyllea (Sl)*
Rhytidiadelphus squarrosus	*Danthonia decumbens*
Rhacomitrium lanuginosum	*Briza media (Sl)*
Deschampsia flexuosa (Sl)	*Barbilophozia floerkei*
	Dicranum scoparium
	Potentilla erecta
	Vaccinium myrtillus (Sl)
	Cetraria islandica

Table 3.13- Table of changes occurring in vegetative nodum 33, showing species which have either increased or decreased in abundance or distribution since the original survey. Where the letters "Sl" are included in parentheses after a species this indicates only a slight change.

3.5.3.5 Nodum 23, Nodum with *Erica* and *Trichophorum* and Nodum 28, Nodum with *Empetrum* and *Sphagnum recurvum* of the Class Oxycocco- Sphagnetea

If the results of the Twinspan analysis of the two data sets of Nodum 23 vegetation are first examined (Figure 3.13), it can be seen that (with one exception) the vegetation of the original and present survey are conclusively divided at the level of the first division. The Twinspan analysis of the two Nodum 28 data sets (Figure 3.14) are similarly fairly well split at the level of the first division. This would seem to indicate some change in the vegetation of both noda over the time interval between the two studies.

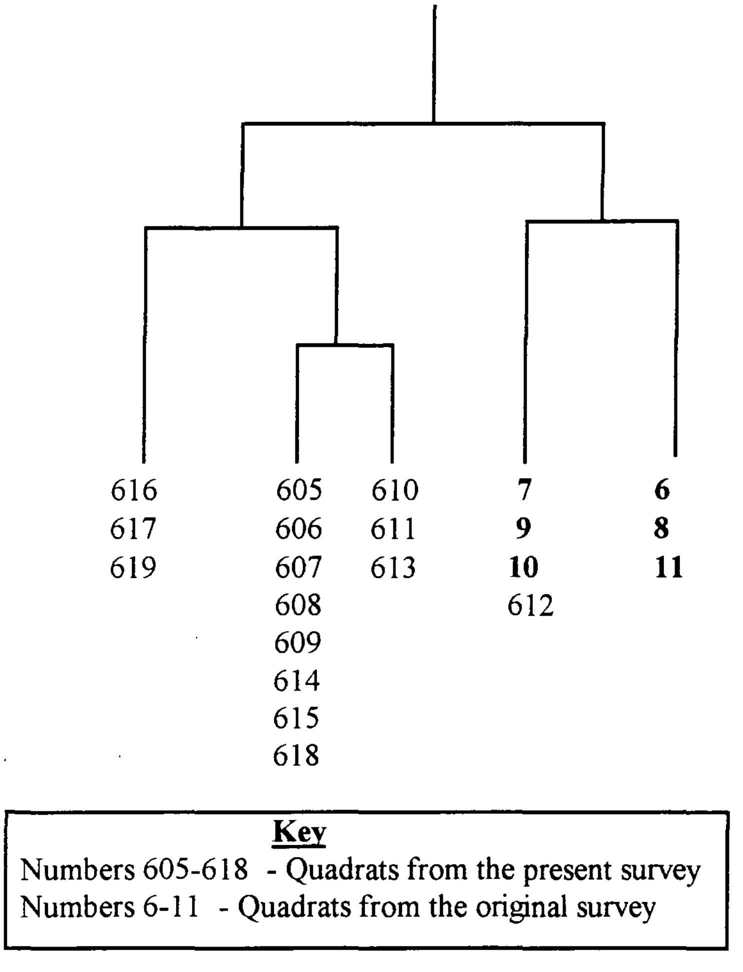
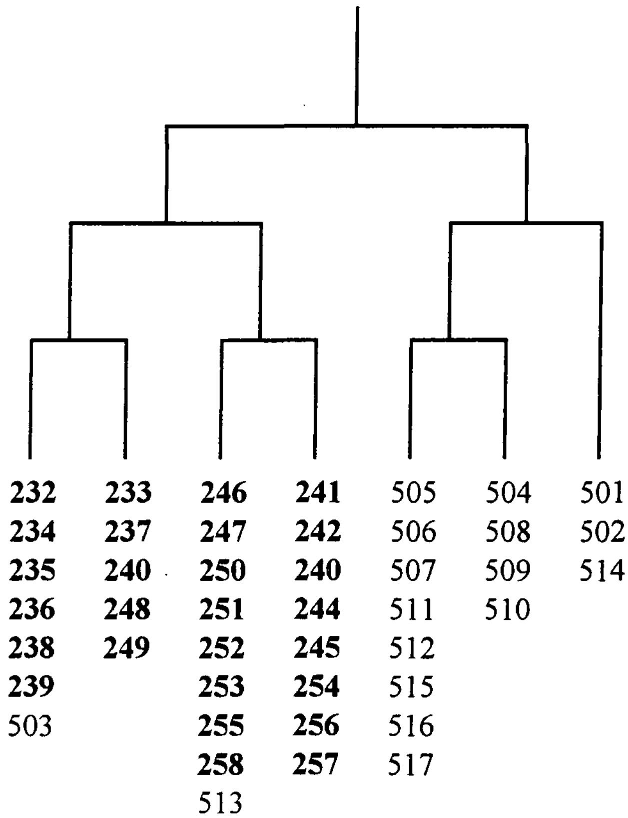


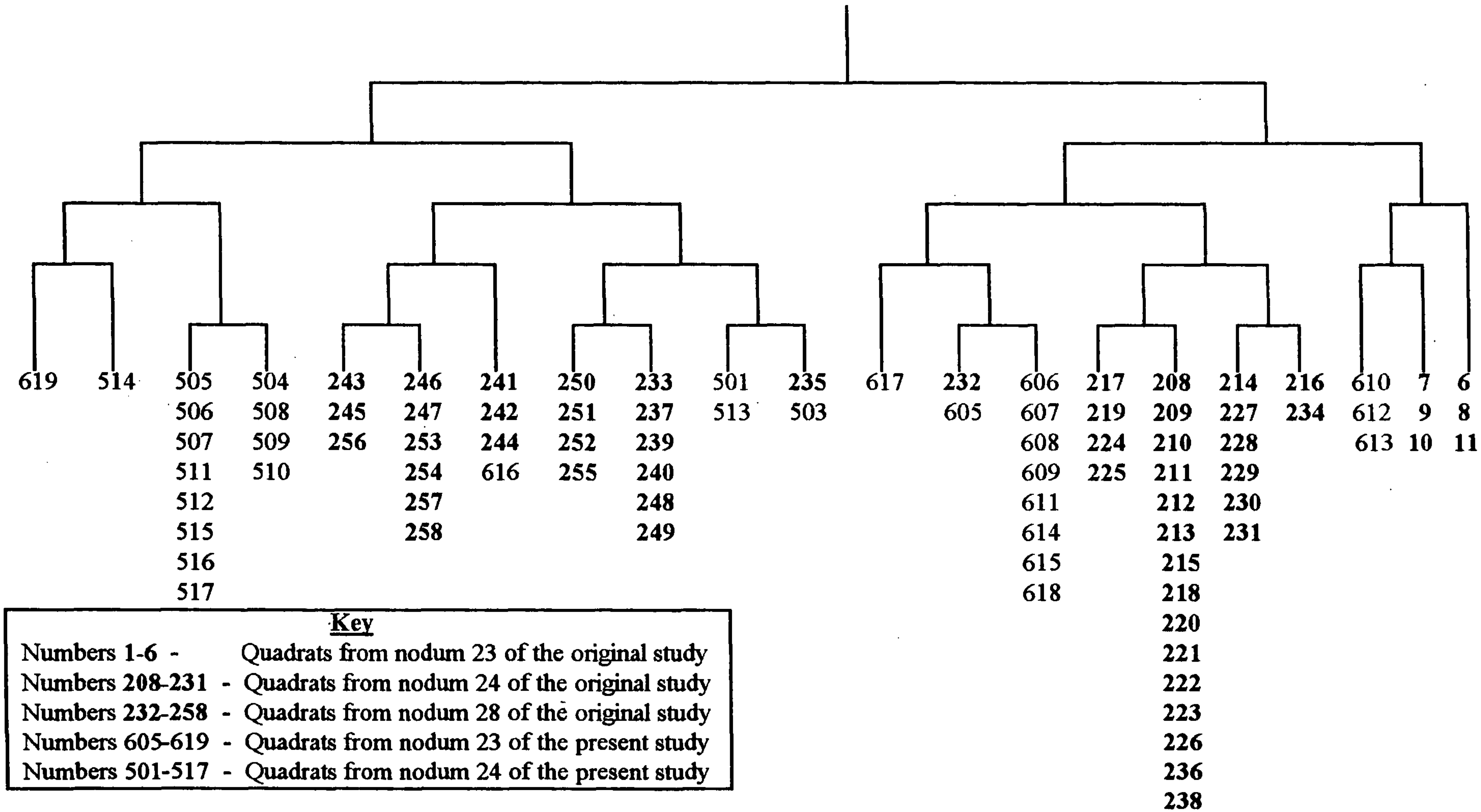
Figure 3.13 - A dendrogram depicting the Twinspan divisions produced from analysing the nodum 23 quadrats from both the original and present survey. See key for explanations of the numbers used in the dendrogram



Key
Numbers 501-517 - Quadrats from the present survey
Numbers 232-258 - Quadrats from the original survey

Figure 3.14 - A dendrogram depicting the Twinspan divisions produced from analysing the nodum 28 quadrats from both the original and present survey. See key for explanations of the numbers used in the dendrogram

These two noda can then be considered in relation to each other and the other noda in the Class in Figure 3.15. The two sets of nodum 23 data are partially split at the level of the second division, although some quadrats from the present data set are not split from the original data set until the level of the fourth division. At the level of the second division however the majority of the present data set for nodum 23 remain with a group containing almost all of the nodum 24 quadrats. This would seem to indicate that many of the quadrats carried out at locations of the original nodum 23 vegetation are more akin to nodum 24 vegetation than to the original nodum 23 vegetation. The fact that these quadrats are decisively split into two separate groups corresponding to the two different noda at the level of the third division seems to indicate that there are still differences between the two types of vegetation and there has not been a direct succession to a



Key

Numbers 1-6 -	Quadrats from nodum 23 of the original study
Numbers 208-231 -	Quadrats from nodum 24 of the original study
Numbers 232-258 -	Quadrats from nodum 28 of the original study
Numbers 605-619 -	Quadrats from nodum 23 of the present study
Numbers 501-517 -	Quadrats from nodum 24 of the present study

Figure 3.15 - A dendrogram depicting the Twinspan divisions produced from analysing all of the *Oxycocco-Sphagnetea* and *Sphagnetalia magellanici* communities. See key for explanations of the numbers used in the dendrogram.

nodum 24 community. It was supposed when examining the raw data that there seemed to be a transition occurring in the nodum 23 vegetation, it seeming on first impressions to be tending towards a nodum 28 community. These results seem to show that this is not the case and the sampled areas are in fact more like nodum 24 vegetation than either of the two sets of nodum 28 vegetation. This is in conflict with the results shown in Figure 3.4 which indicated that the nodum 23 vegetation is not changing towards a nodum 24 community. It can therefore only be concluded that a change is occurring, with different analyses showing it to move in different directions.

If the tables showing changes which have occurred in nodum 23 are examined (Tables 3.14 & 3.15) it can be seen that there are more species decreasing than increasing and more new species recorded than there are species lost. The only formerly frequent species which has been lost is *Splachnum ovatum*, which may have been overlooked as a result of the hot summer causing the species to dry up and be overlooked rather than actually having declined drastically. Several of the new species recorded were quite common during the present survey and seem to be indicative of slightly drier conditions than those at the time of the original sampling. Such species include *Empetrum nigrum* and *Eriophorum vaginatum* and some of the increasing species are also characteristic of drier conditions, the exception here being *Sphagnum capillifolium* which occurred in the central pool areas

In terms of declining species there is also a general loss of the more characteristically wet ground species. Also of note amongst the declining species are two species of open peat (*Cephaloziella hampeana* and *Rhacomitrium lanuginosum*). This may be indicative of a drying of the surface or less fluctuating water table both of which could lead to an increased colonisation by other species at the expense of the open peat inhabitants.

Species lost since the Original Survey	New species detected in the Present Survey
Lepidozia setacea (1)	*Eriophorum vaginatum (~1/2)*
Splachnum ovatum (~1/2)	*Sphagnum papillosum (~1/2)*
Cornicularia aculeata (2)	*Polytrichum commune (~1/3)*
Potentilla erecta (2)	*Calypogeia trichomanis (1)*
Juncus kochii/ bulbosa (2)	*Empetrum nigrum (~1/2)*
Sphagnum subsecundens (1)	*Sphagnum capillifolium (~2/3)*
Polygala serpyllifolia (1)	*Sphagnum magellanicum (2)*
Cladonia chlorophaea (1)	*Pleurozium schreberi (3)*
Molinea caerulea (1)	*Rhytidiadelphus squarrosus (1)*
	Rhytidiadelphus triquetrus (1)
	Lophocolea bidentata (1)
	Plagiothecium undulatum (4)

Table 3.14 - Table of changes occurring in vegetative nodum 23, showing species lost or gained since the original survey. Numbers in parentheses refer to the number of occurrences of the species or when represented in fractional form indicate an approximation of the percentage of quadrats containing the species; those in the left-hand column referring to occurrences in the original survey and those in the right-hand column referring to the present survey.

Species increasing since the original survey	Species decreasing since the original survey
Calluna vulgaris	*Erica tetralix (Sl)*
Eriophorum angustifolium (Sl)	*Scirpus cespitosa (Sl)*
Nardus stricta (Sl?)	*Narthecium ossifragum*
Sphagnum cuspidatum	*Cladonia uncialis*
Hypnum jutlandicum	*Juncus squarrosus (Sl)*
	Cladonia furcata
	Cladonia arbuscula
	Rhacomitrium lanuginosum
	Cladonia squamosa
	Carex panicea
	Carex echinata (Sl)
	Agrostis canina (Sl)
	Odontoschisma sphagni
	Diplophyllum albicans
	Sphagnum recurvum
	Cephaloziella hampeana

Table 3.15 - Table of changes occurring in vegetative nodum 23, showing species which have either increased or decreased in abundance or distribution since the original survey. Where the letters "Sl" are included in parentheses after a species this indicates only a slight change

Most of the species lost only occurred in one or two of the quadrats (remembering however that there were only six quadrats in the original data-set), whilst several of the newly located species are present in over half of the quadrats. The number of new species detected may be partly due to the increased number of quadrats undertaken in this community during the present survey (seventeen compared with six).

If the nodum 28 communities are considered (Figure 3.15), the Twinspan analysis seems to split the majority of the quadrats from the present survey into a separate group from the quadrats from the original study at the level of the second division. Although there are a few quadrats from the present survey classified in the same group as the original quadrats, at this level there is a fairly clear distinction for most of the data.

Relevé 619 of the nodum 23 data from the present survey is classified with the nodum 28 quadrats. This quadrat was collected in an area adjacent to a recently constructed drainage ditch. The transition of the community here towards a vegetation more akin to a nodum 28 community is likely to be as a result of this ditch causing a change in local hydrology (e.g. Stewart and Lance 1991).

The fact that only a few of the present nodum 28 quadrats are classified close to the original quadrats does not seem to suggest that all of the present quadrats are from a drier facies of the vegetation. If this were the case, we would expect the drier facies quadrats from the original survey to be classified with the majority of the present data set.

The tables of species changes in nodum 28 (Tables 3.16 & 3.17) seem to show almost equal numbers of species lost and gained but a disproportionate number of decreasing species compared to increasing species. Of the decreasing species most are characteristic of wetter areas of bog (e.g. *Narthecium ossifragum, Drosera rotundifolia* and *Vaccinium oxycoccus)* although some are more characteristic of drier habitats (e.g. *Ptilidium ciliare*). There are also several liverworts missing from the original species list. Of the recent colonists the two most notable in terms of the largest increases in abundance are *Vaccinium myrtillus* and *Hylocomium splendens*. Increasing species consist of *Calluna* and three mosses which tend to thrive below and between the *Calluna* canopy. Many of the decreasing species only show slight decreases which may arise as a result of sampling only a particular facies of the vegetation. There is a notable trend of decreasing aquiphilous species (e.g. *Erica tetralix, Eriophorum angustifolium).*

Species lost since the Original Survey	New species detected in the Present Survey
Vaccinium oxycoccus (1)	*Hylocomium splendens (~1/2)*
Narthecium ossifragum (~1/3)	*Cladonia uncialis (2)*
Ptilidium ciliare (~1/2)	*Cladonia ciliata (2)*
Drosera rotundifolia (4)	*Vaccinium myrtillus (~All)*
Lepidozia setacea (1)	*Acrocladium cuspidatum (2)*
Cephalozia connivens (3)	*Vaccinium vitis idaea (1)*
Cephalozia bicuspidata (4)	
Potentilla erecta (4)	

Table 3.16 - Table of changes occurring in vegetative nodum 28, showing species lost or gained since the original survey. Numbers in parentheses refer to the number of occurrences of the species or when represented in fractional form indicate an approximation of the percentage of quadrats containing the species; those in the left-hand column referring to occurrences in the original survey and those in the right-hand column referring to the present survey.

Species increasing since the original survey	Species decreasing since the original survey
Calluna vulgaris	*Sphagnum papillosum (Sl?)*
Hypnum jutlandicum (Sl)	*Cladonia arbuscula (Sl?)*
Rhytidiadelphus squarrosus (Sl)	*Eriophorum angustifolium*
Pleurozium schreberi (Sl)	*Erica tetralix*
	Polytrichum commune (Sl)
	Festuca ovina (Sl)
	Deschampsia flexuosa (Sl)
	Juncus squarrosus (Sl)
	Calypogeia trichomanis
	Odontoschisma sphagni
	Parmelia physodes (Sl)
	Aulacomnium palustre (Sl)
	Campylopus flexuosus (Sl)
	Lophozia ventricosa
	Agrostis canina (Sl?)
	Carex echinata (Sl?)
	Pohlia nutans (Sl)

Table 3.17 - Table of changes occurring in vegetative nodum 28, showing species which have either increased or decreased in abundance or distribution since the original survey. Where the letters "Sl" are included in parentheses after a species this indicates only a slight change

Changes which seem to be evident in some of the communities, especially those of the more acidophilous vegetation communities, may in part be explained by the nature of the sample areas utilised. The only areas which were accurately mapped to individual noda at a scale of 1: 2,500 were the areas in the vicinity of the calcicolous communities. As a result of this, the quadrats undertaken with respect to the other vegetation types were not strictly random but were in effect a random sample of areas in the close vicinity of the calcicole communities. It is likely in this respect for example that some of the more aquiphilous, ombrogenous facies of the Sphagnetalia-magellanici association will have been missed entirely from the present study. It would however not have been possible to have made accurate comparisons of changes occurring in areas of this vegetation elsewhere on the fell as it could not be known for certain to which nodum of a particular association an area originally belonged, due to the less exact nature of the larger scale mapping.

However as there are also noticeable changes in the calcicole communities, it is equally possible that changes could have occurred in other communities and that the effects of locality on the acidophilous communities is of lesser importance in terms of differences between the present and original survey. Conversely changes that have taken place on the calcareous areas as a result of increased sheep grazing could affect these areas disproportionately and that the acidophilous vegetation may have actually changed little; observed changes being a result of recording occurring on a facies of a nodum which is drier and possibly more topogenous, with increased through-flow of water.

Whilst the study of the changes within vegetation noda concentrated only on six noda, the study of community boundary movements across the fell considered a much wider number of noda. This was for several reasons. In order to accurately locate and map a particular nodum in an area of vegetation it was necessary to also distinguish other surrounding noda. Because of this it took little extra effort to map most of the noda in an area than it did to map a single nodum. Also it was relevant to know if a nodum is spreading specifically onto another nodum or whether they are just generally spreading. This would also show whether a particular community was being reduced in extent, or whether losses in one area were made up elsewhere, as would be predicted from a carousel successional model (Shmider and Ellner, 1984). The mapping of the boundaries of many of the noda was easier than intensively studying individual noda as this only required the utilisation of the simple keys as constructed by Jones (1973) and detailed vegetation study was not necessary.

3.5.4 Decorana Analysis of the Amalgamated Data Set

A Decorana plot of the two major axes of variation (figure 3.16) depicts a well spread scatter of points along both axes. The first axis of variation is a very distinct spread associated with the calcium content of a community habitat or a measure of the pH of a community. This is shown by the left to right trend of calcicolous communities merging into calcareous flushed communities, then into slightly calcifuge communities such as the nodum of Whin Sill screes and acidic grasslands and finally onto the communities of deep peat substrate.

It is also quite easy to interpret the second axis as being an axis determined by the water availability, although the axis seems to be reduced in its efficiency at separating the different water regimes of the peat based communities. At the highest point of this axis is the nodum of the very well drained Whin Sill scree and on the low end of the scale are the continually wet communities such as the nodum with *Potamageton polygonifolius,* and spring heads with *Cardamine* and *Cratoneuron commutatum.* The calcicole vegetation at the left-hand side is well spread with the dry grasslands of the sugar limestone outcrops grading into other communities of the *Festuco-Brometea* and then the slightly more flushed communities of the *Molineo-Arrhenatheretea,* then onto the sedge marshes and finally the spring heads and open water. In the centre of the diagram there is also a distinct separation of the drier heath grasslands of the *Calluno-Ulicetalia* from the wet grasslands of the *Nardo-Callunetea* and finally down to the *Juncus effusus/Carex rostrata* mires. The bog communities at the right of the diagram are not effectively separated however.

In terms of the quadrats collected during the present survey only nodum 28 is circled in the diagram, showing it to be slightly higher up the dryness gradient than the original nodum 28 quadrats. This helps to validate the idea of sampling a drier facies during the present study. Similarly the most recent nodum 29 quadrats are slightly above the original quadrats along this axis. Along the first axis the present nodum 33 quadrats at situated at the more calcareous end of the axis than the original quadrats which again seems to substantiate the idea of a more calcareous community developing.

