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DECLARATION:

This work has not previously been accepted for any degree and is not being concurrently submitted for any degree.

Signed……………………………

Date…… 10th Sept 04 ……

STATEMENT 1

This thesis is the result of my own investigation, except where otherwise stated. Other sources are acknowledged by explicit references. A full reference list is appended.

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I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

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Acknowledgements

Many thanks to all those who helped me with the research and writing of this thesis:

UWCN:
Dr. Hilary Thomas for help and advice

Forestry Commission:
John Harvey, Peter Kelsall, Dr Andrew Moffat and Dr David Fourt

The Forest of Dean Heritage Centre:
Kate Biggs & staff

Personal:
The Fletchers and Bakers for helping me though the bad times, particularly Rich, Anne, Will, John and Sal. Thanks also to friends, colleagues and flatmates –Elle, Simon, Alex, Alison, Justin, John, Ruth, Ruaridh, Jim, Lauren, Jess & Ian, Harry, Sean, with special thanks to Dr Kerry Curran.

Title:

The colonisation by vegetation of colliery spoil heaps in the Forest of Dean, Gloucestershire, and implications for biodiversity management.

Summary:

In the Forest of Dean Coalfield industrial activities have created a landscape where colliery spoil heaps have ecological, cultural, historical and amenity interest. Sensitive management of the sites is therefore important. The study aims to provide information relevant to their conservation management. This is particularly valuable due to the cull of all 'free-roaming' Forest sheep following Foot and Mouth Disease (2002).

A chronosequence was constructed by applying selection criteria to more than 30 spoil heaps of different ages. On the 36-year site, one grazed plot was selected and one enclosed plot. Floristic and environmental data (pH, pyrites content, slope factor and aspect, canopy cover and plant vigour) were collected from 8 plots ranging 0-100 years since disturbance. Correlation analysis was used to identify potential relationships between the vegetation and environmental data. Floristic data were analysed using complementary multivariate analysis techniques, TWINSPAN and DCA. Mean (S)/quadrat and Shannon 'E' diversity indices were calculated.

Succession was measured using a series of 'expected trends'. Species-richness increased over time until 60 years since disturbance, but the species-evenness pattern did not appear to be affected by time or pH. The bryophyte layer colonised plots over 16 years since disturbance rather than starting the succession, and its abundance appeared to be affected by aspect more than age.

On the 36-year site, the grazed plot had developed a higher species diversity that the non-grazed plot, but woody species were starting to colonise. Temporary exclusion of grazing was recommended on plots vulnerable to disturbance in order to reduce additional pressures from grazing. However, management techniques would still be required on sites valued as open grassland or heathland habitats to prevent potential colonisation by woody species.

Key words: Plant succession, primary succession, chronosequence, derelict land, colliery spoil, Forest of Dean, nature conservation, biodiversity, species diversity, species-area effect.

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Chapter 1.0: Introduction

This chapter sets out the aims and objectives of the research study. It introduces the study area in terms of location, geology, industrial history, and the resulting spoil heaps. Plant succession is defined, together with a discussion of the application of the study for practical purposes.

1.1. Aims and objectives

This study examines the vegetation and environmental factors present on a unique landscape feature of the Forest of Dean - a series of colliery spoil heaps dating from the 19th century to the present day. Some of these spoil heaps have naturally re-vegetated, and can be considered to be a visually attractive or 'neutral' feature of the landscape (Section 1.3). These features may also serve to remind people of the area's industrial history (Section 1.3.3). However, other spoil heaps have recently been disturbed and present problems as derelict land, and can be visually 'negative' landscape features. An opportunity is therefore presented to undertake research on the colonisation and successional processes occurring on spoil heaps of different ages, to examine the underlying environmental gradients that may be influencing the vegetation composition, and to discuss how these sites may be managed for nature conservation. This study will therefore address the following aims and objectives:

1.1.1. Aims

To collect floristic and environmental data on the Forest of Dean spoil heaps in order to examine how the environmental gradients may influence floristic composition. To place the vegetation processes occurring on these spoil heaps in a wider context by relating the findings to successional theory and to previous studies undertaken on colliery spoil. To produce recommendations regarding the management of vegetation on colliery spoil for nature conservation.