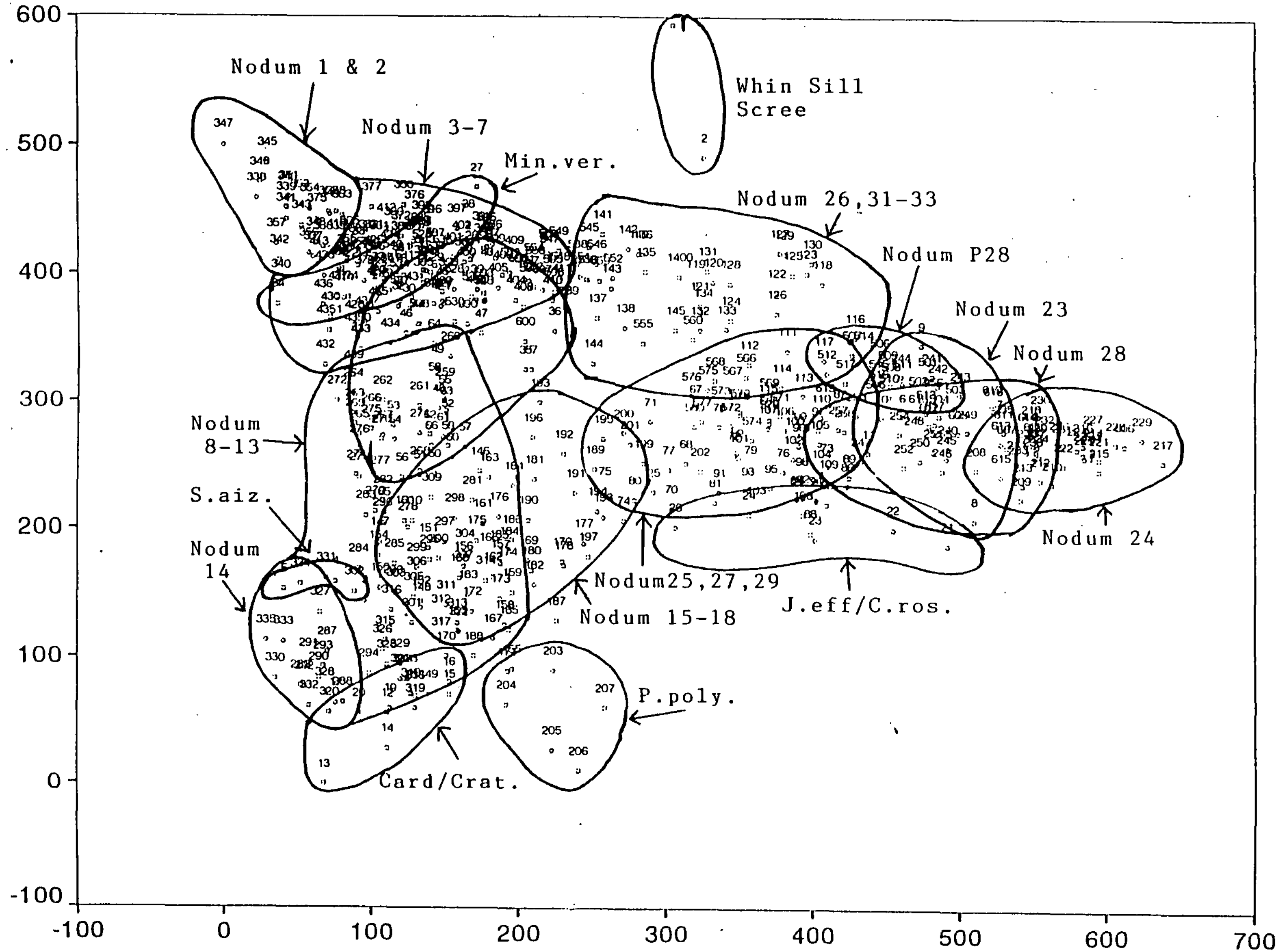


Figure 3.16 - Decorana plot of the first two axes of variation for the amalgamated data set of Jones' original quadrats plus the quadrats collected during the present survey. Numbers refer to the quadrat numbers as defined in Table 1.1. Labelled noda refer to the mapping units as defined by Jones (1973) and given in Table 1.1.Nodum 28 from the present survey is labelled P28.

Photograph 7 - *Drosera rotundifolia*, one of the species characteristic of wetter areas of the acidic peat communities.

Photograph 8 - *Dryas octopetala*, an Arctic-alpine species associated with the driest and most open areas of the saccharoidal limestone.

3.6 The Community Distribution Maps

On the whole the four mapped areas seem to depict a fairly static assemblage of communities with no large scale changes. The following comparisons of the four areas of study highlight those changes which were apparent.

3.6.1 Map of the top of Fold Sike

Much of this area of investigation (Figure 3.17 and 3.18) is composed of calcareous sedge marsh which is by nature very fragile and easily disturbed. For this reason vegetation boundaries of this area were created entirely from the aerial photographs and derived images, and there was no on the ground verification of the exact communities present. Any changes in the composition of these areas therefore are precluded, although a comparison of the present distribution of the flush communities compared to those other communities present shows a seemingly static system with no migration of communities over the flushed area. The vegetation of the drier sedge-marsh, grassland and heath communities, which allowed on-the-ground verification was also predominantly static over the period of the two studies, the only changes of any note being some slight changes in the distribution of the nodum 21 and 31 vegetation in the area of grid reference 82672905 and what seems to be the establishment of a community type similar to that of a nodum 4 vegetation type at grid reference 82702916. Other changes in the mapped area are slight and probably insignificant.

3.6.2 Map near the base of Red Sike (Figure 3.19 and 3.20)

As with the above area, the communities of the flush complex were produced purely from the aerial photographs and derived images and could not be checked for exact identification on the ground. In terms of boundaries between the actual calcareous sedge marsh communities and the other interspersed communities the maps depict a very stable association between the two types of vegetation and no noticeable changes. There seems to have been some slight change in the extent of the small calcareous sedge marsh community by the road at grid reference 81682958 which may possibly have arisen as a result of the road altering the local hydrology. The extent of most of the communities, much of which is calcareous grassland vegetation, has remained

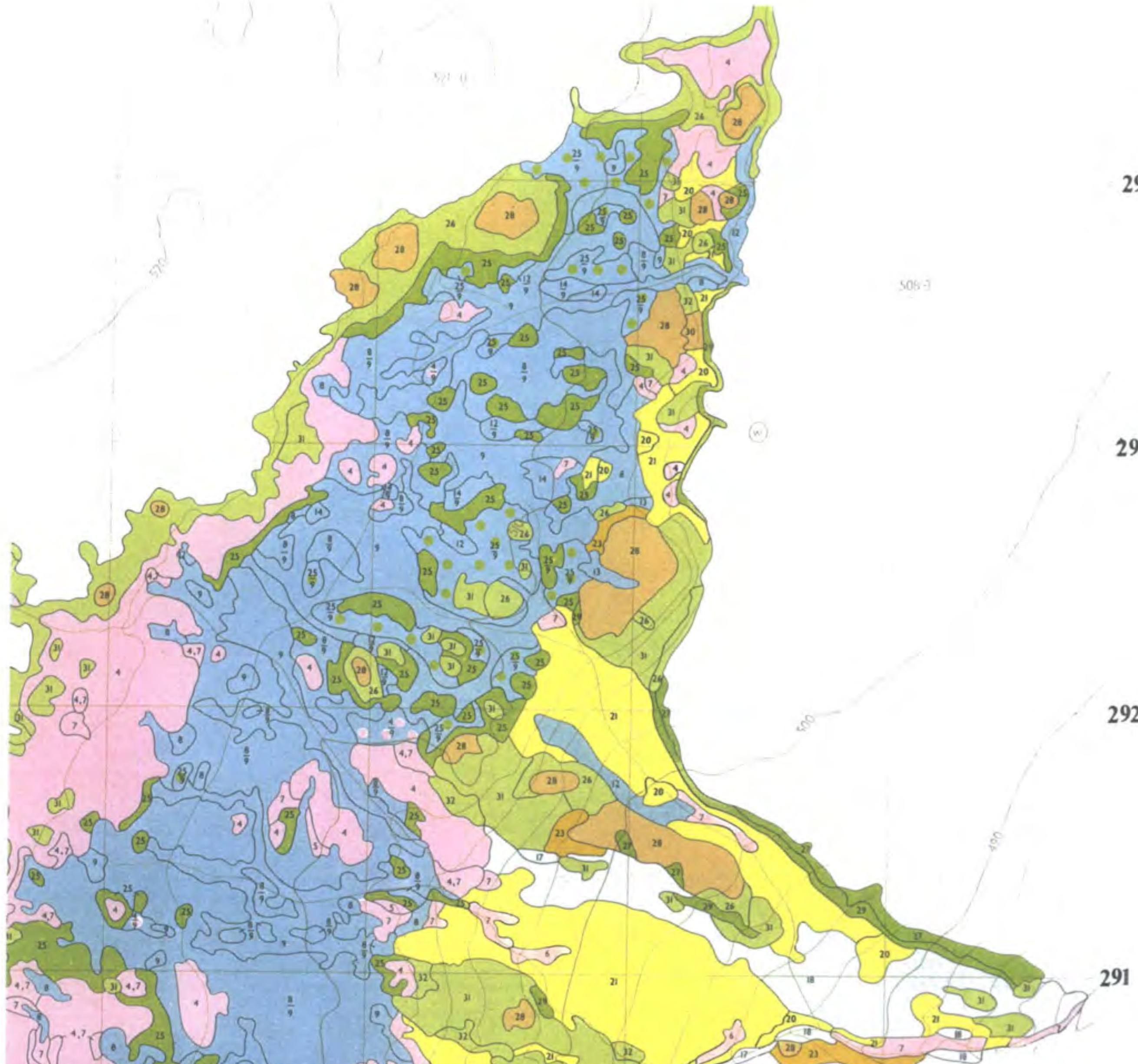


Figure 3.17 - Vegetation community map of an area at the top of Fold Sike as originally defined by Bradshaw and Jones (1973), at a scale of 1:2,500. For a key to the various features see Appendix I

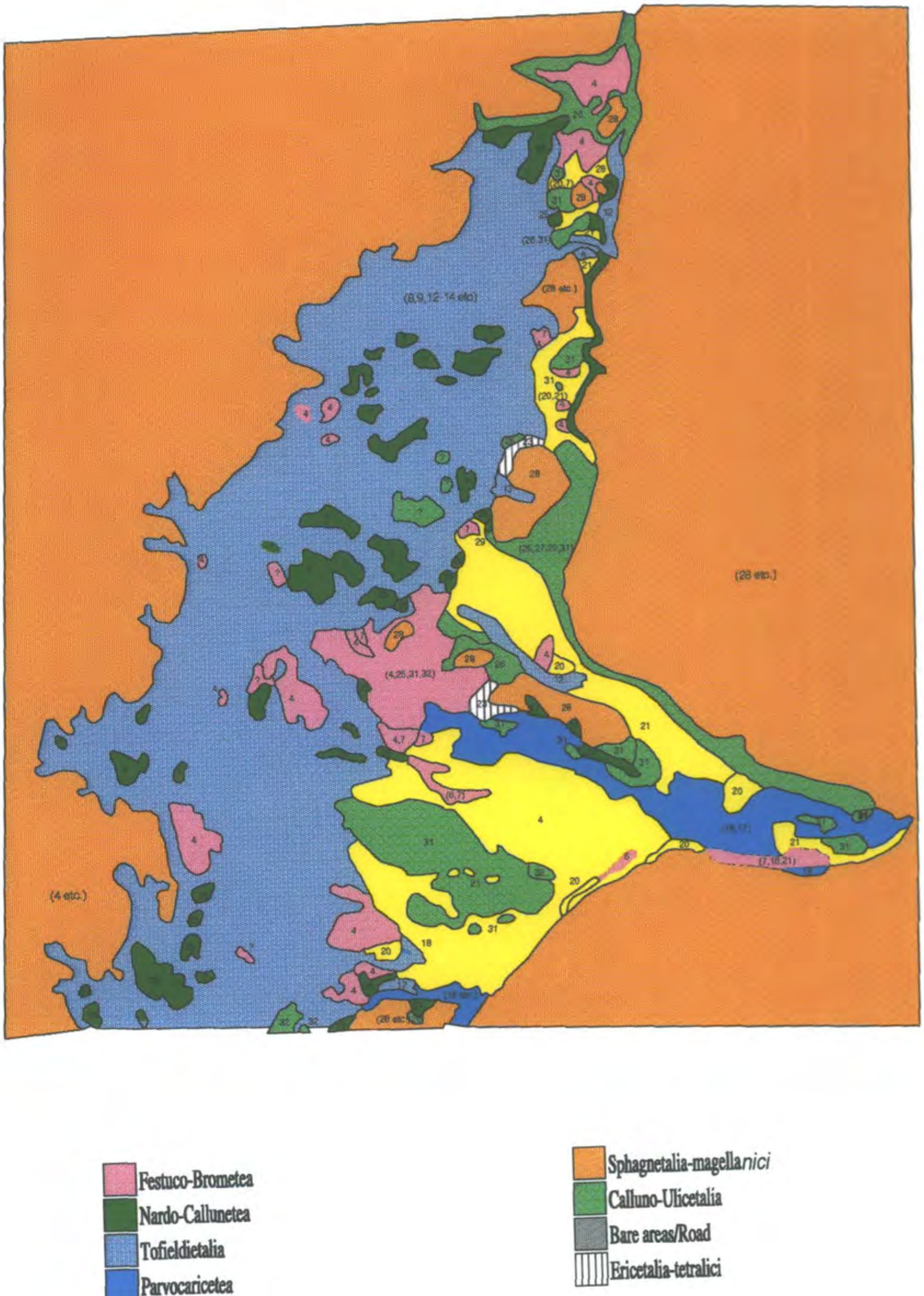


Figure 3.18 - Vegetation community map of an area at the top of Fold Sike as defined from the present survey, at a scale of approximately 1:3,000. For a key to the various community numbers see Table 1.1. Community numbers in parentheses refer to amalgamated noda.

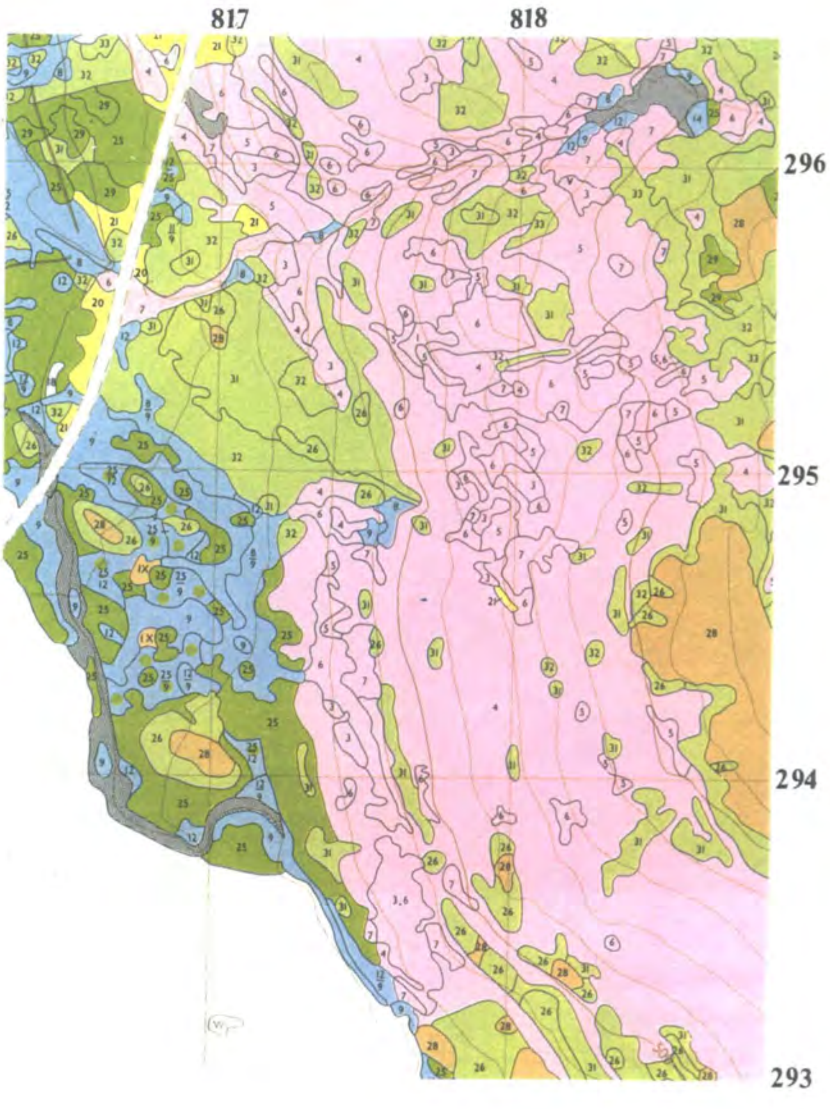


Figure 3.19 - Vegetation community map of an area near the base of Red Sike as originally defined by Bradshaw and Jones (1973), at a scale of 1:2,500. For a key to the various features see Appendix I.

largely unchanged as have the unvegetated areas mapped. An area of largely unvegetated exposed rock by the road at grid reference 81722960 was not mapped on the original map although it was present at that time. It has therefore also been left off the map produced from the present study. The unidentified Festuco-Brometea area at the bottom right of Figure 3.20 and a second further up the right hand edge were noted in the aerial photographs but not on the ground. These may well have been areas which had been burnt at the time of the photograph (1989). The unidentified area near the flushes (grid reference 81732943) could not be reliably identified as a particular community. This particular area however seems to have undergone some local change which may suggest some sort of disturbance.

3.6.3 Map of the Sugar Limestone outcrops (Figure 3.21 and 3.22)

This area of vegetation was chosen primarily to look at the drier grassland communities and to see if changes had occurred in their distribution. This area again seems to have remained remarkably stable with respect to vegetative community distribution. The map from the present study shows that almost all of the small outcrops of various limestone grassland, dry heath and bog within the predominant nodum 4 vegetation of the area have remained intact. Within these small patches the vegetation has also remained unchanged with no conversion to different communities within the patches. Similarly the areas of open limestone grassland (noda 1-3 and 5-7) which were mapped in detail show static boundaries. At this scale movement of the sugar limestone communities as a result of erosion is not apparent over the period of comparison. Despite initial thoughts that the sheep-walks through the nodum 4 vegetation had resulted in an extension of the open grassland communities, actual mapping of areas large enough to be shown reveals little difference to Jones' map, much of the area being too narrow to map.

The large area of community 4/5 at grid reference 82232897 was not defined on the original maps but the presence of remnant *Calluna* stumps suggests some form of recent management to attempt to check the *Calluna* growth. This area seems to be regenerating towards a nodum 4 type community. Other changes noted included a small area of nodum 5 and 4 appearing around one of the original grassland patches (Grid. Ref. 82162908). Conversely there is a slight encroachment of nodum 4 onto an area of noda 1 and 2 at grid reference 82272893.

It is also necessary to note that the boundaries between the nodum 4 vegetation and the nodum 26 heath and nodum 28 bog vegetation (approximate Grid Ref. 82062919 to 82302902) were not defined. Similarly none of the other community boundaries were drawn above this defined line.

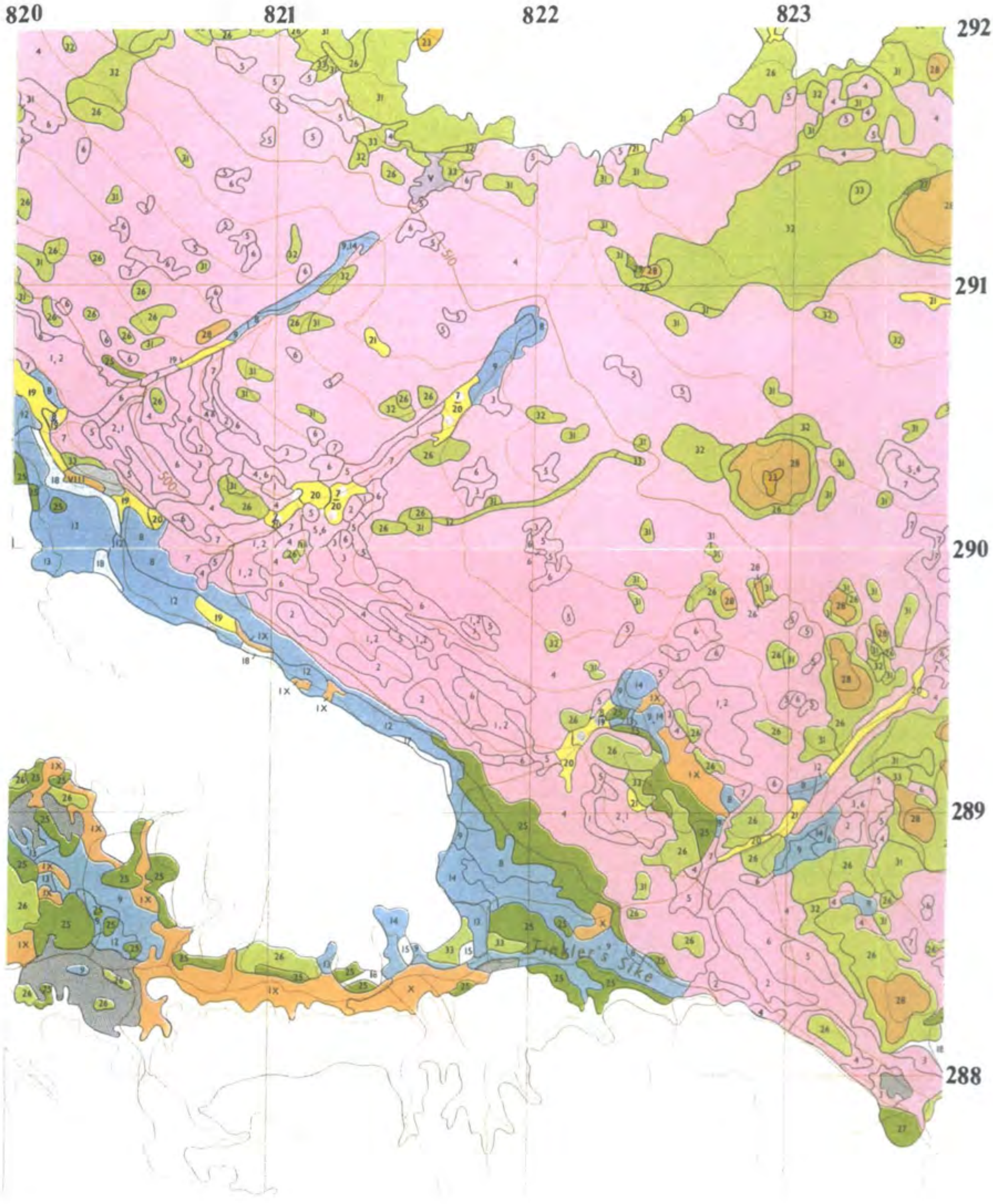


Figure 3.21 - Vegetation community map of an area of sugar limestone as originally defined by Bradshaw and Jones (1973), at a scale of 1:2,500. For a key to the various features see Appendix I.