1.1.2 Objectives

i) Review previous studies of plant succession on colliery spoil, and identify through this review environmental gradients likely to be present at the sites

ii) Identify and select sites within the study area to form a time-series suitable for the study of vegetation succession

iii) Implement a suitable experimental design at each of the selected study sites

iv) Collect floristic data from within the framework of the experimental design at each site together with environmental data such as aspect, slope factor, pH and pyrites

v) Identify appropriate statistical methods to analyse the floristic and environmental data provided by iii) and iv)

vi) Examine the results in relation to previous studies of plant succession on colliery spoil

vii) Use the findings of the study to make management recommendations for nature conservation

1.2 Study location

The focus of this study is the Royal Forest of Dean, Gloucestershire, the location of which is shown in Figure 1.1a. The term “Forest of Dean” can refer either to an administrative county district, or to a region within that district (Land Use Consultants, 1999). Within this study, the term “Forest of Dean” refers to the Royal Forest of Dean, demarcated in Figure 1.1b, which also encompasses the 85km^2 coalfield central to this research.

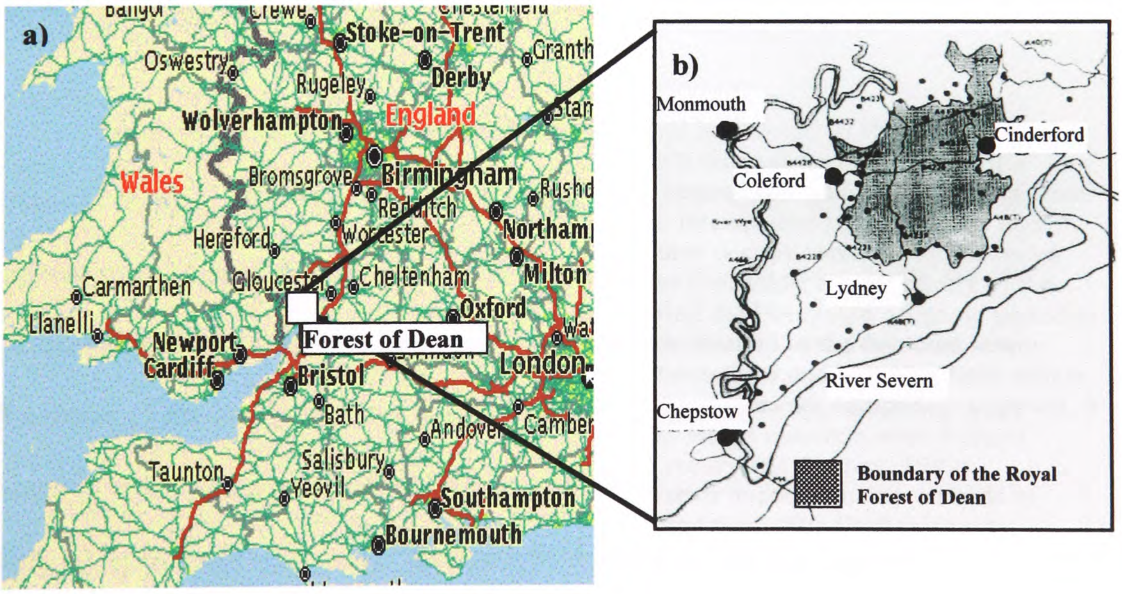


Figure 1.1

a) Location of the Forest of Dean within the UK
Source: (http:www.fweb.org.uk/deanframes/htm. Accessed 10.11.01)

b) Boundaries of the Royal Forest of Dean within a regional setting
Source: Land Use Consultants (1999)

A further useful demarcation is that of the "Dean Plateau and Wye Valley Natural Area" within which the Royal Forest of Dean lies. The Natural Areas project was created by English Nature (1999) for setting regional nature conservation objectives by dividing England into areas of similar wildlife, natural features, geology, land use patterns and land-use history rather than using administrative boundaries. The fact that the study area lies wholly within the same natural area is a factor influencing the choice of methodology used in this study, because it can be assumed that plant succession occurring on spoil heaps of different ages will have been subject to similar climatic, topographic, and geological processes. By minimising the variability of these environmental gradients, the effects of time can be isolated so that plant succession can be studied, as discussed further in Section 3.1.

1.3 Landscape and history

It is argued in this study that the post-industrial landscape of the Forest of Dean is unique, and that a more strategic and deliberate approach to the management of spoil heaps needs to be formulated because spoil heaps are an integral part of the landscape. Information on industrial history, the post industrial landscape of the Forest of Dean, and the 'value' or interest of the resulting spoil heaps in terms of amenity, cultural value, and nature conservation have therefore been included within this study. Background information such as geology, mining history, and the types of surfaces available for study is presented in Sections 1.3.1-1.3.3 to help put the study into context. Section 4.2 follows on from Section 1.3 with arguments as to why the spoil heaps are considered important within the

Forest of Dean landscape, and therefore why a study that aims to produce management recommendations for the spoil heaps is of value.

1.3.1 Geology

The Forest of Dean forms a saucer-shaped plateau of high land with elevated areas over 250m above sea level. As illustrated in Figure 1.2, this central plateau is a synclinal basin. The rocks that form the basin are mainly of Pennant sandstones, interspersed by coal seams and shales. These layers rest unconformably on Carboniferous Limestone. Iron-ore deposits are found in the limestone, formed during the Permian period (290-248 Ma ago) when desert conditions denuded the pyrites in coal seams and the ferrous carbonate in ironstone bands, giving rise to a surface rich in iron. Where the iron rich surface came into contact with the Carboniferous limestone, acidic iron-bearing solutions reacted with limestones to deposit haematite (Welch and Trotter, 1961).

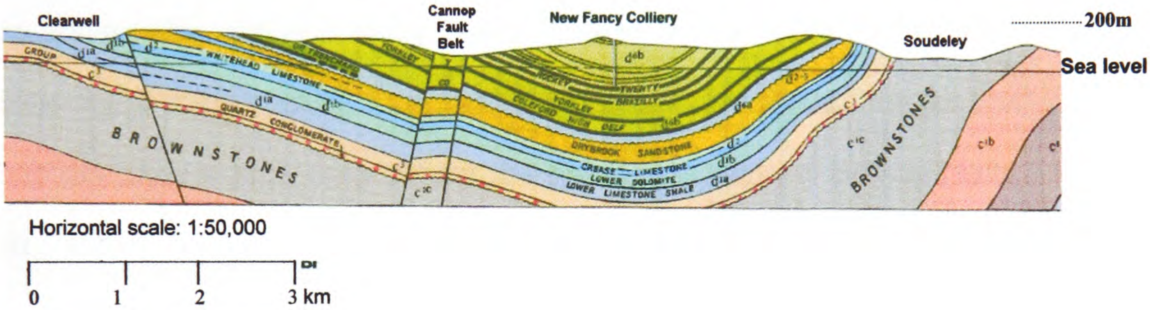


Figure 1.2: Geological profile of the Forest of Dean synclinal basin.

Source: British Geological Survey 1974, Sheet 233.

The Forest of Dean therefore has coal, iron-ore and stone resources all within a small 85km^2 area. As seen in Figure 1.2, the geological deposits and earth movements have resulted in the coal and iron-ore bearing limestone seams being exposed at the surface. As discussed further in Section 1.3.2 below, the accessibility of the resources facilitated their excavation long before the industrial revolution of the 18th Century and the advent of deep mining techniques, a contributory factor to the area's long industrial history.

1.3.2 Coal mining history

Coal shards dating to the Roman occupation (c. 4AD) have been found at an iron-working site near to the Forest of Dean at Woolaston (SO596 986), indicating that coal mining in the area may date to this period. Iron-ore was certainly being worked in the Dean at this period, with evidence including adits, slag, and smelting sites (Walters, 1992; Hart, 1971, 1968).