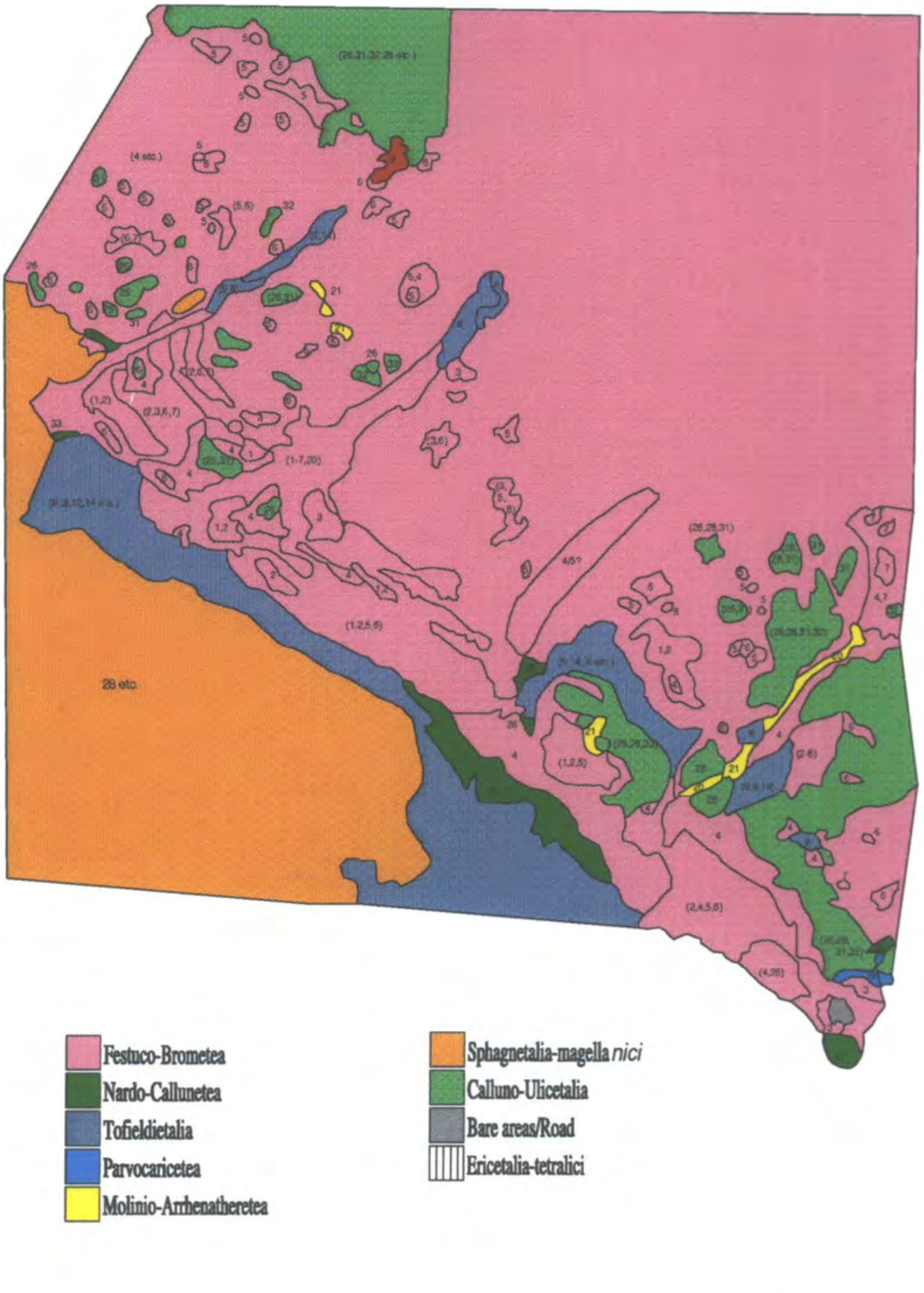


Figure 3.22 - Vegetation community map of an area of sugar limestone as defined from the present survey, at a scale of approximately 1:2,750. For a key to the various community numbers see Table 1.1. Community numbers in parentheses refer to amalgamated noda.

3.6.4 Map of the area around the Meteorological Station (Figure 3.23 and 3.24)

The map created from the present study reveals a remarkable stability in terms of the community boundaries examined. As would perhaps be expected, the boundaries between the calcareous and peat based communities have remained exceptionally stable. The areas of Festuco-Brometea are also very stable, the one exception being the reduction in extent of the area of nodum 4,5 (Grid Ref. ~81932994) at the expense of pure nodum 4 vegetation. There is also a slight advance of nodum 5 vegetation into that of nodum 4 at grid reference 81932997. Overall however there seems to have been a slight gain in extent of the nodum 4 vegetation. The apparent loss of areas of nodum 5 vegetation from beside the road does not represent a change of vegetation but simply the fact that locating these areas was time consuming so only those shown on the present map were actually selected for examination.

The vegetation of the various dry heath and acid grassland communities was often not mapped in great detail but where accurate mapping occurs the vegetation seems to have remained fairly stable, although some small changes are apparent. Similarly the vegetation of nodum 28 was also relatively unchanged.

The areas of nodum 23 vegetation mapped in the original study still key out as being most similar to this community, although it is apparent that there are some changes. Most interesting of the changes are the new areas of nodum 23 mapped in Figure 3.22. In one case this community seems to have replaced an area of nodum 26 heath, whilst in the other locations it has replaced nodum 28 bog.There are many similarities in the species composition of noda 26 and 23 but the latter nodum was chosen during the present study as best fitting the above mentioned area previously mapped as nodum 26. This was due to the intermittent presence of *Sphagnum cuspidatum* within the pool complexes. This species similarly occurs as a characteristic species in the other newly mapped areas. One possible explanation of this is that Jones omitted these areas of small bog pools during her initial mapping and classified such areas ignoring the pool flora and assuming them to be an interim community within these noda but being too small to map. Indeed the N.V.C. classification system does separate *Sphagnum cuspidatum* pools as a separate community and this is possibly a community overlooked by Jones as being such. Of note is the fact that the aerial photographs from the time of the original study do show a similar boundary differentiation, in terms of the new nodum 23 areas, to those mapped in Figure 20.

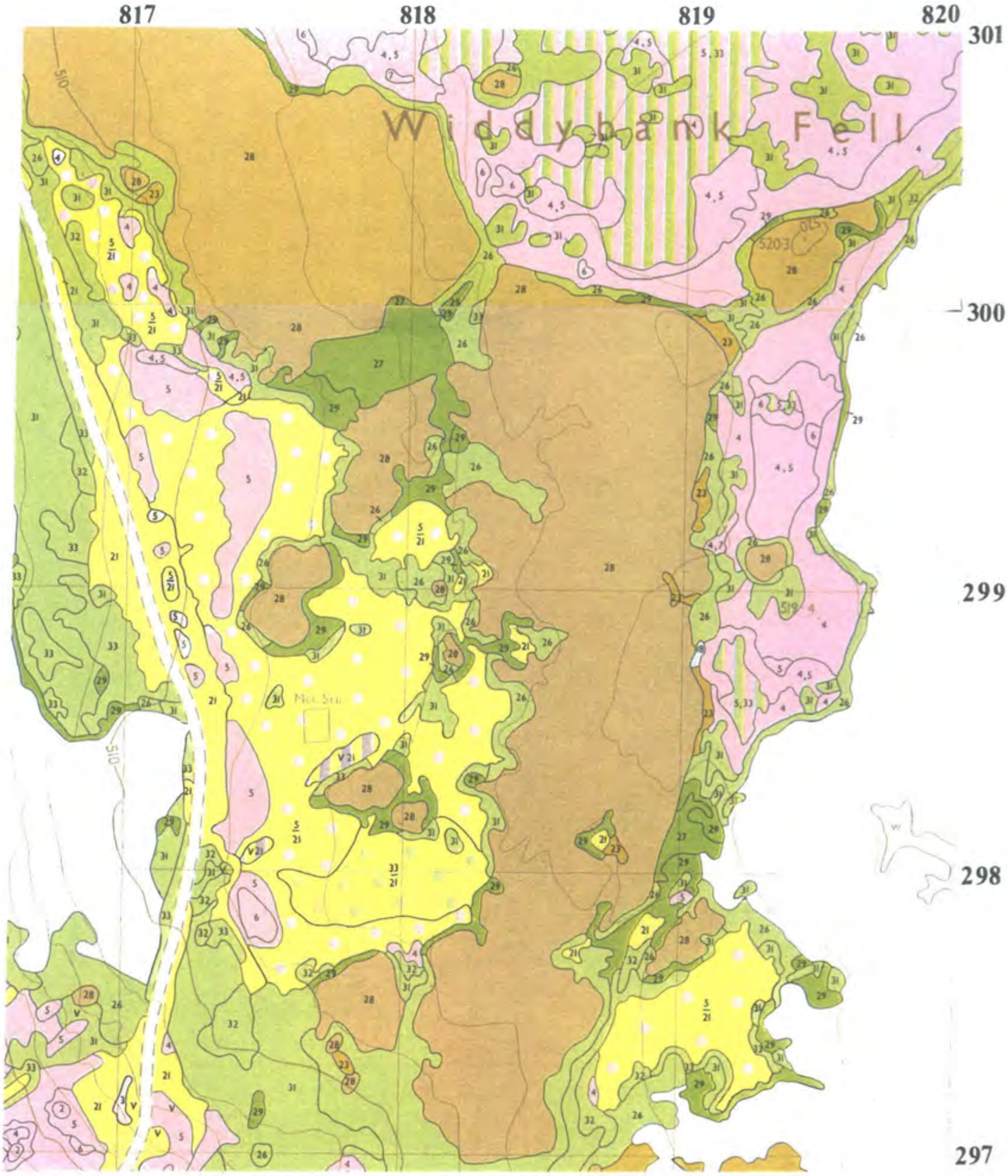


Figure 3.23 - Vegetation community map of an area around the meteorological station as originally defined by Bradshaw and Jones (1973), at a scale of 1:2,500. For a key to the various features see Appendix I.

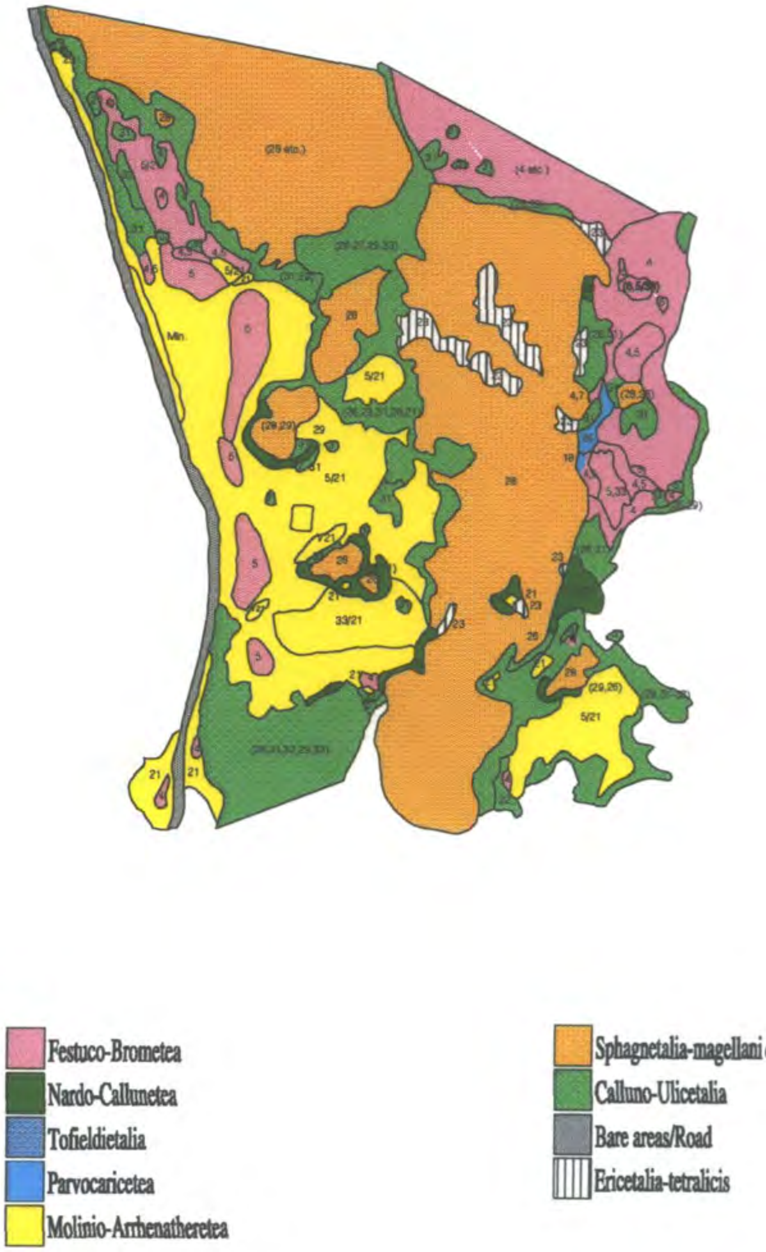


Figure 3.24 - Vegetation community map of an area surrounding the meteorological station as defined from the present survey, at a scale of approximately 1:3,750. For a key to the various community numbers see Table 1.1. Community numbers in parentheses refer to amalgamated noda.

3.7 Meteorological Data

Data for the monthly means of the maximum and minimum air temperature along with the total monthly rainfall were made available from the Widdybank Fell meteorological station. This data ran from the period from 1968 when the station was started through until the present day. Graphs drawn up from this data revealed no particular trends with regards the monthly rainfall and mean maximum temperatures. However when the monthly mean minimum temperature was analysed there are some apparent trends. In order to average out the data and to reduce the amount of data, the average monthly minimum temperatures were calculated in three month blocks for each year. These blocks ran from January to March, from April to June, from July to September and from October to December. When plotted in this format trends were apparent in two of the four blocks. The major difference over time occurred in the October to December block (see Figure 3.25).

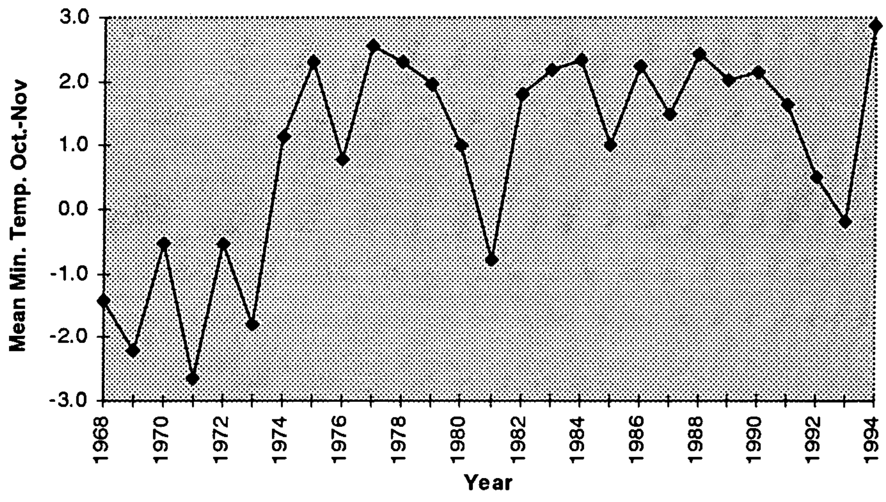


Figure 3.25 - Graph showing the mean minimum temperatures observed at the Widdybank Fell meteorological station over the period from October to November, from 1968 to 1994

Here the monthly minimum temperature seems to rise from values of around -1°C and -2°C to values in the region of +1°C and +2°C. This change in the minimum temperature seemed to occur in the period between 1973 and 1974, the time when the Cow Green Reservoir was filled. It therefore seems that the reservoir is acting to accumulate heat during the summer period and then slowly loses this heat during the autumn resulting in the ameliorated minimum temperatures. The January to March temperatures show no notable change which may indicate that by this time any retained heat has been lost. This increase in the minimum temperature may serve to increase the length of the growing season around the reservoir.

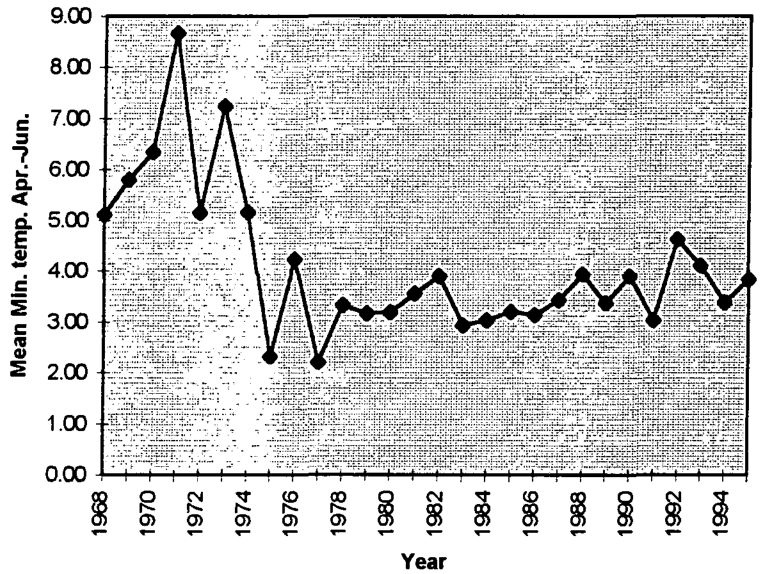


Figure 3.26 - Graph showing the mean minimum temperatures observed at the Widdybank Fell meteorological station over the period from April to June, from 1968 to 1994

The second observed change occurs in the April to June block (see Figure 3.26). Here seem to show a drop from average of 5°C or more before 1973 to values of about 3°C after this time. There also seems to be something of a damping of the temperature fluctuations after 1973. This reduction in the minimum temperature may be as a result of the body of water taking on much of the atmospheric heat and resulting in a depression of the minimum temperatures. This mechanism may therefore tend to delay the start of the growing season or at least retard the growth of some species during this period. As Arnold and Monteith (1974) noted a close similarity between the 'mean screen temperature' and the mean at ground level at Widdybank Fell meteorological station, it is probably safe to assume that these changes will be equally occurring at the level of the vegetation.

It therefore seems that, as suggested at the time when the reservoir was first proposed (Bradshaw 1966), the Cow Green reservoir has resulted in a local climatic effect on the surrounding area. This may have important repercussions with regards to the rare alpine and sub-alpine species which occur on the fell and would be expected to alter the communities as different species respond differently to the changing micro-climate.

These changes are however based on a low amount of 'pre-reservoir' data. In order to confirm the changes with greater certain, temperature data from earlier years are needed. As this is not available the changes could be compared with fluctuations at nearby meteorological stations to see if the changes are a general phenomenon.

Chapter 4

Discussion

4.1 The affinities of all the communities, and more specifically the noda studied during the present survey, to other upland communities

The following brief discussion uses the Match output derived from the original classification (Jones 1973) to compare the NVC communities produced by Match with those recorded in the Durham Flora (Graham, 1988) and by Rodwell (1991-1995). No discussion is provided for communities with low numbers of samples as these could well be misclassified communities and it is not appropriate to discuss them any further.

Jones (1973) compared and contrasted the vegetation of Widdybank Fell to that of other upland areas where similar data was available. With the advances which have occurred since that time in the production of a National Vegetation Classification it is appropriate to now analyse the affinities of the communities in the light of this new classification. The nomenclature used to describe the communities follows that of the communities produced by Rodwell (1992a, 1992b) and refers to the community fits produced by Match(Figures 3.1 and 3.3).

The spring head community of *Cardamine* and *Cratoneuron communtatum* is quite poorly classified to the NVC M37 community despite having an adequate number of quadrats collected. This poor classification could be due to the fact that this community as classified by Jones (1973) as being one of the unique communities of the Teesdale Assemblage.

There are several differences between the nodum 21 areas studied during the present survey and the CG9 and CG10 NVC communities proper in terms of species composition. If they are first compared to CG10 they can be seen to contain many unexpected species more characteristic of the CG9 grasslands such as *Gentiana verna, Gentianella amarella*; *Sesleria albicans* and *Minuartia verna*, as well as having more occurrences of other species such as *Carex caryophyllea, Hieracium pilosella, Plantago maritima, Polygonum viviparum and Briza media*. Similarly they contain many species which are not characteristic of CG9. This would seem to indicate that this community is somewhat of an anomaly in terms of the NVC classification and cannot be adequately classified into any suitable community, being something of a mixture of the CG9 and CG10. This is not such a surprise as three of the four noda of the Molinio-Arrhenatheretea association (including nodum 21) are communities unique to the Teesdale Assemblage. In terms of a British distribution, this community is therefore limited to Teesdale and not adequately recorded in the NVC classification.

Photograph 9 - *Carex capillaris,* a species occurring commonly in several of the noda of the Festuco -Brometea and Molinio-Arrhenatheretea.

Photograph 10 - *Kobresia simpliciuscula,* a species occuring commonly in several of the Festuco-Brometea and Tofieldietalia noda.

The other calcareous grasslands of the fell, the Festuca-Brometea (noda 1-7), all correspond quite well to the NVC CG9d sub-community. The Durham Flora (Graham 1988) mentions the CG9 community as being present on the upland Carboniferous and Sugar Limestone but does not describe it further. The results here however seem to unanimously ascribe these Widdybank grassland to the CG9d sub-community.

The Match coefficient of the nodum 4 community of the present survey is low compared to some of the other noda of this association from the original study. This is largely due to the presence of the *Calluna* shrub layer and its associated companion species such as *Agrostis canina, Empetrum nigrum, Galium saxatile, Polygala serpyllifolia, Pleurozium schreberi, Hypnum jutlandicum* and *Polytrichum formosum.* This is a result of the unique structure of this Teesdale Assemblage community. Two calcicole species which are present in this nodum yet not normally found in CG9d are *Thalictrum alpinum and Viola lutea.* The absence of *Viola lutea* from all of the CG9 communities proper is somewhat surprising as it is commonly found in much of the CG9d grasslands on Widdybank Fell. Species which are present to a lesser degree in this noda than the CG9d proper are mostly calcicoles which are more common on the open grassland such as *Rhacomitrium lanuginosum, Viola rupestris, Ctenidium molluscum, Helianthemum nummularium and Antennaria dioica.*

In terms of a British distribution the CG9 as a whole is limited to a small area running west from the North Pennines to the top of Morecambe Bay. The CG9d sub-community is confined to the area of Upper Teesdale (Rodwell 1992b).

It is noticeable that most of the noda of the class Festuco-Brometea on Widdybank Fell are unique Teesdale assemblage communities and yet fit into the NVC classification system quite well compared to those noda of the Molinio-Arrhenatheretea mentioned previously. This may be due to the vegetation of the former community being sampled when creating the classification system and hence being utilised in producing the classification. The community of the latter seems to have been over-looked by the NVC classification in this respect and hence has a much poorer match to any communities.

The acidic grasslands of nodum 27 and 29 are fitted most closely to NVC communities of U6 in the original survey and the nodum 29 vegetation of the present survey is similarly classified as being best fitted to U5 or U6. If the major differences between the community derived from the present survey (nodum 29) and these two NVC communities are examined it seems that this community is more akin to U5 than U6. Species more abundant than would be expected in a U5 community proper include wet ground species such as *Juncus squarrosus* and *Eriophorum angustifolium* but also include *Deschampsia flexuosa* which is more characteristic of dry ground areas (Grime *et al.* 1995). Under-represented species comprise *Potentilla erecta, Agrostis canina* and

Hylocomium splendens. Species which would be expected to be present but which are absent include *Hypnum cupressiforme,* which actually was recorded here but as *Hypnum jutlandicum,* and *Luzula multiflora* which may have been overlooked as *Luzula campestris* as this latter species was recorded as being more common than typical for U5 communities. The other species absent were *Danthonia decumbens, Carex pilulifera* and *Ptilidium ciliare*, the latter species however seemed to be practically absent from several of the Widdybank communities where it would have been expected. Comparing the noda to the typical U6 community, the differences are greater and not so easily explained.

In terms of their distribution through Britain the U5 is quite widespread in the uplands whilst the communities of U6 are slightly more localised. Both are recorded in Rodwell (1992a) as occurring in the Northern Pennines. Graham (1988) records the neither the U5 or the U6 in the Durham flora, although his *Nardo-Juncetum squarrosi* communities of HE4 and HE5 are essentially the same. Similarly McVean & Ratcliffe (1962) state that sub-montane *Nardus* grasslands which are not conditioned by snow cover are similar in many parts of upland Britain.

Jones' noda of the other class of acidic grassland, the Calluno-Ulicetalia are not satisfactorily matched to any particular NVC community or group of communities and all produce quite low Match coefficients. Similarly the best fitting communities for the nodum 33 data from the present study are equally poor matches. The fact that the present community is assigned with almost equal Match coefficients to both a calcicolous and calcifuge community may indicate that this is a community undergoing some change. This is discussed later (Section 4.5.4). If the species' abundances of the nodum 33 community of the present study are compared to the two nearest communities (U4a and CG10a), species which are over-represented or which should not be present in the U4a community are calcicoles and those under-represented or missing are calcifuges. The opposite is generally true when comparing the noda to the CG10a community.