Written records show that coal was also being worked in the Forest of Dean in 1244 (Hart *op. cit.*). However, coal production increased in the 17th century due to demand from the local iron-smelting industry. The availability of deposits at the surface meant that coal was worked by shallow adits at this time. By the 18th century, mining technology had improved, and many new pits and levels were opened; over 100 coal works were recorded in 1788 (Hart, *op. cit.*). Due to the free-mining rights of the Foresters however, the mines remained relatively small-scale and locally owned during this period. Samuel (1977) considers this a fundamental difference from mine ownership patterns within neighbouring coalfields such as South Wales where 1 person could own several mines in an area. This person could therefore have a profound influence on both the working and living conditions of the miners.

Throughout the 19th century, deep-mining methods were developed and improved, and by 1900 the Dean coal industry produced over a million tons per year and employed some 3-5,000 men (Hart *op. cit.*). The mines at this time, such as Lightmoor, Cannop, and True Blue were larger than those of the 18th Century. The investment needed to modernise the mines lead to the amalgamation of ownership. These larger mines increasingly came under single or ownership by industrial entrepreneurs from outside the Forest of Dean (Hart *op. cit.*). From the 1920s onwards there was a downturn in production, which was only temporarily halted by nationalisation in 1948. In 1920, three large collieries closed, and by 1955 the number of people employed was down to 2,575. The last of the large national deep-mines, Northern United, closed in 1965 (Hart, 1971).

The common right of local people to mine coal has however, survived for at least 700 years. Three small free-mines were still producing coal in 2000 (Hayes, 2000; Prestage, 1990), although mining is now on a much smaller scale. At least one mine is operated just on weekends (John Harvey, *pers. comm.*, 1999).

1.3.3 Colliery spoil heaps in today's landscape

Table 1.1 is a list of collieries that were registered with the Government between 1895 and 1945, and created spoil heaps still present today. Preliminary surveys (Appendix 1, Table 3.2) show that many of the spoil heaps servicing these mines are small and localised. 8ha of spoil heaps were however, registered as derelict in the Forest of Dean district (DoE, 1991). Derelict land is classified as "Land so damaged by industrial or other development that it is incapable of beneficial use without treatment". Spoil heaps such as Northern United fall under this category, and Hawkeswell, which was part of the Northern United colliery (Section 4.1). These sites have not developed vegetation, and are not useful economically or for amenity purposes (Section 1.3).

Table 1.1: List of collieries with existing spoil heaps as recorded in Her Majesty's Inspectorate of Mines (1895, 1911, 1945).

1895	1911	1945
	Arthur & Edward	Arthur & Edward
Bailey Hill	Bailey Hill	
		Barnhill coalpit
Bixslade		Bixslade
Cannop	Cannop	Cannop
Crumpmeadow	Crumpmeadow	
		Eastern United
Foxes Bridge	Foxes Bridge	
Flourmill	Flour Mill	
		Heywood level
Hopewell	Hopewell	
Lightmoor	Lightmoor	
New Fancy	New Fancy	New Fancy
		Northern United
Parkend	Parkend	Parkend
Princess Royal		Princess Royal
		Speculation
Trafalgar	Trafalgar	
True Blue		True Blue
		Union

Table 1.1 also shows that there are gaps during the registration of mines such as Bixlade, Princess Royal and True Blue. It is likely that production at these mines will have also been intermittent. Mining at True Blue for example, stopped before the First World War, but re-started during the 1930s (Dreghorn, 1968). Different areas of the spoil heaps servicing these mines may therefore have been tipped at different times. The dates of pit closures (provided in Table 3.2) indicate a final cut-off date when tipping ceased. Wherever possible however, further confirmation of the age of the particular spoil heap faces was sought (Section 4.1)

to reduce errors in dating the slopes because differential age may affect plant succession results.

Many of the spoil heaps were planted with conifers after colliery closure (Table 3.2) in an attempt to screen the bare substrates from public view, such as parts of Cannop, Northern United, New Fancy and Trafalgar. Others, such as Bailey Hill, Barnhill coal-pit, Lightmoor and True Blue were left to naturally re-colonise. Except for Northern United and Hawkeswell, all tips were found to have developed vegetation cover unless disturbed by re-working or human activities such as mountain biking or dog-walking (Section 4.1).

Further industrial activity has meant that some spoil heaps or faces of spoil heaps have been disturbed more recently than the date of the pit closures. Within the past 15 years, parts of Northern United, Foxes Bridge and Cannop have been excavated for fire-clays and aggregates, and Hawkeswell sifted for remaining coal content at the time of study. This means that coal spoil heap faces from 100 years or more, to 0 years since substrate disturbance, are available in the Forest of Dean for the study of plant succession.

1.4. Plant succession and its role in conservation management

The concept of plant succession is explored more fully in Chapter 2, but is introduced here in relation to conservation management to place the subject into the context of this study. The definition of succession used within this document is that of Begon *et al.* (1996): the "non-seasonal, directional and continuous pattern of colonisation and extinction on a site by species populations". Whilst many types of changes may occur within plant communities such as fluctuations, seasonal, or cyclical changes (Miles, 1979), successional changes are considered to cause cumulative changes in species composition over a longer time-frame.

Succession occurs within both animal and plant communities (for example Pizl (1999), Koehler (1999), and Wheater & Cullen (1997) studied invertebrate succession on derelict land). Vegetation data was however, collected in this study due to the applied focus (objective viii) on nature conservation, because vegetation data collected at the level of the plant community provides useful information on the overall habitat within which organisms live (Kent and Coker, 1992).

As the term 'primary succession' is used throughout Section 2.3, the distinction between primary succession and secondary succession must also be defined. Walker (1999) explains that primary succession is used to distinguish a successional starting point on a substrate where no organic matter is present (e.g. cooled volcanic lava flows), from a 'secondary' starting point where some organic matter may remain, such as forest gaps, or habitats disturbed by fire. Walker (*op. cit.*) notes that in reality there is a continuum of successional starting points where the amount and type of remaining organic matter may vary.

The distinction can still be useful however. Succession on colliery spoil (Section 2.3) for example, is considered a primary succession, as Bradshaw and Chadwick (1980) have shown that very little organic matter and nutrients are typically present in coal wastes after tipping (Bradshaw and Chadwick, 1980). Plants colonising such substrates, as summarised in Figure 1.3, face specific problems.

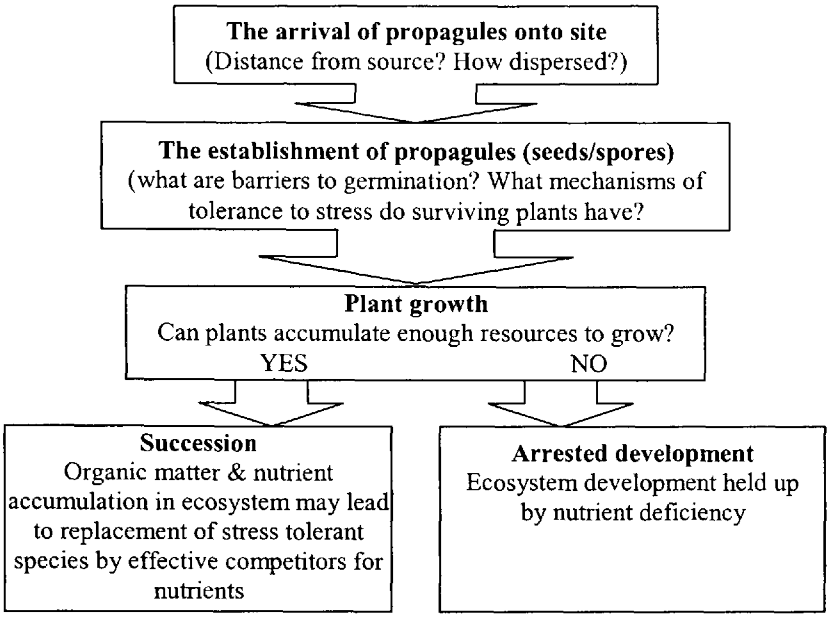


Figure 1.3: the stages involved in primary succession, and problems faced by plants trying to establish. Summarised from Bradshaw (1993).