The nodum 23 community of the original survey is most similar to the M16d NVC community but the Match coefficient is quite low, possibly as a result of the small number of quadrats which were used to define the noda. The Match coefficient produced from the data of the present study is somewhat higher although the most likely community matches are the M18 communities. In terms of other community matches of the present data, the constant presence of *Sphagnum papillosum,* which is a constant species of this nodum on Widdybank, is not as common, if at all present in the other possible NVC communities. The small number of differences of the present nodum 23 community when compared to the M18 *per se* support the suggestion of this being the best fitting community. *Molinia caerulea,* one of the missing character species of M18 from the present survey, was recorded by Jones in the original quadrats of this noda. The missing M18 species; *Sphagnum magellanicum, Mylia anomala* and *Drosera* *rotundifolia,* are all component species of Jones' nodum 24, whilst the latter along with the further missing species *Vaccinium oxycoccus, Rhytidiadelphus loreus* and *Cephalozia connivens* are present in nodum 28 of Jones original survey. It is possible that the nodum 23 vegetation is changing away from its original weak M16 affinity towards one of the more widespread communities of the fell and the missing species will eventually colonise. Jones did not separate the *Sphagnum cuspidatum* pools as a distinct community on Widdybank, something which the NVC classification does. If these areas were excluded from the nodum 23 quadrats and only the more terrestrial areas surveyed perhaps the vegetation would be more confidently allocated to a different NVC mire community.

The M16 community, the best produced match for the original data set, is largely restricted to the south coast of England, although it is recorded in the North Pennines (Rodwell 1992a). The M18 and M19 communities which best fit the present data set are more widespread in the Pennines (see below). The *Sphagnum cuspidatum* pools included within Jones nodum 23 are similar in composition to the NVC M10b community, which Rodwell (1992a) records as occurring through the range of *Erica-Sphagnum* mires.

The vegetation of nodum 28 from both the present and the original surveys is most closely matched to the M19 communities but the small differences in terms of Match coefficients between the sub-communities does not allow for any more precise allocation of the nodum. There is only one species which is uncharacteristic of this community (*Cladonia subrangiformis*) and only one species which seems to be under-represented (*Eriophorum angustifolium*). Species which are notable by their absence include three liverworts (*Mylia taylori, Cephalozia bicuspidata* and *Ptilidium ciliare*) and *Hypnum cupressiforme*. However as *Hypnum jutlandicum* is one of the over-represented species, it may be that there was some confusion in the separation of these two variants/species. Other species more common than would be expected in this community are *Hylocomium splendens, Sphagnum papillosum, Plagiothecium undulatum, Sphagnum recurvum* and *Rhytidiadelphus squarrosus.* It is notable that all of these species are mosses and generally grow between and under the clumps of *Calluna.* This may be indicative of a more open stand relative to other areas used to define the NVC communities, possibly as a result of burning temporarily opening the canopy, or overgrazing resulting in a less bushy, retarded growth of *Calluna.* Reductions in several of the hepatic species may also be indicative of burning (see, for example Hobbs (1978)) but the presence of expected amounts of the larger *Cladonia spp.* would seem to indicate otherwise. The decrease of these species could also be linked to changing atmospheric deposition which may be expected to affect such delicate species. The other nodum of this association, nodum 24, is quite well matched to the NVC M18 community.

The M19 blanket bog community which is suggested as being present on Widdybank is recorded in the Durham Flora (Graham 1988) but not the M18 raised/blanket mire which is suggested as the best match for nodum 24. Rodwell (1992a) records the M18 in the Pennines but not in the Teesdale area, whilst the M19 communities and particularly the M19b community seem to be ubiquitous throughout the North Pennines.

The match coefficients produced for the noda of the Parvocaricetea (noda 15-18 and nodum with *Potamageton polygonifolius*) are variable, though quite low. This variation does not seem to be linked to the unique Teesdale Assemblage communities, noda 15, 17 and the nodum with *Potamageton*, as nodum 15 has the highest coefficient, whilst nodum 18, part of a more widespread British community, has one of the lowest coefficients. The nodum with *Potamageton* has a very low Match coefficient which could be due to either its unique composition or the low number of relev•s collected by Jones (1973). Variations may also be due to only sampling facies of NVC communities

In contrast to the previous results, the matches of all of the Tofieldietalia to NVC community M10 are very good, despite this group having many unique community assemblages. This may again be a result of data for the NVC classification of such noda having been collected in Teesdale. Of the mire communities produced by Match, community M10 is recorded in Durham by Graham 1988 but not to the level of sub-communities M10b and M10c which have quite high matches with many of the fell mire communities. The M10b community is quite local in North England and the M10c is restricted to Teesdale (Rodwell 1992a).

It can be seen by this comparison of the communities present on Widdybank to other similar communities as defined by the NVC (Rodwell 1992a, 1992b) that there is a large range in the distribution of the communities throughout Britain. In general the raised and blanket mire communities are widespread throughout much of the uplands, as are the acidic grasslands and heath. Conversely the calcareous sedge-marsh and limestone grassland communities are more local in their distribution, many being restricted to Teesdale.

In terms of ranges in the number of species present in quadrats for all of the communities studied in the present survey, as well as the average number of species per quadrat, the data collected all fit in well with that expected from the most similar NVC communities.

4.2 Gentiana seed production

From the study of *Gentiana* seed-head production (Table 3.4) in the various communities and enclosures, it seems that even though there are only small numbers of seed-heads produced in any of the areas studied there seems to be a distinct increase in the areas of reduced grazing , regardless of the actual amount of reduction. It is likely that a larger scale investigation would clearer reveal trends, some regimes being more preferable for seed production. It seems that the intensive grazing over much of the fell is serving to reduce sexual reproduction and hence genetic diversity as Bradshaw and Doody (1978) suggested. The structure of the nodum with *Calluna* allows some sexual reproduction to be maintained as mentioned earlier, and may be an important mechanism of maintaining genetic diversity. The possibility of complete cessation of grazing creating a closed sward and reducing the distribution of species such as *Gentiana* is discussed below.

4.3 The Effects of Grazing Density on the Communities

The very low densities of sheep on the bog areas (see Table 3.5) can be explained by the lack of nutritious vegetation in such areas. Similarly the extensive calcareous sedge marsh area on the top of Widdybank has very low densities because of the paucity of vegetation in such an extreme vegetation environment. The value obtained for the area of ombrogenous bog (1) is very similar to the value of 0.2 sheep/ha calculated by Rawes and Heal (1978) for the bog community of Moor House NNR. The higher grazing densities for many of the vegetation types on Widdybank when compared to work undertaken at nearby Moor House NNR (Rawes and Heal 1978) may arise as a result of a very restricted time of sampling; recording on Widdybank only taking place during mid-summer in an unusually hot summer and generally during the middle of the day. Alternatively it may be the case that Widdybank Fell can support higher densities of sheep because of its less extreme climate.

When the densities calculated for the three different areas of limestone grassland are compared it can be seen that even in different locations with varying size and distribution, they are all utilised to a relatively similar extent. This would tend to fit in with the findings of Rawes and Heal (1978) who state that grazing of the Agrosto-Festuceta grasslands on Moor House NNR, tends to be at a set density related to the territorial behaviour of the sheep. This would also seem to be the case on the Festuco-Brometea grasslands on Widdybank Fell. The grazing densities calculated by Rawes and

Heal for the Agrosto-Festuceta grasslands were approximately 7.0 sheep/ha, much less than the calculated densities on the Widdybank calcareous grasslands.

The nodum 4 vegetation contains many of the species characteristic of the closed sward calcareous grasslands but also has a cover of *Calluna,* albeit at a reduced density to some of the more calcifuge communities. This community is one of several present on Widdybank Fell which are unique to Upper Teesdale and compose the Teesdale assemblage. It would seem that the growth of *Calluna* tends to protect the calcareous species to some extent, resulting in the low grazing densities. This could have important implications with respect to some of the rare species of the Teesdale assemblage which are present in this community. This is shown with respect to *Gentiana* seed-head production, the community providing additional cover for *Gentiana* and allows a higher percentage of seed-heads to be produced relative to open grasslands. Similarly one could also propose that the increased presence of species such as *Thalictrum alpinum* and *Galium boreale* are also a result of more successful seed production compared to elsewhere. It may therefore be that the structural composition of this community produces one of the few areas of open vegetation on the fell where seeds of some species are successfully produced and hence where genetic diversity, rather than vegetative growth can occur under intensive grazing. The composition of this community may also be more akin to that which would have occurred on other areas of closed sward limestone grassland (as opposed to the out-crop communities) if the grazing densities were lower. If this community was present during the Flandrian period of Quaternary history it is possible that it could have acted to sustain several of the species of the Teesdale assemblage (or at least maintained the genetic diversity of such species) which may otherwise have been lost due to encroachment by tree species, blanket bog spread and overgrazing. Could it be possible that one of the reasons for the persistence of some species of the Teesdale Assemblage lies partly in the nature of the structure of the communities themselves?

Grazing densities on two of the acidic grassland (site 1 and 2) are similar (7.1 and 9.2 sheep/ha) but somewhat higher than that of 2.0 sheep/ha calculated by Rawes and Heal (1968) on similar vegetation at Moor House NNR. Possible explanations for this include those mentioned with respect to the bog communities. The third site of acidic grassland on Widdybank (site 3) is somewhat different with more than twice the grazing density of the other two sites. Several factors may contribute to this difference including the fact that this area lies on a flood plain of the Tees and hence may have a better quality of soil for growth of edible plants and can support higher densities of sheep. Similarly the lower altitude of this site (average 390 m *c.f.* averages of 450 m and 500 m for the other two sites) could lead to better conditions for plant growth and also possibly less extreme conditions for the sheep, being probably the lowest area of the fell. Another factor which could be considered is the drainage and irrigation of the different areas especially during such an unusually warm summer as that which Teesdale experienced this year. Along a different line of reasoning it could be possible that this area is favoured as a result of the social behaviour of the sheep. This area being the site to which the sheep come during winter and spring in times of snow cover on the fell and also being the place at which hay is distributed to help the sheep through periods when there is little vegetation. Furthermore sheep often have a tendency to wander down to lower ground, often requiring shepherding back onto the fell tops. Some or all of these factors may therefore combine to some extent and result in a very high density of sheep at this one site.

The areas of calcareous flushes and sub-alpine pastures support the highest sheep densities of all. The anomalous site with a density of only 13.7 sheep/ha is the area surrounding the meteorological station. There are several possible explanations why this site has a lower density of sheep. Reasons given previously for differences in the densities of sheep between similar areas probably also apply here. These could include differences in the community composition and distribution, and the fact that the higher density area is above the acidic grassland area which had high sheep densities and may be the area to which sheep are driven back up the fell to. The fact that the site with the lower densities is flat land and with no flushes or streams draining through it and therefore may be drier and less conducive to plant growth in dry weather must also be considered. A further possibility which may also affect the number of sheep at the site by the meteorological station is the constant presence of people along the road. This may discourage sheep from grazing the area so heavily due to a boundary effect of the road and associated people, although this seems an unlikely explanation. The highest densities of all occurred on the small areas of calcareous flush/pasture. This may be partly as a result of sheep from surrounding nodum 4 vegetation moving onto this area as the wet conditions continue to produce good herbage whilst the drier areas become less profitable feeding areas. Other factors mentioned previously such as differing community composition etc. may also apply here.

The suggestions of Rawes and Welsh (1966) that the densities on the better quality grassland seem to be related to the territorial behaviour of sheep seems to apply equally well here, as do their suggestions that factors other than food also affect the distribution of sheep. It can probably be assumed that the diurnal pattern observed at Moor House would also occur on Widdybank Fell and hence a survey taking this into account would affect the distribution of sheep to some extent. They suggest that any change in the stocking density would affect the grazing intensity first on the bog, then on the *Juncus* and *Nardetum* and finally on the *Agrosto-Festuceta*. The observed densities on Widdybank equate quite well to those calculated at Moor House NNR with respect to the densities on the bog areas but the values of the calcareous and acidic grasslands are somewhat higher than those calculated at Moor House. If the suggestion by Rawes and Welsh (1969) about the effects of increased stocking are applied here, it could be tentatively proposed that the stocking of sheep on Widdybank is higher than at Moor House due to the less extreme climate and the dry weather has caused those excess sheep that would normally be on the bog areas to move onto the calcareous and acidic grassland for a period. Nothing can be said with any great certainty however with regards to the grazing of Widdybank due to the brevity of the study of grazing densities.

To summarise therefore it can be said that on Widdybank Fell the areas of poor nutritional food, be it because of the dry weather or because of the harshness of the habitat, have much lower densities of sheep than areas of more nutritious vegetation, the one possible exception to this being the limestone grassland community with *Calluna* which also has very low grazing densities. Similarly the acidic grasslands support lower sheep densities than do the calcareous grasslands. It is also suggested that the presence of the calcareous grassland with *Calluna* nodum of the Teesdale assemblage may be important with regards to the seed production of several species such as *Gentiana* which are normally grazed down in open calcareous grassland.

Despite the variation in grazing densities recorded on the different communities, none of the communities show any progressive changes which can be confidently attributed to either under- or over-grazing (see individual noda descriptions later).

4.4 Enclosures

The presence of several of the quadrats from within enclosure four in the Twinspan end group of unenclosed quadrats (see Figure 3.1) suggests they are more akin to unenclosed areas than to the other enclosure areas.

Similarly the fact that enclosure three quadrats were not split from the unenclosed and enclosure 4 communities until near the base of the dendrogram would seem to indicate that they are also more similar to the grazed areas than are the quadrats of enclosures 1 and 2 but less so than enclosure 4 quadrats. Hence it seems that there is a gradation in the difference of the enclosed communities from the unenclosed areas, with enclosure 4 which has the most grazing being most alike the grazed communities, through to enclosures 3 and 2 which are less similar but which have correspondingly less grazing/management, to enclosure 1 which is ungrazed/unmanaged and is most different from the grazed communities. One interesting point to note is that the enclosed quadrats are not all grouped together and hence there does not seem to be a grouping of the ungrazed areas due to a similar community composition, indicating that enclosure is of secondary importance in determining the species composition of these areas. This is probably partly as a result of the slightly different vegetation types of the different areas in combination of the effects of different levels of grazing/management for each of the areas.

With respect to the species composition and abundance in the enclosed and unenclosed areas, there are several points of interest which should be noted. There are a group of species which seem to be more or less restricted to the enclosed areas, at least on the open grassland of the fell. These species include *Listera ovata, Geum rivale, Solidago virgaurea, Succisa pratensis, Anemone nemorosa* and *Galium boreale.* Similar studies on enclosures elsewhere have also found some of these species starting to increase or colonise (Rawes 1981, Edgell 1969). It is noticeable that most of these species tend to be quite large compared to many of the species present in the grazed community and are susceptible to grazing. It may be that under a less rigorous grazing regime they would make up a natural component of the open grassland communities. There are also several species which are present only in enclosure 2, these including *Vicia cracca, Heracleum sphondylium* and *Cochlearia pyrenaica.* It is thought that seeds of some species may have been imported in with soil which was used to construct some of the features of the meteorological station which is present in this enclosure and this may well explain the presence of the first two species.

Edgell (1969) noted that several of the species which occurred only within enclosures at his Merionethshire study site normally occur on cliff-ledges and therefore would seem to be grazing-intolerant. Relevant species mentioned include *Heracleum sphondylium, Solidago virgaurea* and *Succisa pratensis.* It is also noticeable in the enclosed areas (except for enclosure 4) that several of the species present obtain greater stature in terms of height and/or produce seeds/spores more successfully than in the grazed areas; such species including *Gentiana verna, Achillea millefolium, Sesleria albicans, Carex capillaris, Ranunculus acris, Polygonum viviparum* and *Botrychium lunaria.* This was also found by Jeffrey and Pigott (1973) on several Widdybank enclosures (including enclosure 1) only 18 months after initial enclosure.

In terms of species lost in the enclosures as a result of the reduction in grazing there seems to be little change. Even in the completely unmanaged enclosure diminutive species such as *Thymus drucei, Viola lutea, V. riviniana, Campanula rotundifolia, Polygala serpyllifolia* and mosses continue to persist, some of the mosses even faring better in the longer ungrazed sward, probably as a result of its more humid microclimate. The only species which seems to have been lost as a result of the higher sward is *Euphrasia officinalis agg.* There is a change in the dominance of species as a result of reduced grazing especially in enclosures 1 and 2; with many of the species mentioned previously as being restricted to, or faring better in the enclosures becoming more dominant. Those species which increase most notably include *Sesleria albicans* and

Galium boreale, whilst species tolerant of heavy grazing such as *Festuca ovina* lose dominance in the community.

Hill, Evans and Bell (1992), working on the effects of permanent enclosure on upland grassland, found that voles became the dominant vertebrate herbivore and as such caused large year to year variation in the herbage biomass. As vole runs were also noted in enclosure 1, it is appropriate to try and relate some of their findings to the Widdybank situation. In parallel to the findings of Hill *et al., Hylocomium splendens* and *Pleurozium schreberi* were both found to increase greatly within the Widdybank enclosure. Some species may also be grazed preferentially, changing the species composition.

When the quadrats which were carried out along the perimeter of the enclosures are compared to other quadrats from similar communities elsewhere on the fell (Jones 1973), one major difference tends to arise. This being that the quadrats in the grazed areas surrounding the enclosures seem to contain more of some of the species which are generally confined to the enclosed area. Hence species such as *Galium boreale, Geum rivale* and *Botrychium lunaria* seem to occur in the grazed areas surrounding the enclosures to a greater extent than they do in similar communities elsewhere. It could be hypothesised that this arises as a result of the increased propagule production of these species within the enclosure, leading to plants continually establishing close to the enclosures and persisting for some time vegetatively. It would therefore seem that in order to allow these species to persist over the rest of the fell grassland it would be necessary to reduce the grazing pressure to such an extent so as to allow successful seed production. This is in contrast to *Gentiana verna* which can persist in the closely grazed sward by means of vegetative reproduction. The continued presence of *Gentiana* in the permanent exclosure would seem to indicate that this species could survive even under a regime of non-grazing, for some considerable time, and does not necessarily rely on short turf.

In summary, the effect of enclosure upon the vegetative sward of the areas of calcareous grassland results in a change in the species composition of the sward with the more grazing sensitive species tending to appear in the enclosures. There also seems to be a trend of increased cover and abundance of such species as the severity of the enclosure regime increases. Management by annual cutting may be the mechanism which maintains the most diverse sward in terms of allowing grazing sensitive species to colonise but also maintaining the species which prefer a low sward and open areas.

The presence of one or two plants of *Senecio jacobea* by burrows in the enclosure which was rabbit grazed may represent the presence of a niche unavailable over much of the rest of the grassland where rabbits have been largely eliminated. This species is avoided by rabbits (Watt 1957) and can therefore colonise the open areas around the rabbit burrows.

In terms of the theory that complete cessation of grazing in grasslands tends to result in an impoverished sward of a few dominant species, the enclosed site does not provide a classic example. Although there is an obvious increase in the abundance of *Sesleria albicans* at the expense of the other species more common in the grazed areas, these species are by no means completely eliminated, even *Minuartia verna* still being present within the enclosure.

The area of complete enclosure was originally set up in 1969 as a controlled experiment by Jeffrey and Pigott (1973) to test whether shortness and patchiness of the vegetation arises because of sheep grazing and wind/water erosion or whether it was due to the chemical features of the soil. The fact that they found that nitrogen alone had little effect on the sward composition may indicate that in these limestone grassland habitats such aerial deposition as is currently occurring (Sutton, Moncrieff and Fowler 1992) may have little effect. They suggested that because there was no change in the shortness and sparseness of the vegetation after 20 months, the short, cool growing season, possibly along with the high levels of lead in the soils, reduces phosphorus uptake resulting in little change in the sward structure. However the results of the present survey on enclosure 1 which has been unmanaged for about twenty years depicts a different scenario. Now the vegetative sward has grown up to such an extent so as to match a similar enclosure which Jeffrey and Pigott described at Malham Tarn two years after its enclosure. There, as in the Widdybank enclosure now, there was a dense sward with much matted dead material. The suggestion by Jeffrey and Pigott that the small standing crop was due to phosphorus deficiencies on sugar limestone, would not seem to be true in the long term. The results at Malham suggested to Jeffrey and Pigott that the short, cool growing season could not alone explain the lack of growth and they instead tried to explain this due to the high lead content of the soil. Alternatively the short, cool growing season alone may be responsible for the lack of biomass production and low phosphorus breakdown rate and Jeffrey and Pigott may not have monitored the vegetation for a sufficient length of time to note this. If this is the case however it must be that over time the sward can accumulate enough of a phosphorus pool to allow the sward to build up to the stature of less extreme localities. It is possible that *Sesleria,* a plant adapted to the shallow limestone soils of northern Britain, can somehow extract phosphorus as it becomes available through breakdown of organic matter over time and store this phosphorus, so that there is an overall accumulation of phosphorus within the sward over time. The mass of dead litter below *Sesleria* may build up to such an extent that, even though there is only a small amount of phosphorus leaching as it breaks down, the large amount of litter can provide enough phosphorus to maintain a more usual growth regime.It must also be remembered that *Sesleria* has a very low phosphate requirement (Dixon 1982) and this may explain the lush sward on such a phosphate poor soil.

Alternatively, as this site is close to one of the larger mineral mining veins, the cessation of mining may have resulted in a gradual leaching away of the lead from the upper soil horizons in which the plants are rooted. If lead was retarding biomass accumulation this would allow growth to continue at a more expected rate.

Watts (1962) looked at the effects of complete grazing exclusion with regards to rabbits on an East Anglian heath and found a succession of stable dominant vegetation types. He found that initially there was a dominance of a few species at the expense of the rest of the sward and that several species were lost. Comparing this to the situation of the permanent unmanaged enclosure on Widdybank several parallels can be drawn. With regards to the initial domination by several species, *Sesleria* seems to occupy this role here although *Carex flacca, Calluna* and *Helianthemum* are also forming larger growth forms. However there are still species more characteristic of the open sward which would seem to indicate a less uniform community.

In light of Watts initial observations that a single species generally controlled the dynamics of an ungrazed community, it may be that in enclosure one the presence of voles may prevent such dominance to some extent, as suggested by Hill *et al.* (1989). Watts (1967) later concluded that there seemed to be a sequence of physiognomic dominants which were partially linked to environmental conditions.

It will be interesting to see future changes in these enclosures bearing in mind the long term changes noted in other similar enclosures (Watts 1967; Marrs, Bravinton & Rawes 1989).

4.5 Changes in the Distribution and Composition of the Communities on the Fell

4.5.1 Festuco - Brometea (including nodum 4)

The distribution of these noda (see Figures 3.17-3.24) seems to have changed little since the initial survey despite worries of sheep rubbing causing erosion on sugar limestone outcrops. It seems that if any changes are occurring they are at a scale too small to be detected by the large scale of the current survey. The changes which have been noted are all small scale and have occurred in the distribution of noda within the class rather than involving any of the other classes of vegetation. The most commonly noted change is the small scale expansion and retreat of the nodum 4 vegetation. It is worth noting that the many isolated areas of open grassland within nodum 4 vegetation have remained relatively static. The stability of these small pockets of grassland amongst nodum 4 vegetation could be linked to differing soil conditions or heavy grazing preventing an encroachment of *Calluna*. The findings of Clark, Welsh and Gordon (1995a, 1995b) may also provide.a mechanism to explain this stability. They found that in areas with grassland patches within larger areas of heather sheep tended to graze the areas of heather around the perimeter of the grassland areas more intensively than heather further away. This may act to stem any heather encroachment. Similarly this could be a mechanism to explain the areas where the grassland patches are expanding or the *Calluna* is becoming sparser around the edge of grassland patches.