Successional theory underpins this research because one of the aims of the study (Section 1.1.1) is to produce recommendations regarding the management of vegetation on colliery spoil for nature conservation. As explained by Luken (1990), if plant communities do not exist in a "stable" state, succession is a constant process, and management activities may be required to modify the rate and direction of succession. On a grassland or heathland in the UK, for example, management via grazing or mowing is needed to prevent natural succession to scrub and woodland from occurring (Tait *et al.* 1988). An understanding of the long-term changes that may occur in specific communities is therefore vital to be able to produce management prescriptions. This is particularly true for habitats that are not well known and understood, for example the communities that colonise colliery spoil.

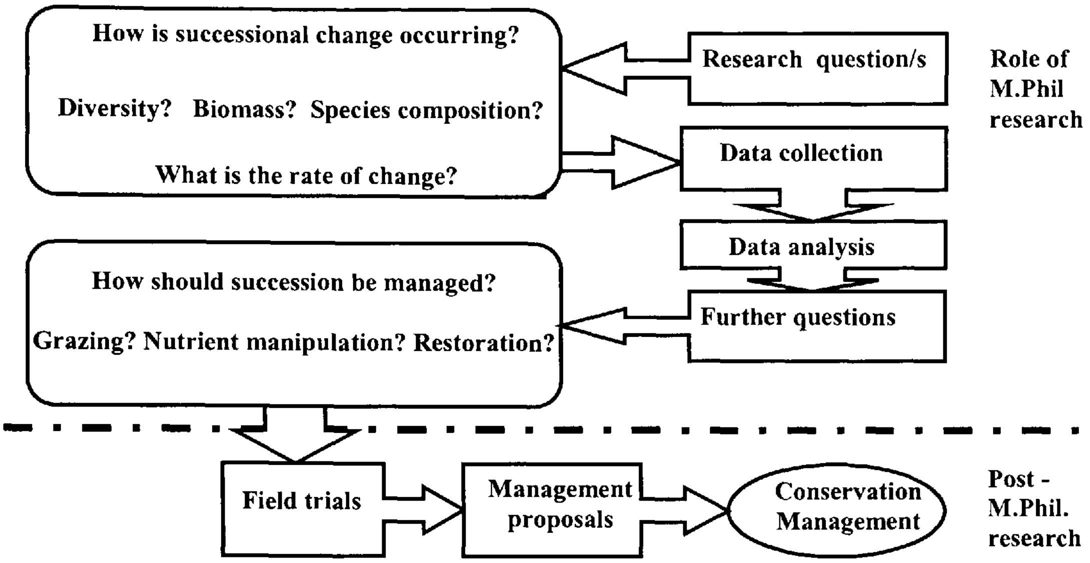


Figure 1.4: The process by which an M.phil level study of succession feeds into conservation management

Figure 1.4 illustrates how this study can aid the conservation management of a site. If the ways in which succession is occurring can be identified in this study, via vegetation surveys and analysis (Section 2.2), the knowledge can help land-managers to formulate clearer aims precisely formulated for managing succession of the defined habitats. Ideally, further research should then be undertaken via field trials to establish the efficacy of the management proposals before wide scale application, as Luken (*op. cit.*) argues that the response of a particular system to management may not be totally predictable.

This study also contributes to theoretical ecological knowledge through examining and testing theories on how succession occurs and on species strategies and species diversity.

1.5 Summary

The aims and objectives of the research study are set out in this chapter. The focus of the study is the colonisation by vegetation of colliery spoil heaps in the Forest of Dean. The aims of the study are to examine how environmental gradients may affect floristic composition, to relate the findings to previous studies, and to produce recommendations for future management.

The study area is introduced in terms of location, geology and industrial history. The Forest of Dean encompasses an 85km^2 coalfield, centred over a synclinal basin where coal, iron and sandstone are easily accessible at the surface. Coal has been mined since at least 1244. The peak of coal production was in the 1900s, but from the 1920s there was a downturn in production and the last deep mine closed in 1965. Mining has traditionally been undertaken on a smaller scale in the Forest of Dean to other coalfields, partly due to ancient Freemining rights of local people. There are a range of spoil heaps remaining in the landscape today. Some sites are classified as derelict land, some were replanted after mining ceased, some were left to re-colonise naturally and some sites have been re-worked for clays, aggregates and remaining coal.

Plant succession (long-term directional change) can therefore be studied on spoil heaps of a range of different ages, particularly because the spoil heaps occur within the same Natural Area, helping to minimise environmental variance and isolate time as a factor that may affect vegetation composition. The study of succession in this study is useful because an understanding of the long-term changes that may occur in specific communities is vital to be able to produce management prescriptions.

Chapter 2.0: Theories of plant succession relating to colliery spoil

This chapter reviews previous studies of plant succession on colliery spoil, and identifies environmental gradients likely to be present on colliery spoil heaps in the Forest of Dean (Objective i, Section 1.1). The chapter also provides theoretical knowledge and practical evidence against which the findings of this study can be compared and placed in context (Chapters 9 and 10).

The historical development of the succession concept is described in Section 2.1.1 to provide an understanding of later theories, and to set the applied studies into context. Modern viewpoints on succession relevant to this study are reviewed in Section 2.1.2. Theories on the ways in which succession may occur (mechanisms) are also reviewed (Section 2.1.2.3). A series of trends that may be expected to occur during the course of a succession is introduced (Section 2.2). These are used as measurable parameters to determine whether (and how) succession is occurring on spoil heaps in the Forest of Dean (Chapter 9). Applied studies undertaken on coal wastes and other relevant substrates are reviewed (Section 2.3) to evaluate the types of environmental gradients that are likely to be found on Forest of Dean spoil heaps, and the effects of these gradients on plant communities.

2.1 Colonisation and succession theory

2.1.1 Historical development of the succession concept

Miles (1987) considers that there is no one accepted or "universal" theory for explaining how succession occurs. It is therefore useful for the purposes of this study to review the historical development of the succession concept to put modern theories and the applied research on spoil heaps into context. It is also useful because some of the concepts and methods used in this study are based on particular viewpoints of succession. The vegetation sampling method used in this study (Section 5.7.1.1) for example, was selected here for its practicality. It was originally developed however, by Braun-Blanquet (1932) as part of his work to distinguish, delimit, and classify vegetation communities into distinct groups. The ordination methods used to analyse vegetation data meanwhile (Section 6.3.2.2), were developed by ecologists such as Bray and Curtis (1957) and Whittaker (1967) who believed that vegetation communities are distributed as a continuum along environmental gradients. An understanding of the historical successional concepts helps to understand the thinking behind the methods, and how to apply them objectively to ensure that bias towards one viewpoint or another is minimised.

Two early, opposing, viewpoints on what succession is, and how it occurs originated with Clements (*op. cit.*), and Gleason (*op. cit.*). Whittaker (1953, 1974) developed a third concept that drew together elements of Clements' and Gleason's viewpoints.

2.1.1.1 Clementsian succession: an orderly systematic process

Figure 2.1 shows how succession may occur on colliery spoil, taken from a generalised sequence described by Hall (1957), who studied vegetation on five different coal fields. This diagram illustrates the traditional or "organismistic" viewpoint of succession that originated with Clements (1916). Clements theorised that change over time occurs at the level of the plant community as an organised, distinct entity, or "super-organism", more than the sum of the constituent individuals, and therefore that distinct and recognisable plant replacement sequences occur. Clements drew evidence from successions occurring on habitats such as sand dunes that often occur in distinct phases or sequences, and concluded that all successions occur in a progressive, orderly and systematic way. He argued that succession occurs as waves of "seres" – distinct plant communities that invade the site, establish and modify the environment through build-up of organic matter and nutrients. These modifications render conditions unsuitable for themselves, but suited for invasion by the next seral community. Clements recognised that different sequences may occur on different substrates (e.g. a hydrosere on water, and a lithosere on bare rock), but it is always uni-directional. A succession was thought to always start with lower plants, and eventually end with higher plants that form a