The loss of *Potentilla crantzii* and the colonisation by *Ctenidium molluscum* and *Agrostis canina* as well as the increase in *Viola lutea* in nodum 4 may be due to overgrazing, the former species being prone to grazing (Ian Findlay pers. comm.) and the latter three able to colonise a more open sward and bare areas. This could result from rabbits activity rather than that of sheep. The decrease of mosses and liverworts may be due to a more closely grazed sward, or is perhaps as a result of the dry summer or other generally changing environmental variables such as temperature and nutrient deposition.

4.5.2 Molinio-Arrhenatheretea (including nodum 21)

The noda of this class have changed little in their distribution (see Figures 3.17-3.24) and have also altered little in their species composition. Species which have colonised nodum 21 include both calcicole and calcifuginous species, some of these becoming quite common. As with several of the other noda studied there again seems to be some reduction in the hepatic flora which may again be due to factors such as the hot summer, increasing atmospheric deposits and climatic changes due to the reservoir (see Section 4.6).

It is worth noting, especially with regards to this and the previous nodum, the conclusions of Hill, Evans and Bell (1989) with regards to the long term effects of excluding sheep from hill pastures. They found that changes in *Festuca ovina/Agrostis tenuis* grassland occurred more slowly than in *Nardus stricta/Festuca ovina* grassland. In this respect any changes which may occur as a result of recent changes in grazing on Widdybank may not become apparent for some time after the changes and hence any effects of recent changes in grazing etc. may not become noticeable for some time yet.

The decrease of *Koeleria* within this sward may be as a result of increased grazing on these limestone grasslands, which has led to a reduction in the seeding frequency of *Koeleria*. Intense grazing would favour the expansion of species which can spread vegetatively (e.g. *Festuca ovina*) and this may be at the expense of species such as *Koeleria* which rely much more on regeneration from seed (Watt 1981). Alternatively Watt also noted that *Koeleria* declined as a result of a particularly warm summer which could also explain the general decline of *Koeleria*.

Ranunculus acris seems to be grazing sensitive and in nodum 21 is more common at the base of small gullies where there tends to be a slightly longer sward. It is also more common in the enclosed area of the meteorological station than in the surrounding grassland, suggesting a preference for reduced grazing.

4.5.3 Nardo- Callunetea (including nodum 29)

The distribution of the various noda of this group have not changed in any particular direction (see Figures 3.17-3.24) and to any great extent since the time of the initial survey at any of the four mapping sites. Marrs, Bravington and Rawes (1988) found that in both enclosed and unenclosed *Juncus squarrosus* grassland there was a successional trend towards blanket bog dominated by *Eriophorum vaginatum* and *Calluna vulgaris*. In the nodum 29 vegetation studied on Widdybank however this does not seem apparent. The species which Marrs *et al.* give as changing in abundance over time do not parallel those changes which have occurred on Widdybank. With regards to the trends observed at Moor House (Marrs *et al.* 1988), the changes noted at Widdybank conflict when attempting to postulate a grazing explanation for such changes. The only notably increasing species in this noda at Widdybank, *Deschampsia flexuosa*, was found at Moor House to be a species of variable response to grazing. Similarly species which seemed to have decreased in this noda but which were noted at Moor House to have variable changes over time include *Plagiothecium undulatum*, *Barbilophozia floerkei* and *Aulacomnium palustre*. These changes at Widdybank may not therefore represent a long term trend but just a short term fluctuation. The slight decline in *Calluna* in this noda and slight increase in *Pleurozium schreberi* may be indicative of increased grazing intensity if considered with respect to the Moor House results (Marrs *et al.* 1988), but decreases in species such as *Agrostis canina* and *Potentilla erecta* and the increase in *Deschampsia flexuosa* seem to suggest an opposite trend (Marrs *et al.* 1988; Ball 1974). Species noted as increasing after a cessation of grazing over a similar community (Hill *et al.* 1989), which have decreased over the intervening period on Widdybank, include *Agrostis canina,* and *Narthecium ossifragum.* This may suggest changes due to an increase in grazing intensity on Widdybank, although the number of other species which Hill *et al.* noted as changing following the cessation of grazing includes many species which have not changed their abundance on Widdybank.

Rhyser (1993) mentions the importance of a fungal pathogen in the elimination of a species during one year of his study period and such short term changes should also be borne in mind when describing species changes in this study. It therefore seems impossible to confidently postulate any causal grazing mechanism for the observed changes within this noda.

Ratcliffe (1959) notes that the effect of no longer grazing mature wethers on the hills may have resulted in an expansion of *Nardus* due to under-grazing as the wethers were capable of grazing this species. Such an expansion of *Nardus* may have occurred before the surveys of Jones and therefore has not been detected in this study.

It therefore seems that, although the vegetation has changed, no single factor can be offered to explain the observed changes.

4.5.4 Calluno -Ulicetalia (including nodum 33)

As with the previous noda there are no noticeable changes occurring within the areas studied in terms of these noda increasing or decreasing in extent (see Figures 3.17-3.24). However as many of the noda of this class were often mapped together, some intra-class changes may have been masked. This is also the case for the Nardo-Callunetea noda.

There seems to have been a distinct change in the vegetation of nodum 33 which cannot be readily explained via a restricted sampling of one facies of the vegetation as many species are new to this community. Therefore other theories have to be postulated.

Grime (1963) described a shallow acid humus site expanding onto a former rendzina soil and if the reverse can also occur (i.e. the humus retreats) perhaps an event of this kind could explain the changes noted in nodum 33. Maybe a similar advance occurred over rendzinas on Widdybank and the slightly calcifuge vegetation of nodum 33 occupied these area. Now if we propose a mechanism, perhaps as a result of increased grazing, whereby the accumulated ranker biomass has slowly been translocated to other locations via sheep grazing these areas and then defecating elsewhere, it would be possible to begin to get the re-establishment of species more characteristic of a rendzina soil. This however is no more than supposition. Another possible explanation could arise as a result of the cessation of mineral mining in the local vicinity. When mining for barytes and pyrite was carried out on nearby areas of Widdybank (as it did at least until the 1950's in the case of Barytes (Bondi, Leech and Leech, 1994)), then perhaps the local deposition of sulphurous compounds and very acidic leachate caused a local acidification effect on the nearby vegetation. The vegetation of nodum 33 therefore arose as a result of this acidification effect. As a result of the cessation of mining the pH of the soils may have slowly returned to their original level as the acid forming inputs ceased and the more calcicolous vegetation recolonised. There is a need for further investigation of the observed changes.

There is a parallel situation to some extent in the observations of Bradshaw and Dooley (1978) with regards to the vegetation of the Weel area of the River Tees which is now submerged by the Cow Green Dam. Here the vegetation of the river, especially the macrophyte species, was noted as becoming impoverished as a result of the mining slurries polluting the river where cleansing effluent discharged into it. There were however signs of a return to the more species rich conditions recorded before the advent of the mining activities up to the time of the flooding of the area. This change may therefore have been paralleled, albeit with somewhat of a lag period, with regards to the terrestrial flora close to the mines.

As crushing was carried out at some distance from the mines and the main areas of this community are not directly adjacent to the most recent barytes mine, perhaps an alternative explanation is needed. A fuller explanation for these changes requires a more detailed investigation of the soil etc..

Gibson and Brown (1992), looking at calcareous former arable land concluded that irrespective of grazing treatment and local conditions, secondary succession towards species rich calcareous grassland appears to take at least 100 years to run its course. If the change in composition of nodum 33 towards a species-rich calcareous grassland is accepted, then this particular example has taken less than one quarter of the time suggested to occur. However the areas of this noda did still have some calcicoles present and other calcicoles close-by. It may also have retained a viable seed bank of many species if the more acidic conditions were only a transient phase. This may not therefore represent a valid comparison, as, if the theory of local acidic deposition is accepted, this may only represent an example of a temporarily deflected successional community.

Photograph 11 - Depicting a mosaic of several of the Festuco-Brometea communities. Note the patches of the nodum 4 community with *Calluna* surrounding various other open grassland noda.

Photograph 12 - Showing banding of several noda across an area of undulating calcareous and acidic soils. Note the sheep preferentially grazing the calcareous grassland areas.

4.5.5 Oxycocco- Sphagnetea (nodum 23)

In terms of distribution (see Figures 3.17-3.24), it may be that *Sphagnum cuspidatum* pools and their associated edge flora are one of the more mobile communities of the fell, possibly as a result of the build up of *Sphagnum* species filling in some pools over time and other areas become lower lying relative to these areas and hence the areas of standing water shift. Other factors such as bog bursts, peat hag formation, and erosion in the gully systems may also result in some shifting of the water table and hence damper communities over time. Similarly, work on the effects of drainage of moorlands (Stewart and Lance 1991) has been shown to change the local hydrology and hence the distribution of such communities. Rodwell (1992a) suggests that there is some evidence that the pattern of *Sphagnum cuspidatum* pools grading to drier, flat and hummock vegetation may represent cyclic complexes. This may explain the changes in the species composition, although Rodwell states that such succession may be extremely slow.

The findings of Tallis (1985) may be relevant to the apparent changing distribution of this community. He noted that peat erosion instituted by bog slide and bursts caused drainage gullies to form extending back into the peat, in turn causing slumping of marginal peat downslope and the drawing off of water from pools of the hummock hollow complex on the watershed. Tallis also found that death of *Sphagnum* species from air pollution has led to renewed erosion of the peat. He concluded that air pollution seemed to be causing recent peat erosion and this was clearly being accentuated, if not caused at the peat margins by intensive sheep grazing (Tallis & Yalden 1984).

With regards to changing species composition of nodum 23, Rawes and Hobbs (1979) when studying an enclosed area of similar community at Moor House noted changes which are comparable to those noted during the present study. These changes could not be definitely attributed to the fencing and they indicate that a decrease in the precipitation over twelve years previous to an initial study, compared to the twelve years after, may have been partly to blame. Similarities include an increase in *Calluna* and *Sphagnum papillosum.* However the appearance of *Sphagnum capillifolium* and the increase in *Sphagnum cuspidatum* at Widdybank are opposite to the trend noted at Moor House. Perhaps the increase in *Sphagnum capillifolium* represents the advance of this edge into the wetter area of Jones' mapped nodum 23 due to a general drying. This would therefore also be in agreement with the Moor House results of an overall decrease of this band of vegetation. The increase in *Sphagnum cuspidatum* seems anomalous here but, as mentioned elsewhere, may be as a result of Jones omitting to monitor the open water vegetation. However the general trend can be seen to be the same with a decrease in the more aquiphilous species and an advance of the drier heath species into the community. This is perhaps then a community where there is some evidence of long term changes as a result of climatic variations or natural processes.

4.5.6 Sphagnetalia magellanici (nodum 28)

It is appropriate to consider changes in the extent of this nodum (see Figures 3.17-3.24) in the light of changes which have been reported in similar communities elsewhere. The changes on Widdybank can then be dicussed in the context of these other changes. The most commonly occurring reasons for changes in the extent of bog communities are grazing and burning, factors which will be considered later with regards to changing species composition within this noda, and also changes due to atmospheric depositions which are more appropriately discussed here.

The nodum 28 communities mapped during the present study have not changed their distribution to a noticeable degree, the only changes being due to conversion to nodum 23 communities and possibly as parallel gain in some of the areas which were originally classified as nodum 23.

Bobbink, Heil and Raessen (1992), working in the Netherlands, found that on artificial *Calluna* canopies there was co-deposition of SO_x and NO_x compounds, however in the real canopy lots of NH_3 /NH_4 was directly assimilated by the plant shoots. They calculated total atmospheric deposition of sulphur and nitrogen as being 27-33 Kg S $ha^{-1}y^{-1}$ and 30-45 Kg N $ha^{-1}y^{-1}$ respectively and concluded that present atmospheric nitrogen deposition is a threat to the existence of western European heathlands. In a similar vein, Prins, Berdowski and Latubihen (1991), again in the Netherlands, concluded that nitrogen deposition may accelerate the opening up of the *Calluna* canopy and , once opened, the negative effects of the high nitrogen input may speed up even more the transition of heathlands to grasslands. Work in Britain with regards to ammonia deposition (Sutton, Moncrieff and Fowler, 1992) has found that deposition occurred rapidly at all sites investigated and that, at two typical UK sites subject to background air concentrations, ammonia dry deposition is of a similar magnitude to ammonium wet deposition and, near emissions sources ammonia dry deposition is expected to dominate. Houdijk *et al.* (1993) found that high ammonium deposition affected the physical and chemical status of the soil. They also suggested that the decline of rare herb species on heath vegetation is not likely to be as a result of increased competition from grasses because of eutrophication but is more likely to be because of acidification and changes in the soil mineral balance. If this is the case at Widdybank, then increased nitrogen deposition could still cause changes in the flora despite the fact that phosphorus is the limiting nutrient on the limestone soils (Jeffrey and Pigott, 1973).

Despite the high grazing on Widdybank Fell and the documented examples elsewhere of *Calluna* heath declines due to such grazing (e.g. Marrs 1993; Smith and Charman 1988; Edgell 1969), there does not seem to have been a similar decline over the study period on Widdybank. Marrs (1993) postulates that the critical part of the *Calluna* cycle with respect to conversion to grassland is the time between the building/mature/degenerative stages and the new pioneer phase. He states that factors such as climate, management and insect herbivory, which all cause large scale *Calluna* death could interact with the effects of high pollution. The generally harsh climate of Teesdale when compared to the Breckland study sites of Marrs may operate so as to reduce the climatic effects which occur in lower, less oceanic areas and also maintain invertebrate herbivore numbers at low levels. Hence the nature of the Teesdale environment may result in no large scale death of *Calluna* which could allow a break in the cycle and the colonisation by grassland noted in other areas.

In terms of the changes in species composition, Chapman (1964) notes that *Drosera rotundifolia* and *Lepidozia setacea,* two of the species lost are more frequent on deeper, wetter areas of peat, whilst *Calluna,* which is increasing here, is more common on shallower peat. Chapman defined a separate bog community in areas of more flushed peat which tended to have more *Drosera, Erica tetralix, Vaccinium oxycoccus* and *Sphagnum magellanicum.* Edgell (1969) similarly noted *Erica tetralix, Drosera* and *Sphagnum spp.* increase with reduced drainage. All but the last of these species are decreasing within nodum 28. Edgell (1969) also states that *Hypnum jutlandicum* (an increasing species here) dominates the ground layer on excessively drained slopes of *Calluna* heath. All the above correlate with changes noted at Widdybank and suggest that either the present study of this nodum was biased towards a drier facies of the community due to being limited to areas near limestone, possibly resulting in sampling over shallower peat, or that the community as a whole is tending to become drier. This latter suggestion would need substantiating with further fieldwork.
The huge increase in *Vaccinium myrtillus* since the initial study may be indicative of a transition occurring towards an acidic grassland (Edgell 1969; Ratcliffe 1959), however the parallel increase in *Calluna* would not suggest this. Ratcliffe also notes that in the transition zone between the heath communities of *Calluna* and *Vaccinium, Vaccinium* has the competitive advantage as it is grazed less and spreads at the expense of *Calluna.* There may therefore be an increase in *Vaccinium* on the Widdybank study areas due to a temporary effect of burning and heavy grazing.

Edgell and Tallis (1985) also note that *Calluna, Vaccinium myrtillus* and *Empetrum nigrum* tend to occur on free-draining sites. Tallis (1973) however notes that

Empetrum nigrum and *Vaccinium myrtillus* are species characteristic of margins of the peat and haggs of erosion complexes. It may therefore be that the present study covered an edge facies of this community or that there has been increased erosion over the intervening period.

The findings of Miles (1973) regarding changes in species abundance within *Calluna* vegetation as a result of fertilisation would seem to suggest that increased fertilisation via atmospheric deposition is not an important factor in the changing species abundances.

Of note with regards the decreasing and lost liverworts, and the occurrence of two new *Cladonia* species are the findings of Stewart and Lance (1991), who looked at moorland drainage. They found that liverwort cover near drained areas was about one third less than elsewhere whilst lichens eventually increased. This would fit in with the current findings, again indicating drier situations. As many of the areas studied were extensively burnt in 1986 (from aerial photographs) it may be that this slightly atypical species composition is a result of this, although there is no reduction in *Cladonia spp.* which may have been expected (e.g. Rawes and Hobbs 1967).

The increase in *Calluna* over the intervening period between the two studies may be as a result of much of the areas studied during the present survey having undergone burning several years earlier, which has led to more of a *Calluna* dominance.

The suggestion by Rawes and Hobbs (1979) that an increase in grazing pressure results in an increase in the dominance of *Eriophorum vaginatum* at the expense of dwarf shrubs and decreased lichen cover would suggest that present changes are not due to over-grazing of this noda.

Miles (1973) noted that *Poa annua* colonised a peaty podzol site following fertilization. This may suggest then that an observed spread of *Poa annua* along the sheep-walks on Widdybank (I. Findlay *pers. comm.*) is a result of increased fertilisation in the form of sheep droppings along these regularly used routes. Ratcliffe (1959) also noted an increase in *Poa annua* in areas where sheep spent any length of time.

Tofieldietalia and Parvocaricetea

The distribution of these two classes on Widdybank Fell can be seen to have altered little over the period between the two studies. The areas mapped generally have very little Parvocaricetea, whilst Tofieldietalia is somewhat better represented (see Figures 3.17-3.24). Bearing in mind these differences in coverage it does seem this class and order have altered little in their distribution. When compared to the pool communities of the bog areas, the limestone flushes are remarkably unaltered in their distribution, reflecting little change in the hydrology of these areas as a result of recent changes.

4.6. The effects of temperature changes on the Teesdale communities

The noted minimum temperature changes (Figures 3.25 and 3.26) could have far-ranging effects on the Teesdale Assemblage communities. Generally there does not seem to have been any noted decrease in any of the more characteristically arctic and arctic-alpine species as a result of temperature changes, the only such species which is noticeably declining being *Potentilla crantzii.* However if the short growing season of Upper Teesdale is considered, it may be that changes will take many more years to become apparent.

The possible implications of the temperature changes via changes in the growing season, vernalization, pollination and even population genotypic frequency need to be considered individually for each species. For example the apparent extension of the growing season into autumn and the postponement of its initialisation in spring could have effects on many species for which the timing of the growing season is important. The decreasing hepatics may be invoked as a group which are being affected as many species put on much of their growth in the spring and autumn. However as many factors are involved such ideas are no more than suppositions.

The effects on seed germination and pollination may not be noticeable on the fell as a result of the heavy grazing favouring vegetative expansion. A reduction in grazing pressure on the fell may therefore not necessarily result in increased sexual reproduction and seed production. Even when changes in the species abundance and distribution are not apparent there could still be genetic changes in the composition of a species' population, with shifts towards genotypes better adapted to less extreme environments at the expense of those genotypes better able to cope with harsh conditions.

In addition to the noted temperature changes, other changes such as increased atmospheric CO_2 and nitrogen deposition may act in parallel with the temperature changes to produce a compound effect.

If the species changes in the studied noda are considered together, several species are seen to be increasing in more than one nodum. The vascular plants in this class include *Achillea millefolium, Agrostis canina, Agrostis tenuis, Trifolium repens, Lotus corniculatus* and *Viola lutea.* All but the last species are classified in the wide element of the European flora (Graham 1988), the latter species being classified as a widespread sub-Atlantic species. This may be indicative of a general warming effect, as such species would be expected to increase as a result of an ameliorated climate. Increases in such species may result in deleterious competitive interactions with the more restricted species. However it may be that these species are the only ones noted as increasing several habitats simply as a result of them being present in many of the noda. The decline of characteristic upland liverworts such as *Barbilophozia floerkei* and *Ptilidium ciliare* may represent a reverse trend as a result of the changing conditions.

4.7 General Discussion

Species which have been noted as increasing on Widdybank Fell in general recently include *Poa annua* and *Cirsium arvensis* (Ian Findlay *pers. comm.*). The former seems to be increasing along the road edge and along sheep walks. This may indicate an increase in trampling and fertilization of these areas due to high sheep numbers. Similarly the effects of sheep and people along paths and roads tend to trample the vegetation benefiting trampling resistant species and species characteristic of open areas. Species which seem to be more common along path edges etc.. include *Plantago major, P. Lanceolata, P. Maritima* and *Minuartia verna.* The increase in *Cirsium* may also represent an increase in the amount of bare ground due to poaching and heavy grazing allowing colonisation, although the import of hay from the lowlands to supplement the feed for livestock in the Environmentally Sensitive Area has also been implicated as being a possible source of seed contamination causing the increase in abundance (Ian Findlay *pers. comm.*).

Aspinall and Pye (1987) found that floristic composition and structure in trampled areas respond to both trampling pressure and changed local environmental conditions.

One of the problems of carrying out such a study over only one field season is that any effects due to the conditions of that particular year cannot be smoothed out. In this respect some of the changes which have been partly attributed to drier conditions cannot be confidently explained in terms of long term changes. The exceptionally hot summer may have resulted in a die-off of the most susceptible species resulting in an slightly abnormal data set. In this respect it is interesting to consider the findings of Marrs, Bravington and Rawes (1988), who when considering the effects of enclosure also studied changes in the vegetation outside the enclosures. They found that several of the changes in the vegetation within the enclosures were paralleled by changes in the grazed areas. Some species fluctuated widely in their response and changes were the same between the two areas. Similar trends are also noted by Watts (1981). This would seem to indicate that some species do undergo fluctuating trends of abundance due to climatic conditions. Therefore by only sampling over one season, the results may depict a skewed image of the general abundance of some species, and changes may not be so drastic in some of the studied noda.

The fact that several bryophytes (e.g. *Ptilidium ciliare*) which were noted to decrease in some of the Widdybank noda also were noted as decreasing at Moor House (Marrs *et al.*) may indicate a longer term, wider scale change and not simply a response to the conditions of one season. This may be as a result of changes such as increasing atmospheric pollution or nitrogen deposition having deleterious effects upon these species.

The lack of apparent change in the distribution of the various classes would perhaps be expected as a result of the very different geological and hydrological variation between areas.

The changes noted in the various noda studied here seem not to be related to increasing grazing pressure, which is in agreement with grazing not having increased greatly over the period since the initial study (Ian Findlay pers. comm.). Changes therefore have to be explained via mechanisms such as increased atmospheric depositions, climatic change, burning, and natural processes such as year to year variations in abundance and natural successional changes. Some of the changes however require further analysis to allow fuller explanations for observed changes.

The analysis of the vegetative communities of the fell has left a lot of unanswered questions with regards to the causes for the observed changes. Although theories for such changes can be put forward, more work is necessary to determine actual widespread changes and the factors causing such changes.

4.8 Implications for future management

Implications for future management must involve the possible idea of a general climatic warming, as has been predicted due to global warming, as well as changes which have been noted in the local climate as a result of the reservoir. These may have profound influences on the species which can invade or thrive on the fell. With regards to theories on plant migration, it has been suggested that predicted large scale changes necessitate plants to migrate at a rate up to one order of magnitude faster than currently observed rates of migration (Huntley 1988). Huntley also draws attention to the need for better connecting links between areas of natural vegetation to allow such migration. In this respect the bog and heath vegetation is quite well connected along the whole of the northern Pennines but the areas of limestone vegetation are more sparse in their distribution, which may be a cause for concern. Similarly the lack of seed production by the plants of the extensively grazed areas will also limit the rate at which migrations could occur; species relying on clonal vegetative spread being overwhelmed by rapid climatic changes. It could therefore be recommended that a seed bank of the upland species and in particular those of restricted habitats be initiated, so as to allow possible introductions to other distant sites as they become more favourable for the species and thoe conditions on Widdybank become less so. An encouragement of seed production by many of the species, perhaps via reduced grazing, would therefore be advisable both in terms of natural migration and also to allow collection of material. Crawford *et al.* (1993) also note that in areas where climatic warming has been occurring for some time (Spitzbergen), there is a change in the ecotype frequency within species and hence sexual reproduction may help species to combat changes in climate via maintaining ecotype diversity.

It may be considered that the rare flora of Teesdale would be little affected by general climatic warming, as this could result in an increase in the summer temperature but little change during the winter as a result of the upland oceanic location. The climate may therefore become more like that of an alpine environment and therefore be favourable towards some of the rare Arctic species, although the Teesdale assemblage *per se* would be likely to change.

The effects of the dam on the temperatures of the fell is very worrying and is not a problem which can be easily overcome if changes in the species composition of the fell do begin to occur. This reiterates the worries at the time of the initial dam construction that the scheme may ultimately lead to a reduction in the diversity of the Teesdale Assemblage. The dam therefore continues to threaten the Teesdale Assemblage of communities.

tolerant of intense grazing are excluded and would perhaps be more widespread on the fell if grazing intensity was reduced. A more worrying effect of the grazing regime may be a reduction in the sexual reproduction of many of the species present, resulting in a reduction in the genetic diversity of several of the species.

- It is suggested that the structure of one of the unique limestone grassland communities may act as a partial refuge for some of the grazing sensitive species, especially with respect to sexual reproduction and in maintaining genetic diversity.
- Changes in the mean minimum temperatures in spring and autumn were detected as a result of the flooding of the reservoir.
- All of the above changes are discussed in relation to several environmental factors operating on the fell which may be responsible for the changes. Such factors include grazing pressure, changing atmospheric deposition and pollution, global warming and associated atmospheric changes, anthropogenic effects including increased usage of the area, the Cow Green Reservoir and the various management activities carried out on the habitats present.
- The findings of the survey are also discussed briefly with regards to the unique Teesdale assemblage of plant species and communities and implications for future management are discussed.

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Appendix I

Legend and key to the original maps provided by Jones and Bradshaw (1976), parts of which are extracted in Figures 3.19, 3.21, 3.23, 3.25.

250 0 feet 250 500 750

100 50 0 metres 100 200

SCALE 1:2500

Heights in metres above Ordnance Datum.

Contour interval 2 metres.

Aerial photography dated Oct. 1969 by Meridian Airmaps Ltd., Lancing, Sussex.

Field survey for control of photogrammetric mapping by Department of Surveying, University of Newcastle upon Tyne.

Vegetation survey prepared from ground observations and air photograph interpretation by A. V. Jones, B.Sc., University of Durham.

Photogrammetric mapping and fair drawing by M. S. Evans, Department of Surveying, University of Newcastle upon Tyne.

Additional cartographic work and printing by A. W. Gatrell & Co. Ltd., London.

LEGEND

river, stream, sike	
surface water	W
fence, wall	
road, track (fenced and unfenced)	
building	
contours (metres)	500
spot level (metres)	. 525·6

VEGETATION CLASSIFICATION

1–7	Class: Festuco-Brometea (calcareous lowland grasslands) Order: Brometalia erecti (dry and semi-dry grasslands) Alliance: Mesobromion erecti Sub Alliance: Seslerio-Mesobromion (short grassland)
V	Class: Violetea calaminariae (vegetation on soils rich in heavy metals) Order: Violetalia calaminariae Alliance: Thlaspion calaminariae (pioneer communities of the class)
▲	Class: Montio-Cardaminetea (vegetation of spring-heads) Order: Montio-Cardaminetalia Alliance: Cratoneurion commutati (vegetation of tufaceous springs)
19–22	Class: Molinio-Arrhenatheretea (cultivated rich pastures and marshy meadows) Order: Arrhenatheretalia (species-rich meadows and pastures) Alliance: Ranunculo-Anthoxanthion (sub-alpine meadows and pastures)
15–18	Class: Parvocaricetea (short-sedge marsh) Order: Caricetalia nigrae (mesotrophic sedge marsh) Alliance: Caricion curto-nigrae
8–14	Order: Tofieldietalia (calcareous sedge marsh) Alliance: Caricion davallianae
23	Class: Oxycocco-Sphagnetea (bogs and wet heaths) Order: Ericetalia tetralicis (wet heaths) Alliance: Ericion tetralicis
24, 28	Order: Sphagnetalia magellanici (ombrogenous bogs) Alliance: Erico-Sphagnion.
25, 27, 29	Class: Nardo-Callunetea (grass heath) Order: Nardetalia (acid grassland) Alliance: Violion caninae
26 31, 32, 33	Order: Calluno-Ulicetalia (heath) Alliance: Empetrion boreale
1–X	Vegetation of uncertain phytosociological affinities and fragmentary units. (For details see booklet)
25/9	Complex of hummock-hollow vegetation: 25 forming hummocks, 9 forming hollows.
V 21	Complex of two Alliances along line of old mineral vein: V along sides of channel, 21 on base.
5, 33	Complex of two Alliances: mosaic of units as indicated.
	Areas without vegetation—natural or man-made

Appendix II

The Domin scale of quantitative presence values used for recording species cover/abundance (*sensu* Dahl and Hadac 1941).

Domin Score	**Percentage cover**
10	91-100
9	76-90
8	51-75
7	34-50
6	26-33
5	11-25
4	4-10
3	<4 (many individuals)
2	<4 (several individuals)
1	<4 (few individuals)

Appendix III

Table of raw data collected to analyse the effects of enclosure on the vegetation of Widdybank Fell. All quadrats were 2x2 metre in size.

Enclosures																													
	701	702	703	704	705	706	707	708	710	711	712	713	714	720	721	722	723	724	725	726	727	730	731	732	733	734	735	736	737
Gentiana verna	2	2	2		1		1	1	2		1	1		2					1	1	1	2		2	3	2	1	1	1
Linum catharticum	2	2	2	2	2	2	1	1	2	1		2							2	1	2	1			2	2		2	1
Gentianella amarella	1		1			1	1	1	2		2	2							1	1			1	2		1			
Helianthemum nummulariu	2	5	2	2	2	1	3	3			4	2			5		5		1		2								
Plantago lanceolata	2	2		2	2	2	2		2		2		2							2		2	3	1	2	3			1
Lotus corniculatus	2	2	3	2	2	1	1		3					2						2	1	1			2	3	2		1
Potentilla erecta	3	3	3	2	2	1	1	1	2	3		1	2	2	2	2	3	3	1	2	2		2		2	2	1	1	1
Campanula rotundifolia	2	2	2	2	2	2			1		2	2	3		2	1	2	2	3	3		2	1	1	2	1	2	3	3
Achillea millefolium	1	1	1	2	1			1			1		3									3	2	4	2	1	1	1	1
Galium sterneri	2	2	3	3	2		1	2	3	3	2	2	2	2	1	2		1	1	2	1	2	1		1		1	2	2
Thymus drucei	3	2	2	2	2	3	4	3	3	4	2	2		2	2	3	3	2	3	4	3	2	2	2	3	2	2	2	3
Selaginella selaginoides		1	2	2	3		1		1	2						1			1	1					2				1
Carex pulicaris							2	2												1	1								2
Polygonum viviparum	2	1		6	5									1	2	4	3			1									
Carex caryophyllea	2	1	2	3	2	3	2	3	2		3	2							4	3	3	2	2		3	2	4	2	2
Euphrasia officinalis agg.	1	2	1	1	1	2	1	1	1	2	2	2				2			2	2		3	2	2	3	3	1	2	1
Galium boreale	1	2	1	2	1									4		2					1	5	8		1	4		1	
Minuartia verna	1		1	1							4		1					1	2		1	1					1	1	1
Prunella vulgaris			1			1		1	3				3						1	1	1						1		2
Ranunculus acris				1	2	1			1			1			1		1					2	3	3	2	6	1		
Plantago maritima	1	1				1																							
Carex flacca	2	2		2	2	3	3	3	2	4	4	3	2	3	4	1	3	2	1	2	2	2		1					1
Carex panicea	4	4		3	2	2	2	2	2		2	4		2	1				2	2	2			2	4	4			2
Festuca ovina	8	7	8	8	7	9	9	8	8	8		8	9	5	4	4	7	4	8	8	8	7	5		6		8	8	8
Fetsuca rubra			2																					4					
Danthonia decumbens	3	2	4	4	5	2		2	3	4	3	3	2	3	2	2	2	2	2	3		4	4	4	4	3	3	4	2
Sesleria albicans	2	3				3	3	4	2			4	2	9	9	7	6	9	2	2	2	5	2	2	6	4	2	2	3
Other grass spp																										2			
Koeleria macrantha							2											3											
Briza media	5	4	4	3	4	3	3	3	3	3	4	3		2		3			4	3	4	4	3	4	4	3	4	5	4
Agrostis tenuis										3			2								1			2					
Agrostis canina															3														
Koeleria cristata	3	3		2																									
Luzula campestris	1		1	1									1									1	1		1	1	2		
Tortella tortuosa	1	3	2		1	3			3		3	2				2			3	2	3	2	2		2		2	2	
Ctenidium molluscum	2	2							2			2				2				3	2		2		2	2			1
Ditrichum flexicaule	1	1	2					2	3		2	2				2													1
Dicranum bonjeanii			1					1																					
Dicranum scoparium				1																									
Cetraria islandica	1																												
Peltigera canina								1								1				1									

Figure I - Raw data from the various enclosure quadrats. For a key to the quadrat numbers see the base of the table.

Enclosures	701	702	703	704	705	706	707	708	710	711	712	713	714	720	721	722	723	724	725	726	727	730	731	732	733	734	735	736	737
Rhacomitrium lanuginosum	2	2			3		2	2	2		2	2	2						2	2									1
Pleurosium schreberi																2													
Hypnum lacunosum	2	2	3			3					3									3	2	2							?1
Hypnum cupressiforme												2		3		2													
Rhacomitrium canescens				4	3				5													1							
Squarrose Cladonia	1	2																											
Cladonia furcata																2													
Bellis perennis		2	2	1	3	2		2	1																1	1	1		2
Carex capillaris		2		2								1				2									3				
Carex ericetorum																									1		2		
Viola riviniana		2	2		2		2	2	2	2		1	2	2	2		1	1	1	2	1	2	2		1			1	1
Viola lutea			2	2	2			1	2	3	2		2	2		1	2		2	2	2	3	1	2	2		3	2	
Listera ovata		1														1													
Hieracium pilosella		1	2	2	2	1		1	1		1		1							1	1			1	1				1
Succisa pratensis		1																						1	1				
Cerastium holostioides			1							1	1		2							1		1		1			1	1	
Geum rivale			2				1							1	1		3		1				1		1	1		1	1
Cirsium palustre										1																			
Cirsium vulgare			1																										
Rhytidiadelphus squarrosus			2				1			4				4	4	2	4	4	2			3		3	2	1			
Rhytidiadelphus triquetrus				1													1						3						1
Rhytidiadelphus loreus																2													
Pseudoscleropodium purum								1			3				4		3	2											
Thuidium tamariscinum			1				1															2							
Hylocomium splendens								1		4	2	2		4	5	5	5	4							1				
Mnium hornum			1																										
Mnium longirostrum																			1										
Atrichum undulatum																						1		1					
Cladonia subrangiformis			1		1											4													
Cladonia arbuscula																3													
Hypnum jutlandicum			1							4																			
Anemone nemorosa				1											1										1				
Alchemilla glabra																										1			
Polygala serpyllifolia				1						1																			
Botrychium lunaria				1																		2		1	2	2		2	
Cetraria islandica					1														1										
Cornicularia aculeata																												1	1
Acrocladium cuspidatum									2		1	2	2							2			2	1				1	
Trifolium repens									1	1			3			2			2		1	2		1	1	2	2	2	2
Senecio jacobaea									1																				

Figure I(cont.) - Raw data from the various enclosure quadrats. For a key to the quadrat numbers see the base of the table.

Enclosures																												
	701	702	703	704	705	706	707	708	710	711	712	713	714	720	721	722	723	724	725	726	727	730	731	732	733	734	735	736	737
Veronica officinalis										1			1																
Galium verum										1												2	1	1		2	??1	1	
Poa annua													3																
Taraxacum officinale agg.						1							2										1					1	1
Holcus lanatus														2		1		1					1						
Solidago virgaurea														2	1			1											
Carex pilulifera																2		4											
Deschampsia flexuosa																							2						
Calluna vulgaris															2														
Antennaria dioica																1			1										
Mnium hornum																		1											
Vicia cracca																						4	3	7		5			
Avenula pratensis																						3							
Cochlearia pyrenaica																							1						
Leontodon autumnalis																							2	1		1	1	1	1
Primula farinosa																							1						
Conopodium majus																									1				
Draba incana							1												1										
Polytrchum formosum							2																						
Fissidens adiantholdes								1																					

Key to the quadrat numbers

Numbers 701-705 - Quadrats carried within enclosure 3
Numbers 706-708 - Quadrats carried out along the outside perimeter of enclosure 3
Numbers 710-714 - Quadrats carried within enclosure 4
Numbers 720-724 - Quadrats carried within enclosure 1
Numbers 725-727 - Quadrats carried out along the outside perimeter of enclosure 1
Numbers 730-734 - Quadrats carried within enclosure 2
Numbers 735-737 - Quadrats carried out along the outside perimeter of enclosure 2

Figure I(cont.) - Raw data from the various enclosure quadrats. For a key to the quadrat numbers see the base of the table.

Appendix IV

Tables of raw quadrat data collected during the analysis of six of the vegetative noda of Widdybank Fell along with a further table giving the eight figure grid references of each quadrat.Quadrats used in all of the noda except nodum 28 were 2x2 metre in size, those of nodum 28 being 4x4metre. This follows the guidelines of Rodwell (undated) in the National Vegetation Classification field manual.

List of Tables

Vegetation Nodum 4	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602
Sesleria albicans	8	8	7	7	3	3	4	5	6	3	4	4	6	3	5	4	4	4
Calluna vulgaris		6	7	7	8	7	8	8	6	8	6	8	8	9	5	8	5	8
Carex panicea	1		2	2	1	4	6	5	5		3	1	4	1	2	3	2	2
Carex caryophyllea	2		2	3	2	2	3	3	3		2	2	3	1	2	2	2	3
Carex ericetorum															1		1	
Carex pilulifera		2		3														
Carex lepidocarpa																2		
Carex hostiana																	1	
Viola lutea		2	2	2	1	1	2		3	2		1	2	1	1			
Viola riviniana	1	3	3	3	3	2	3	3	3	2	3	2	3	3	3	3	3	3
Trifolium repens		2	2															
Campanula rotundifolia	2	3	4		3	3	3	3	3	3	2	2		1	2	2	2	2
Thymus drucei		3	3	3	3	3	3	2	2	3	4	3	2	3	3	3	3	3
Potentilla erecta	2	3	3	2	2	3	3	2	2	3	1	2	2	1	2	3	1	2
Polygala serpyllifolia		1		1		1	1		1				1		1			1
Galium sterneri	2	2	3	3	2	3	2	2	2	2		1	2	1	3	2	2	
Galium saxatile												3		2	1			
Selaginella selaginoides			1	2		2	2		2	1		1	2			3	3	3
Alchemilla glabra		1	1															
Achillea millefolium							1		1				2					
Helianthemum nummularium	3							1					1					
Plantago maritima	2																	
Plantago lanceolata	1																	
Ranunculus acris		1	3															
Festuca ovina	3	4	3		5	5	5	5	5	6	7	6	6	5	7	7	7	6
Festuca rubra	1																	
Danthonia decumbens		2			2	3	2		3	3	2	1	2	1	2			1
Koeleria macrantha	2	3			1	2	2			2	2	2		1	3	1		

FigureII - Raw data collected during the present survey from areas originally mapped as Nodum 4 (Jones and Bradshaw 1979).

Vegetation Nodum 4	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602
Briza media	2	3			2		2	1		1	1	1	2		2	2	3	2
Agrostis canina					3						2			3		1	2	
Carex flacca	2	1			2	4	2		2	2	2	2	3	2		3	3	2
Kobresia simpliciuscula																	1	
Polygonum viviparum	2			1			1	1					1				2	
Lotus corniculatus		2							1		3	1					1	1
Rhacomitrium lanuginosum	3	2				2					1			1	1		2	
Rhacomitrium canescens							2											
Hylocomium splendens	2	2	4	3		2			2	1	1		3				2	
Hypnum jutlandicum	2	4	2	3	3		3	2	2	2	3	2		4	2	3	2	3
Rhytidiadelphus squarrosus		3	2	3	2	2			4	1	2	2	2			1		2
Rhytidiadelphus triquetrus					1							2	2					
Rhytidiadelphus loreus		1					2				1				1			
Hypnum lacunosum	2	1				3		2	1	1	1						2	2
Pleurozium schreberi		2	2		2		2	3			2	2		2		1		
Mnium longirostrum	2																	
Ditrichum flexicaule														1				
Dicranum bonjeanii	2	1			1		2		2	1	2		2			1	1	2
Dicranum scoparium						1		2			1			1			1	
Veronica officinalis		2																
Empetrum nigrum			2	1				1		1						1		
Gentiana verna			2	1		3	3		2			1	3		1	1		2
Gentianella amarella	1								1				1					
Agrostis stolonifera			3		3	1									1			
Agrostis tenuis										3		2					2	
Pseudoscleropodium purum			2			2			3	2			3			1		
Polytrichum formosum			2	2	2					2	1		2	3	1			
Trollius europaeus				3				1										

FigureII (cont.)- Raw data collected during the present survey from areas originally mapped as Nodum 4 (Jones and Bradshaw 1979).

Vegetation Nodum 4	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602
Hieracium pilosella				1														
Cladonia arbuscula				1				2	2	1								
Cladonia pocillum					1			1			1	1		1	1			
Cladonia subrangiformis					1			2	2	1	1	1		1				
Cladonia rangiformis												1						
Cladonia uncialis									1		1							
Cladonia chlorophaea														1				
Cladonia coniocraea										1			1					
Cornicularia aculeata											1							
Tortella tortuosa									1			1	1	3	2			
Thuidium tamariscinum				3	2		2				2						1	
Anthyllis vulneraria				1														
Prunella vulgaris						2	1											
Linum catharticum						2			1					1	1	1	2	1
Galium boreale						1	1						1					
Thalictrum alpinum						2	1		1			2	1					2
Euphrasia officinalis agg.					1	1				1	1	1	1	1	1	2	1	
Carex pulicaris			2		2	2					1	1		2	2	2	1	1
Avenula pratense						1		1	2	2								
Succisa pratensis						1												
Ctenidium molluscum	3					2		2	2					2		2	1	
Sanguisorba officinalis							1								2			
Carex capillaris								2										
Antennaria dioica									1									
Vaccinium myrtillus										2	1	1						
Primula farinosa	1																	
Anthoxanthum odoratum														2		1		

FigureII (cont.)- Raw data collected during the present survey from areas originally mapped as Nodum 4 (Jones and Bradshaw 1979).

Vegetation Nodum 21	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543
Cerastium holostioides	1		1			1		1			1	1	1	1	1				
Carex pulicaris	3	2			3	4		2	2		3	3	2	2			2		2
Potentilla erecta	3	3	3	3	3	4	1	2	2		3	3	1	2	2	1	2		3
Selaginella selaginoides	3	3	3	4	3	3	2		3		3	2							2
Thymus drucei	3	2	4	3	3	3	3	3	3	3	5	2	3	4	4	4	4	1	3
Achillea millefolium	2	1	2	2	2			2	3	1	2	2			1	1	2		1
Viola riviniana	2	2	1	3	3	2	1	2			1	2	2	2		1	1	1	2
Ranunculus acris				1				2	2		1		2	4	1		2	1	
Lotus corniculatus	2	1		1	3	4	2	3	2	2	2	2	3		1	2	2		1
Galium sterneri	2	3	2	2	2		2	3	2	3	3	3	3	2	2	2	2		2
Plantago lanceolata	2	4	4	4	3	4	4		6	6	4		5	4	6	6	7	3	5
Polygonum viviparum	2	2	2		3		2				3	2	2	2					
Carex panicea	4			4	3	3					2	3	2						
Carex pilulifera	3		3	3															
Linum catharticum													1			1			1
Galium saxatile	2		1	2	2	1									1	1	2		
Prunella vulgaris	1	2	1	2	3		3	1	2	2	3		3	3		2		3	
Carex caryophyllea	4	3	2	3	2	2	1		2	2	3	2	1	2	2	2	2		2
Taraxacum officinalis						1			1							1			
Leontodon autumnalis	1				1										1				
Hieracium pilosella						2			3	2	1	3	1		1			1	1
Climacium dendroides	2		1	2		3							1	3	2	2	2		
Carex flacca	4	2	4	3	2	4	2	3	3	3		4	3	4	2	2			3
Polygala serpyllifolia	1					2						1							
Viola lutea	2	2	2	3	2		2	2			2	3	3	2	3	4	3		2
Euphrasia officinalis	1	1	1	2	1	2			3	3		1	3	3	2	1	2		4
Briza media	1	2	3	3	2			2	4	3	3	3	3	4	4		3		
Agrostis canina	3	3	3	3	2	3				3									
Festuca ovina	8	8	7	7	8	8	8	8	7	7	7	9	7	7	7		7	9	8

Figure III - Raw data collected during the present survey from areas originally mapped as Nodum 21 (Jones and Bradshaw 1979).

Vegetation Nodum 21	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543
Sesleria albicans		3								2	2	1	2	1					3
Barbula reflexa								1							2				
Dicranum bonjeanii						2	2		1										2
Dicranum scoparium		2											2			2			
Tortella tortuosa		2			2		1		1	2		1	2		2	2	2		
Thuidium philbertii										1			2						
Thuidium tamariscinum		1				2		2			1	1			1				2
Bryum pseudotriquetrum						1	2	2											
Bryum capillare		2																	
Campylium stellatum			1																
Bare ground			3	3					4										
Gentianella amara			1				1	1		1									1
Gentiana verna			1	1		1		2			1	3				1			1
Bellis perennis			3	3			2	2	2	5	3	2	3	1	1	2	2	3	2
Carex capillaris			1	1															
Hylocomium splendens				2		3	2	2				2	2	2			2		3
Ditrichum flexicaule				2			2		2	3			2	1	2				
Drepanocladus revolvens							1	1	2										1
Mnium longirostrum				1		1				2			1			1			
Cladonia subrangiformis					2		1	1			1	1				1			
Acrocladium cuspidatum					1														1
Primula farinosa						2													
Carex hostiana						2						2							
Cladonia pocillum						1													
Atrichum undulatum						1							2	1					
Scapania aspera						2													
Helianthemum nummularium							4	1			3		1	1		2	2		
Galium boreale							1												
Plantago major							1												

Figure III (cont.)- Raw data collected during the present survey from areas originally mapped as Nodum 21 (Jones and Bradshaw 1979).

Vegetation Nodum 21	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543
Agrostis tenuis	3	2	1	2	2		4				1				4	3	4	3	2
Agrostis stolonifera	1		3											3	1	2	3	2	
Danthonia decumbens	2	2			2	2		2				2		3	1			2	2
Deschampsia cespitosa						1	2						2	3				2	
Koeleria macrantha		2	3		2	1		3		4			1		2		3	3	
Luzula campestris	2							1		1	1				1	1	1		1
Anthoxanthum odoratum		3	3	3													2		
Poa annua																		3	
Trifolium repens	2			2	3	2	3	2	1	2	3	3	3	3	4	2	2	2	
Alchemilla glabra	1	1	1	1	2	1	1	1	1										
Linum catharticum			1		1			2				2					1		
Festuca rubra	2				1								2		2				
Campanula rotundifolia	2		2			3		1		2	3	2	1		3	2	2		1
Nardus stricta	3																		
Carex lepidocarpa	1		2																
Rhacomitrium canescens	2		1		2				2		3	2		1				2	
Rhacomitrium lanuginosum								1					1		2	2	2		
Rhytidiadelphus triquetrus	3	2	2	3		2	2	2	2	1	1								
Rhytidiadelphus squarrosus	3	2	2	2		3	2	2	2	2	2	3	2	4	2		2		2
Rhytidiadelphus loreus												1							
Ctenidium molluscum	2	3	3		3	2		2	4	3	2	1	2		2	2	2		
Hypnum jutlandicum	2					2		3											
Pseudoscleropodium purum	3					1													1
Polytrichum formosum	2				2	3					1	2							
Pleurosium schreberi	2		1							2									
Acrocladium cuspidatum	1					1	1	2					2	3					
Hypnum lacunosum	2	3	2	3	2	3	2	2	2	3	3	1	3	3	3	1	2		3
Fissidens adianthoides	1																		
Plantago maritima		3	3	2	2	2			2					2				3	

Figure III (cont.)- Raw data collected during the present survey from areas originally mapped as Nodum 21 (Jones and Bradshaw 1979).

Vegetation Nodum 21	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543
Minuartia verna							1			1				1	1				
Veronica officinais							1												
Cladonia rangiformis							1				1	1					2		
Cladonia pocillum							1	1				1			1	1			1
Geum rivale								1											1
Fissidens adianthoides								2					1						
Peltigera canina									1			1			1	1	1		1
Cetraria islandica									1					1					1
Calluna vulgaris											1			1	1				
Antennaria dioica											3	2							1
Galium verum												1							
Cornicularia aculeata								1			1	1			1				1
Cladonia arbuscula												1							
Asplenium viride															2	2	1		
Riccardia pinguis																1	1		
Cirsium palustre																	1		

Figure III (cont.)- Raw data collected during the present survey from areas originally mapped as Nodum 21 (Jones and Bradshaw 1979).

Vegetation Nodum 29	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580
Festuca ovina	7	7	6	6	5	7	8		7	6	7	7	7	6	7	9
Galium saxatile	4	3	5	5	6	4	3	3	3		4	4	4	4	5	3
Deschampsia flexuosa	4		3		1			4	3	6	2	2			2	3
Rhytidiadelphus squarrosus	4	5	4	4	3	2	3	3	3		3	4	4	4	3	4
Nardus stricta	5	5	3	3	2	6	5	6	6	4	7	7	7	6	7	5
Eriophorum angustifolium	3	2	2	2	2	1	1									
Scirpus cespitosa				2												
Anthoxanthum odoratum	1		1	2	3	4	3				2	2	2	2		3
Carex echinata	2							1	3		1		2			
Juncus squarrosus	4	4	4	3	5	4	4	6	5	6	5	5	3	6	6	3
Pleurosium schreberi	3	3	2	2				2			3	4	2	2	3	3
Hypnum jutlandicum	3			2		3	2	1	3	3			4	2	2	
Polytrichum commune			3			4	2	2	1	3			1	2	3	3
Polytrichum juniperum	3															
Polytrichum formosum											2	1				
Vaccinium myrtilis		3				2	2					1				
Agrostis canina		3	3	2		2	3					2	3	3	3	3
Agrostis stolonifera												2	2			
Luzula campestris		3	2	2	1	2		2	2		3	3	2	2	2	2
Potentilla erecta		1									1	1	1	1		4
Eriophorum vaginatum			1				2	1								
Calluna vulgaris						1	2									
Sphagnum capillifolium						1										
Carex panicea			2					1		3		2				
Tortella tortuosa						1					1					
Thuidium tamariscinum						2		2								2
Lophocolea bidentata						2				3						
Mnium hornum						1		1			2					

Figure IV - Raw data collected during the present survey from areas originally mapped as Nodum 29 (Jones and Bradshaw 1979).

Vegetation Nodum 29	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580
Sphagnum recurvum							2									
Empetrum nigrum							2									
Plagiothecium undulatum							1	3	3	4	2		1	2	3	
Calypogeia trichomanes							2							2		
Acrocladium stramineum							2									
Cladonia arbuscula								1				2				
Cornicularia aculeata												1				
Poa annua									3							
Carex demissa																2
Carex nigra						1						1	2			
Molinea caerulea				2							2	2				1
Rhytidiadelphus loreus								1								2
Pohlia nutans																2
Hylocomium splendens											2	2			2	
Pseudoscleroodium purum											2					
Drepanocladus fluitans											1					
Dicranum scoparium											2			1		
Vaccinium myrtillus												1				
Lophozia ventricosa															2	
Bryum pseudotriquetrum																2

Figure IV (cont.) - Raw data collected during the present survey from areas originally mapped as Nodum 29 (Jones and Bradshaw 1979).

Vegetation Nodum 33	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560
Galium saxatile	3	3		3	3		3	3	3	3	4	4		2	5	5
Cladonia arburscula	3	2		1	2	1									3	4
Cladonia uncialis	2	3		1	1			1							1	
Cladonia chlorophaea	1			1	1											
Cladonia subrangiformis	2	1	2	3	1	1	2		1	1		2		2	4	4
Cladonia chloreocraea													1			
Cladonia macilenta															1	
Nardus stricta											6	2			3	6
Alchemilla glabra					1											
Achillea millefolium	3	3	3	3	3	3	2	2	2	3				1		
Trifolium repens	4	4	3	4	4	4	4	4	3	2		1	2	1		
Viola lutea	3	3	3	2	2	2	3	3	2	3	1	2	1	2		
Viola riviniana	2	3	2	2	3				1			2	2	3		
Luzula campestris	2	3	3	3	3	2		3		3	2	1			2	1
Lotus corniculatus	2		1		2				3	1						
Carex caryophyll	3	2	2	2	2								2			
Carex flacca													3	3	2	
Hieracium pilosella	2			1	1	1				1						
Pleurozium schreberi	3	3	3	1	3			3				2	1		3	3
Hypnum jutlandicum	4		3	2	2			3	2	2	3	1	1			3
Hypnum lacunosum												2	2	3	2	
Thymus drucei	2	3	2	4	2	4	3		3	3		2	3	3		
Cladonia furcata	1															
Agrostis tenuis	3	3	3	3		4	4	4	4	4		4	4	3		
Agrostis stolonifera		2		2				1	1							
Agrostis canina																2
Briza media	4		4	4	4									1		
Danthonia decumbens						2	2	2		3		2	2	3		

Figure V - Raw data collected during the present survey from areas originally mapped as Nodum 33 (Jones and Bradshaw 1979).

Vegetation Nodum 33	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560
Carex panicea											2					
Carex echinata											1					
Carex pulicaris											2					
Festuca ovina	9	9	8	8	8	9	9	9	8	9	8	8	8	8	7	5
Hylocomium splendens	2	3	3	1			3	3			2	2	3	3		1
Rhytidiadelphus squarrosus	3	3	3		3	2	3	3	3	2	3	3	2	2	2	3
Diplophyllum albicans					2											3
Rhytidiadelphus loreus		2	1	2	1	1										
Rhacomitrium lanuginosum				2	2	1			1				2	1		
Polytrichum formosum	1	4	2	2	2			1	2	2	2	1	1	2	3	
Polytrichum piliferum	1			2												
Dicranum scoparium	1				1	1	2	2	1		1	1		1	1	
Barbilophozia floerkei	1	1			1											3
Pseudoscleropodium purum												2	1	3	2	
Climacium dendroides												1	1			
Ranunculus acris		1		1					1							
Botrychium lunaria			2			1										
Euphrasia officinalis agg.			2	2	2				1	1		1	1	2		1
Acrocladium cuspidatum			2													
Selaginella selaginoides				2	2				1	1						
Prunella vulgaris				1	1	2	1		2	2				1		
Plantago lanceolata				2					2			1	1			
Potentilla erecta				1	1						3	1	1			1
Cerastium holostioides				1		1			1			1				
Thuidium tamariscinum				2		1										
Mnium hornum				2	2											
Mnium longirostrum				1	1											
Atrichum undulatum									1							

Figure V (cont.) - Raw data collected during the present survey from areas originally mapped as Nodum 33 (Jones and Bradshaw 1979).

Vegetation Nodum 33	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560
Cetraria islandica				1												
Lophocolea bidentata	2			1												
Dicranella heteromalla				1												
Plagiomnium undulatum				1		1										
Cornicularia aculeata				1	1											
Campanula rotundifolia					3			2	1			1	2	3	1	
Polygala serpyllifolia					1						2					
Vaccinium myrtillus						2									2	1
Carex pilulifera	3			2	3		3		3		4	3	3	3	2	
Anthoxanthum odoratum							4	2		2	2					
Deschampsia flexuosa							2	2				3	2	2	1	
Peltigera canina									1							
Cirsium vulgare													1			
Cirsium palustre													1			
Gentiana verna													1			
Juncus squarrosus															1	3

Figure V (cont.) - Raw data collected during the present survey from areas originally mapped as Nodum 33 (Jones and Bradshaw 1979).

Vegetation Nodum 23	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619
Calluna vulgaris	4		4	5	2	5	6	5	6	4	2	8	8	8	9
Erica tetralix	4			4		2	3	3	2	3	1	2	2	2	
Eriophorum vaginatum		3	2	5	4		2				3	2	3	2	
Eriophorum angustifolium	3	1	2		3	2	3	2	3	2	2	3	2	1	3
Sphagnum cuspidatum	4	6	4		4	3	3		2	8				4	
Sphagnum papillosum	5	5	6	5	6	4	3		5	4	7		2	6	
Polytrichum commune	3		4							3	3			2	
Calypogeia trichomanis	2														
Rhacomitrium lanuginosum	2		2		3	2									
Juncus squarrosus	2		3			3	2	3	2					3	
Sphagnum recurvum	4	4												2	
Cladonia impexa						3	1								
Cladonia uncialis	3														
Empetrum nigrum	2		2	3	2	2	1			2				1	2
Narthecium ossifragum	2					3	2	3	3		2				
Sphagnum capillifolium		3	3			3	4	5	2	2	2	2	3	5	
Sphagnum tenellum		5		6	5	4	4	5	5		2		1		
Nardus stricta			3	4				2	2	2	2	4	5		3
Sphagnum magellanicum			4			4									
Scirpus cespitosa			3			5	3	8	6	4	3	5	3	2	4
Cladonia arbuscula						2		2							
Hypnum jutlanticum						4	3	4	4	2			1		3
Cladonia furcata	3					2							1		
Cladonia squamosa												1	1		
Pleurosium schreberi						1						1			3
Sphagnum compactum		5				4				3					
Carex panicea											2				
Carex echinata											3	1	1		

Figure VI - Raw data collected during the present survey from areas originally mapped as Nodum 23 (Jones and Bradshaw 1979).

Vegetation Nodum 23	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619
Campylopus flexuosus						2						3	3		
Rhytidiadelphus squarrosus												1			
Rhytidiadelphus triquetrus															2
Lophocolea bidentata													2		
Sphlachnum ampullaceum												2			
Diplophyllum albicans												1	2		
Plagiothecium undulatum						1						1	1		3
Odontoschisma sphagni												1	2		
Agrostis canina													1		
Cephaloziella hampeana						1		1							

Figure VI (cont.)- Raw data collected during the present survey from areas originally mapped as Nodum 23 (Jones and Bradshaw 1979).

Vegetation Nodum 28	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517
Calluna vulgaris	8	7	8	8	9	9	9	9	8	9	9	9	8	8	9	8	8
Eriophorum vaginatum	6	5	5	3		3	3	3	3	3	4	2	7	7	3	4	3
Empetrum nigrum	4	3		3	2	2	2	2	3	2	2	2	2	2	2	3	2
Hypnum jutlandicum	3	3	3	4		4	5	4	5	5	5	4	2	3	3	4	4
Hylocomium splendens	2	1					2				3		2	2		2	2
Sphagnum capillifolium	3	4	3	3	3	2	2	3	3	3	3		4	3	2	3	3
Sphagnum papillosum	4	1	4	3				2	1				2				
Plagiothecium undulatum	2		2	1	1		3	5	4	5	3		3	1	2	4	1
Mylia anomala	2	1	1	2													
Sphagnum recurvum	2	2		3		2	3	3	3	2	3		4		3	1	1
Cladonia arbuscula	1					1									1		
Rubus chamaemorus	1					2		3				1				2	
Cladonia impexa	2	1												1			
Dicranum scoparium	2	2	1		1								1	2	2		
Eriophorum angustifolium		3	3		4	2					2	3				3	1
Sphagnum tenellum		2															
Erica tetralix		3	3											3			
Aulacomnium palustre		4	1		3								3	3	2		
Campylopus flexuosus		1												2			1
Scirpus cespitosa		2		2													
Cladonia uncialis		1	1														
Rhytidiadelphus squarrosus		3		2		2	3	4	2	2		4	2	2	3		4
Cladonia ciliata		1								1							
Sphagnum cuspidatum			1	1													
Lophozia ventricosa			1			1							2	2			

Figure VII - Raw data collected during the present survey from areas originally mapped as Nodum 28 (Jones and Bradshaw 1979).

Vegetation Nodum 28	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517
Polytrichum alpestre			1			2											2
Pleurozium schreberi			2	3	3	2	5	4	5	4	5	4		4	3	4	3
Vaccinium myrtilis				1	1	2	2	2	2	1	1	2				2	2
Rytidiadelphus loreus				2	3	1	2	4	4	4		4	2	2		3	2
Agrostis canina				1													
Carex echinata				1													
Acrocladium cuspidatum					2												2
Pohlia nutans			1			2							1				
Cladonia chlorophaea						1		1		1							
Cladonia squamosa		1				1	1					1					
Barbilophozia floerkei						2											
Vaccinium vitis-idaea							2										
Polytrichum commune										3	2		1	1	2	4	
Festuca ovina												2					
Odontoschisma sphagni														1			
Calypogeia trichomanes													1				
Parmelia physodes															1		
Deschampsia flexuosa																	2
Juncus squarrosus																	2
Carex nigra				2				1		1			2			2	

Figure VII (cont.)- Raw data collected during the present survey from areas originally mapped as Nodum 28 (Jones and Bradshaw 1979).

Appendix V

Details of the Arc-Info G.I.S. Methods and Problems Encountered

In the original thesis study of Widdybank Fell an aerial photograph of part of the study area was included from the time of the original survey (1969). As more recent aerial photographs (1989) are now available, an attempt was made to study the changing vegetation by comparing these photographs. This had the advantages of potentially being able to map larger areas, and to map areas more quickly than the ground surveying methods.

To utilise computer facitities in comparing the photographs it was first necessary to digitise the images to be compared into a format which could be processed by such packages. The photographs used were a 1:7,500 black-and-white photograph from the time of the original survey and a recent similar photograph at a scale of 1:11,000. The area used in the photographic analysis was chosen as it included the entire range of vegetation types present on the fell.

The two photographs were converted into digitised binary format for subsequent computer analysis by scanning the photographs at a resolution of 600 dots per square inch and then converting these scanned images to appropriate file format. The resolution used in scanning the photographs was considered the most appropriate to give the maximum detail, taking into account the grain of the photographs.

Following the conversion of the two photographs to utilisable format for analysis, it was neccesary to adjust the two images to the same scale and alignment. This was done in the Arc-Info Geographical Information System using the REGISTER and RECTIFY commands. Twelve figure grid references were obtained for this process from static features on the large scale vegetation maps of the fell (Bradshaw and Jones 1976). Such features when located on the images allowed accurate alignment and scaling (errors were generally less than five metres). Further analysis required conversion of the now identically scaled and orientated images into a suitable grid format. This was done using the IMAGEGRID command in Arcplot. The images were then available for viewing and manipulation in Arc-Info.

It was intended that, through the use of analysis tools in Arc-Info, it would be possible to both re-map the different vegetation communities, and also to indicate areas of change.

In order to try and re-map the vegetation communities an attempt was made to convert the grid images into polygon coverages, using the GRIDPOLY command in Grid. It was hoped that this would create polygons using the vegetation boundaries and hence outline the limits of the communities. The grid images were first “cleaned up” using the MAJORITYFILTER tool to create a less broken image by smoothing grey-scale pixels, and the BOUNDARYCLEAN tool to make the boundaries more crisp and better defined. This technique of using Arc-Info to define boundaries failed as the GRIDPOLY tool can only produce a maximum of 10,000 arcs. Bands of grey scale colours were coarsely grouped together (using the GRIDSLICE tool) to overcome this problem but computer memory proved insufficient to analyse even these simplified images.

Images were produced composed of five, eight and sixteen grey-scale bands rather than the original 256 in order to assess which was most comparable to actual vegetation types. Visual examination of these modified images showed banding together of various shades within a community to produce a more uniform image for analysis. It was noticed that different outputs, sliced to different degrees from a single image, were better than others in picking out particular community boundaries. Hence the images split into five bands were quite good at picking out the heather-grassland boundaries and subtle boundaries of paler parts of the image whilst images sliced to a greater extent proved better at differentiating between other boundaries. Bearing in mind the varying suitability of the different images to separating different communities, it was decided that a method of re-mapping the community boundaries by hand would be most appropriate. This allowed the communities to be re-mapped using information gleaned from a combination of the sliced image maps.

A direct approach to analysing the changes which had occurred between the time of the earlier and later image was also attempted using the available Arc-Info analysis tools. Here the two grid images were retained in their original format and attempts were made to perform mathematical analyses between the two images so as to highlight areas of change. The two images were subtracted from each other on a cell by cell basis so that the resultant cell values would be zero for areas of no change and either high positive or negative values for the areas of most change. By squaring and then square-rooting these values the negative numbers were converted to positive numbers so areas of most change would be represented by large positive numbers and those of least change by smaller positive numbers. By plotting the resultant image on a grey scale it was then possible to see the areas of most change. However this analysis was unsucessful due to the varying exposure, contrast and colour balance of the two photographs. The most over-riding changes as a result of the dam being flooded resulted in the more subtle vegetation changesbeing less noticable.

A similar analysis was attempted using the LESS-THAN and GREATER-THAN tools in Grid to see which areas had become lighter or darker in the latter image. This technique however had similar problems to those mentioned above.

Appendix VI

Dendrogram of the Zurich-Montpellier classification of the original data set , by Jones (1973).

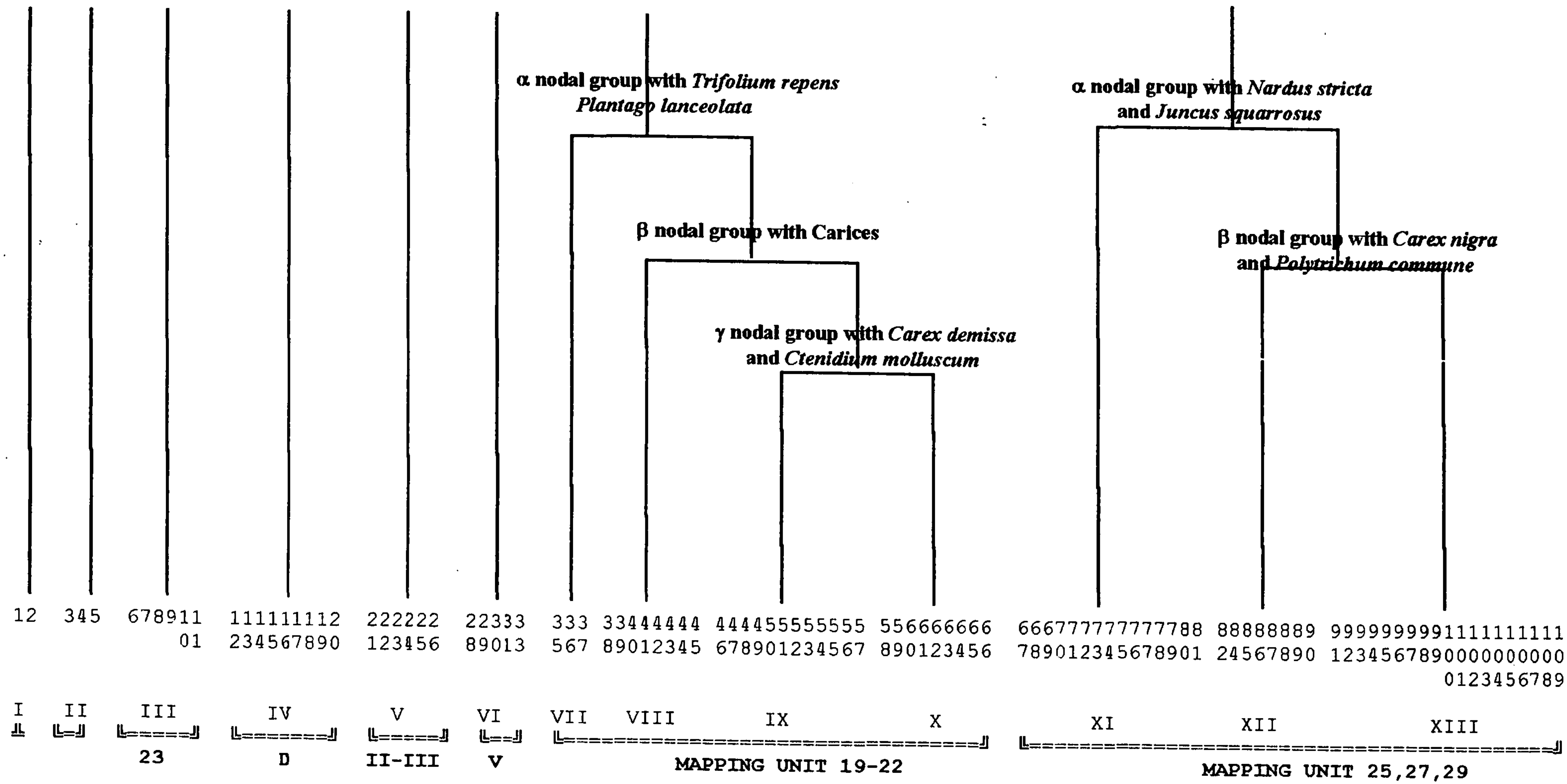

Figure VIII - Dendrogram depicting the various divisions in the Zurich-Montpellier classification of Jones (1973). Numbers immediately below the dendrogram refer to quadrat numbers as defined in Table 1.1. Roman numerals below these represent the various end noda (see key after the figure). Mapping units refer to those originally defined by Jones and Bradshaw (1976).

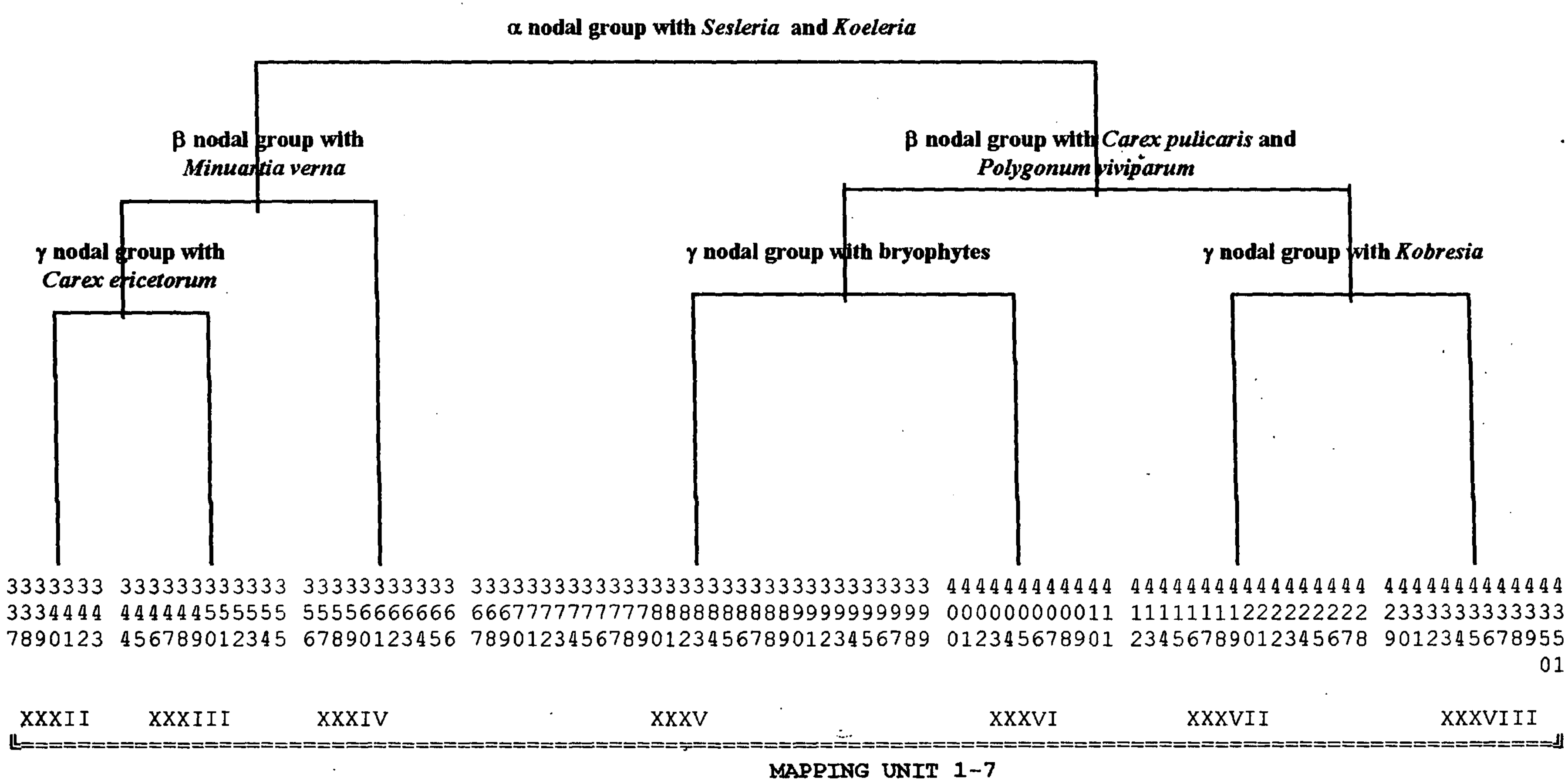

Figure VIII (cont.) - Dendrogram depicting the various divisions in the Zurich-Montpellier classification of Jones (1973). Numbers immediately below the dendrogram refer to quadrat numbers as defined in Table 1.1. Roman numerals below these represent the various end noda (see key after the figure). Mapping units refer to those originally defined by Jones and Bradshaw (1976).

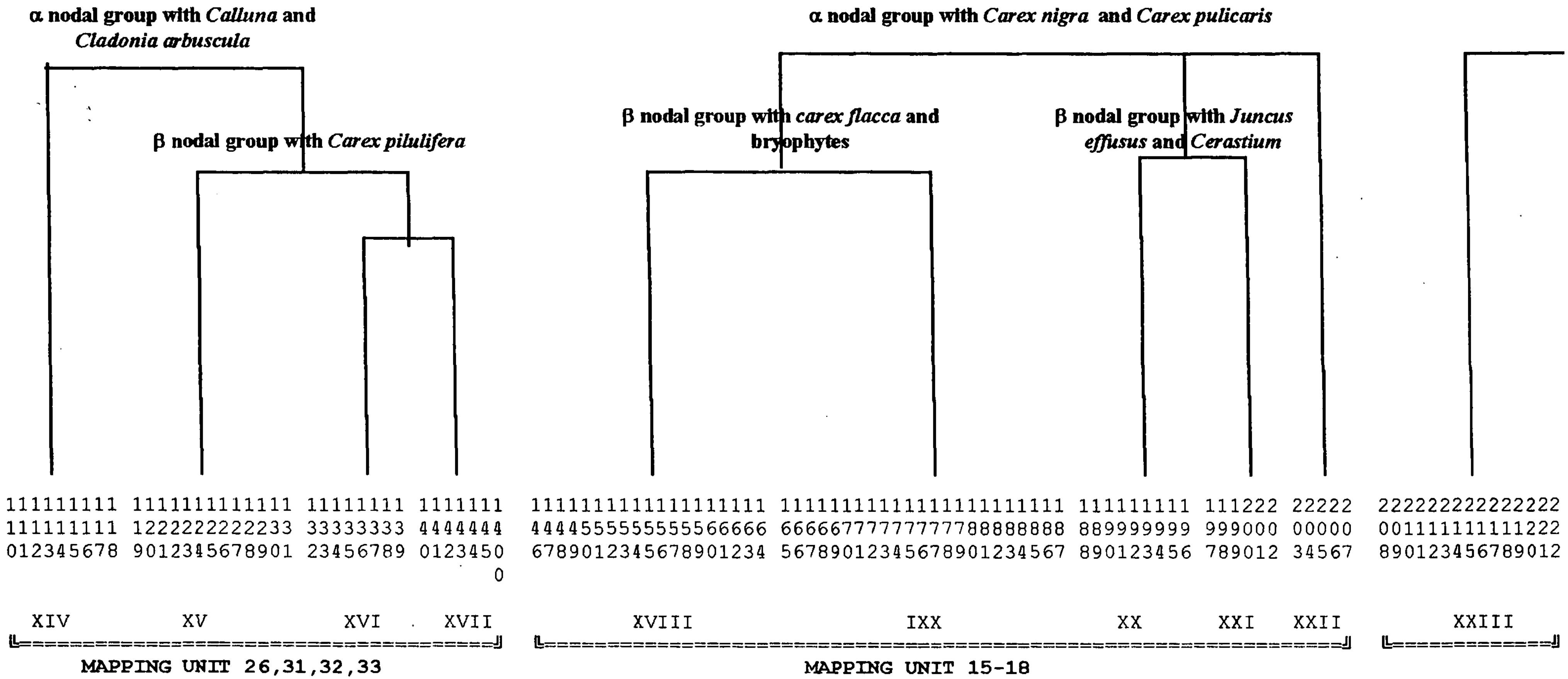

Figure VIII (cont.) - Dendrogram depicting the various divisions in the Zurich-Montpellier classification of Jones (1973). Numbers immediately below the dendrogram refer to quadrat numbers as defined in Table 1.1. Roman numerals below these represent the various end noda (see key after the figure). Mapping units refer to those originally defined by Jones and Bradshaw (1976).

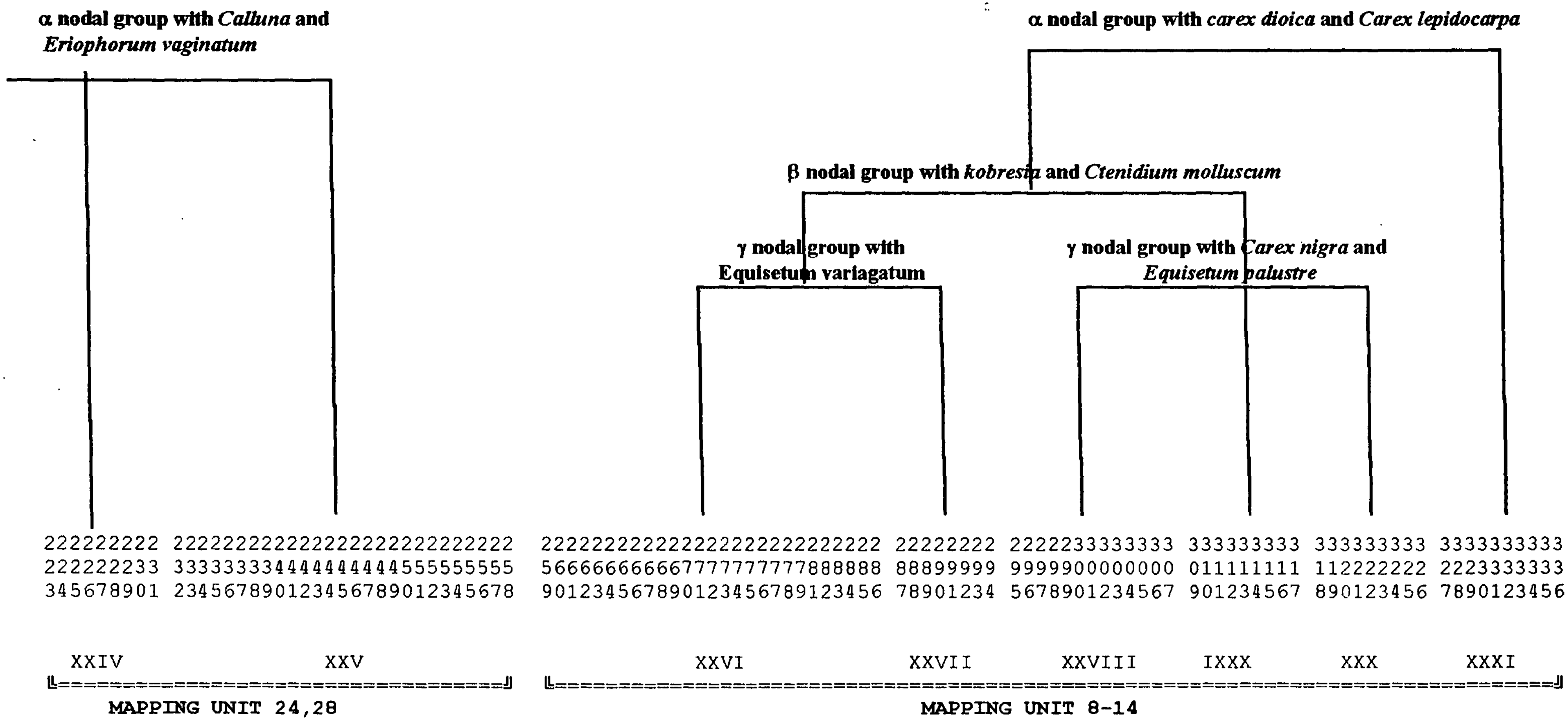

Figure VIII (cont.) - Dendrogram depicting the various divisions in the Zurich-Montpellier classification of Jones (1973). Numbers immediately below the dendrogram refer to quadrat numbers as defined in Table 1.1. Roman numerals below these represent the various end noda (see key after the figure). Mapping units refer to those originally defined by Jones and Bradshaw (1976).

Key to the end noda produced in the phytosociological table above (from Jones 1973)

I - Nodum of Whin Sill block scree
II - Community fragments
III - Nodum with *Erica*
IV - Nodum with *Cardemine* and *Cratoneuron commutatum*
V - *Juncus effusus* &/or *Carex rostrata* dominated mires
VI - Nodum with *Minuartia verna* and *Trifolium repens*
VII - Nodum with *Galium saxatile*
VIII - Nodum with *Carex caryophyllea*
IX - Nodum with *Sesleria*
X - Nodum with *Cardemine*
XI - Nodum with *Erica tetralix* and *Carex dioica*
XII - Nodum with *Eriophorum vaginatum*
XIII - Nodum with *Galium saxatile* and *Sphagnum papillosum*
XIV - Nodum with *Empetrum* and *Erica tetralix*
XV - Nodum with *Pteridium* and *Deschampsia flexuosa*
XVI - Nodum with *Viola rivinialis*
XVII - Nodum with *Danthonia decumbens*
XVIII - Nodum with *Cratoneuron filicinum* and *Equisetum variegatum*
IXX - Nodum with *Ranunculus flammula* and *Carex echinata*
XX - Nodum with *Trifolium repens*
XXI - Nodum with *Viola palustris*
XXII - Nodum with *Potamageton polygonifolious*
XXIII - Nodum with *Narthecium* and *Tricophorum*
XXIV - " " " " " "
XXV - Nodum with *Empetrum* and *Sphagnum recurvum*
XXVI - Nodum with *Sesleria*
XXVII - Nodum with *Juncus triglumis*
XXVIII- Nodum with *Molinea caerulea* and *Eriophorum latifolium*
IXXX - Nodum with *Nardus stricta* and *Carex demissa*
XXX - Nodum typicum
XXXI - Nodum with *Gymnostomum*
XXXII - Nodum with *Kobresia*
XXXIII- Nodum with *Rhytidium*
XXXXIV- Nodum typicum
XXXV - Nodum with *Palantago lanceolata*
XXXVI - Nodum with *Calluna*
XXXVII- Nodum typicum
XXXVIII Nodum with *Primula farinosa*

Appendix VII

Figure IX - Simple diagrammatic representation of the dendrogram drawn in Figure 3.6. This diagram shows the various divisions used in adding the quadrats from the present data survey to the Twinspan classification of the original data. This additional data was added by hand using identical criteria to that of the original analysis. Indiocator species and cut levels are also provided for each division.

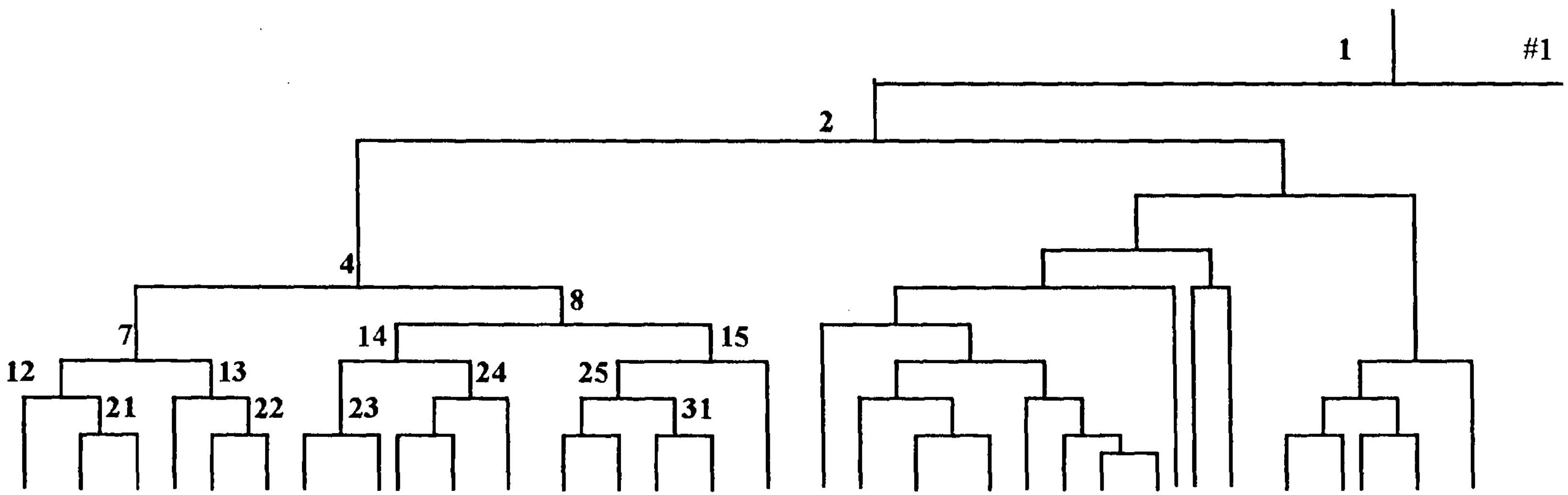

Figure IX - Simple diagrammatic representation of the dendrogram drawn in Figure 3.6. The numbers alongside divisions show the various divisions which were utilised in the hand Twinspan classification of the quadrats from the present survey. The indicator species along with the positive and negative group cut levels for each of these divisions is provided in the key at the end of this figure.

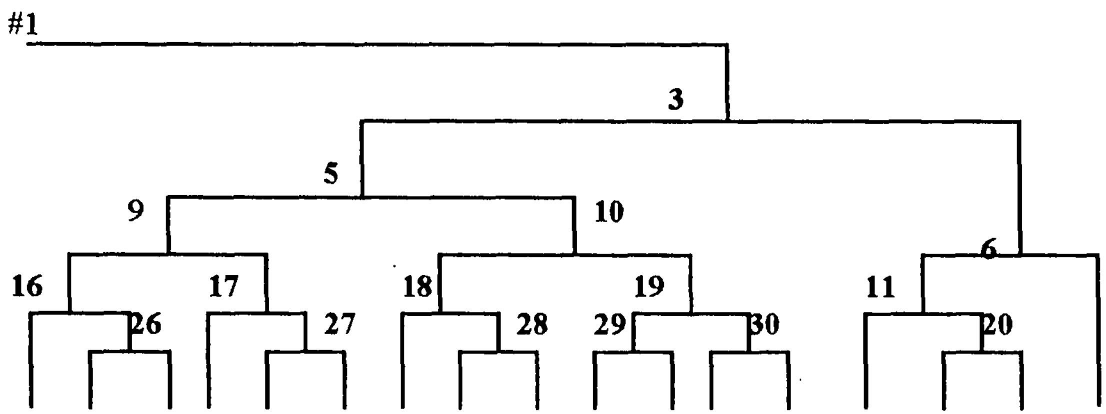

Figure IX (cont.) - Simple diagrammatic representation of the dendrogram drawn in Figure 3.6. The numbers alongside divisions show the various divisions which were utilised in the hand Twinspan classification of the quadrats from the present survey. The indicator species along with the positive and negative group cut levels for each of these divisions is provided in the key at the end of this figure.

Key to the Indicator Species and Cut Levels used in allocating the quadrats from the present data set, by hand, to the modified Twinspan classification

Division 1
Call vulg 2(+) Erio angu 2(+)
Spha papi (2(+) Erio vagi 2(+)
Eric tetr 2(+) Scir cesp 2(+)
Nart ossi 2(+) Spha capi 2(+)
Poly comm 2(+) Sesl albi 2(-)
Care pani 2(-) Care flac 2(-)
Sela sela 2(-) Care dioi 2(-)
Max. Ind. Score For Negative Group 0
Min. Ind. Score for Positive Group 1

Division 2
Thym prae2(-) Care dioi (+)
Sesl albi (-) Junc arti(+) Camp rotu (-)
Erio angu(+) Clad subr (-)
Fest ovin 3(-) Koel macr (-)
Max. Ind. Score For Negative Group -1
Min. Ind. Score for Positive Group 0

Division 3
Eric tetr2(+) Scir cesp3(+)
Nart ossi2(+) Erio vagi2(+)
Nard stri2(-) Spha papi2(+)
Spha capi2(+)Erio angu2(+)
Hypn jutl2(-) Pote erec2(-)
Gali saxa2(-)
Max. Ind. Score For Negative Group 1
Min. Ind. Score for Positive Group 2

Division 4
Gali saxa (-) Sesl albi (+)
Linu cath (+) Scap aspe (+)
Euph offi (+) Cten moll (+)
Agro capi (-) Hypn Jutl 2(-)
Max. Ind. Score For Negative Group -2
Min. Ind. Score for Positive Group -1

Division 5
Poly comm2(+) Call vulg3(-)
Care nigr2(+) Junc squa2(+)
Spha recu2(+) Hypn jutl3(-)
Erio angu2(+) Agro cani2(+)
Aula palu2(+) Spha papi2(+)
Eric tetr2(-)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 6
Scir cesp2(-) Nart ossi2(-)
Empe nigr2(+) Erio vagi4(+)
Caly tric2(+) Spha capi3(+)
Call vulg4(+) Spha recu2(+)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 7
Prun vulg (+) Loph bide (+)
Pleu schr (-)
Max. Ind. Score For Negative Group
0
Min. Ind. Score for Positive Group 1

Division 8
Rhac lanu 2(+) Care puli (-)
Agro capi (-) Rhyt squa (-)
Pote erec 2(-) Ranu acri (-)
Trif repe (-) Hylo sple (-)
Viol rivi 2(-) Prun vulg 2(-)
Max. Ind. Score For Negative Group -4
Min. Ind. Score for Positive Group -3

Division 9
Eric tetr2(+) Nard stri2(+)
Gali saxa2(-) Care pani2(+)
Scir cesp2(+) Care pilu2(-)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 10
Nard stri2(-) Spha recu3(+)
Junc squa2(-) Pote erec2(-)
Moli caer2(-) Call vulg2(+)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 11
Epil obsc2(-)
Max. Ind. Score for Negative Group -1
Min. Ind. Score for Positive Group 0

Division 12
Briza media (+) C;ad subr (+)
Max. Ind. Score For Negative Group 2
Min. Ind. Score for Positive Group 3

Division 13
Fest ovin (+)
Max. Ind. Score For Negative Group 0
Min. Ind. Score for Positive Group 1

Division 14
Koel macr (+) Camp rotu 2(+)
Care cary (+) Cten moll (-)
Call cusp (-) Care demi (-)
Fest rubr (-) Prun vulg 2(-)
Desc cesp (-)
Max. Ind. Score For Negative Group -3
Min. Ind. Score for Positive Group -2

Division 15
Cryp cris (+)
Max. Ind. Score For Negative Group
0
Min. Ind. Score for Positive Group 1

Division 16
Hupe sela2(-)
Max. Ind. Score for Negative Group -1
Min. Ind. Score for Positive Group 0

Division 17
Camp para2(-) Call vulg5(-)
Pote erec2(+) Moli caer2(+)
Raco lanu2(+) Scir cesp3(-)
Care dioi2(+)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 18
Moli caer3(-) Rhyt lore2(-)
Scir cesp2(-)
Max. Ind. Score for Negative Group -2
Min. Ind. Score for Positive Group -1

Division 19
Call vulg2(-) Gali saxa2(+)
Max. Ind. Score for Negative Group -1
Min. Ind. Score for Positive Group 0

Division 20
Junc squa2(-)
Max. Ind. Score for Negative Group -1
Min. Ind. Score for Positive Group 0

Division 21
Anth odor (+)
Max. Ind. Score For Negative Group 0
Min. Ind. Score for Positive Group 1

Division 22
Agro cani (-)
Max. Ind. Score For Negative Group -1
Min. Ind. Score for Positive Group 0

Division 23
Linu cath (-) Kobr simp (-)
Prim fari (-) Clad impe (-)
Care host 3(-) Care pani 3(-)
Max. Ind. Score For Negative Group -3
Min. Ind. Score for Positive Group -2

Division 24
Call vulg (+) Pleu schr (+)
Rhyt lore (+) Prun vulg (-)
Trif repe (-) Cera font (-)
Achi mill (-)
Max. Ind. Score For Negative Group 0
Min. Ind. Score for Positive Group 1

Division 25
Prim fari (+) Kobr simp (+)
Cten moll 3(+) Cera font (+)
Pote erec 2(+)
Max. Ind. Score For Negative Group 2
Min. Ind. Score for Positive Group 3

Division 26
Call vulg2(-)
Max. Ind. Score for Negative Group -1
Min. Ind. Score for Positive Group 0

Division 27
Spha recu2(+)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 28
Gali saxa2(+) Moli caer2(-)
Rhyt squa2(+) Care echi3(-)
Pote erec3(-) Poly comm4(+)
Plag undu3(+) Junc effu2(+)
Pleu schr2(+) Agro stol2(+)
Ptil cili2(+)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 29
Agro stol2(+)
Max. Ind. Score for Negative Group 0
Min. Ind. Score for Positive Group 1

Division 30
Agro cani2(-)
Max. Ind. Score for Negative Group -1
Min. Ind. Score for Positive Group 0

Division 31
Koel macr (-) Viol rivi (-)
Hypn cupp (-) Poly vivi (-)
Aneur ping (+) Camp rotu (-)
Max. Ind. Score For Negative Group -2
Min. Ind. Score for Positive Group -1