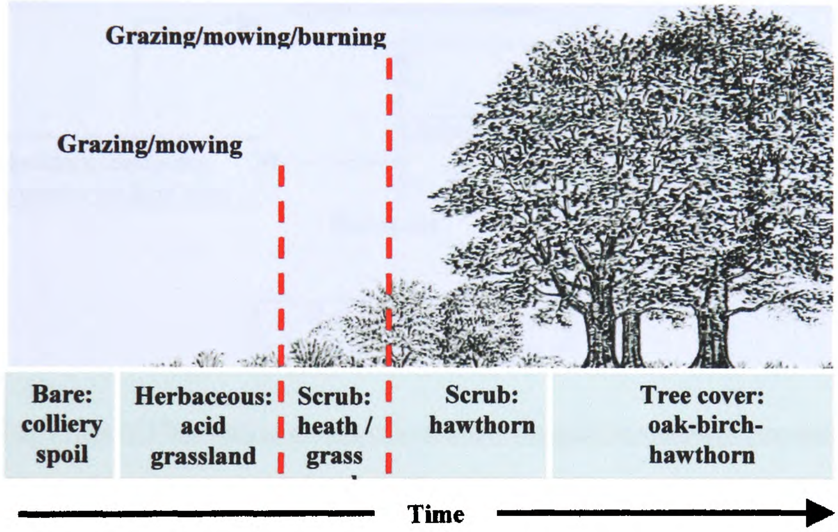


Figure 2.1: The Clementsian view of succession whereby sequences of plant communities replace each other over time. Management activities thereby seek to "arrest" succession at the desired point in time.

Adapted from Tait, Lane and Carr (1988), and Hall (1957) monoclimax community - a stable sere, living in equilibrium with regional climate. Succession is therefore, plant- or community-driven, and always converges towards the climax - a predetermined plant community (Figure 2.2). The climax may be deflected by a limiting factor such as nutrient deficiency (a subclimax), by topographical aberrations from the norm (a pre- or post-climax), or by the activities of man such as grazing (a disclimax or plagioclimax),

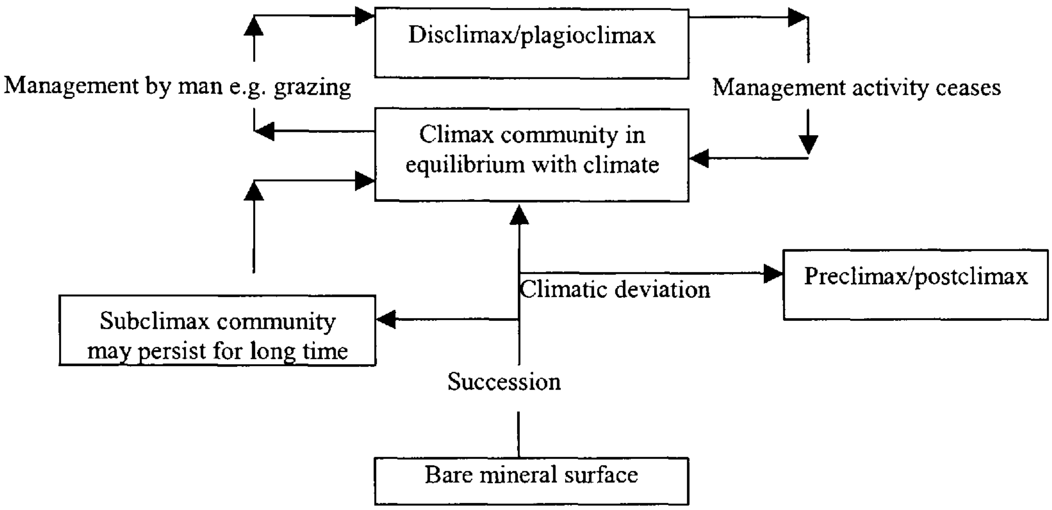


Figure 2.2: Types of Clementsian climax communities thought to end plant succession.

Adapted from Eyre (1963)

Tansley (1935) however, remained unconvinced of Clements' monoclimax concept, arguing that a local climax may be governed by one factor or many factors, such as climate, topography, soils, fire regimes, and human interference, and therefore that a climatic region may contain many different specific climax types.

According to Leps (1991) one of the main scientific problems with any climax idea, is that it is un-testable scientifically because of the vague terminology. The fact that communities "eventually" progress towards a determined end point means that non-convergence can be explained away by the lack of time. Peters

(1976, 1991), also argues that authors subsequent to Clements (such as Tansley) have modified the climax theory to explain so many different successional endpoints that it is circular and thereby also un-testable: vegetation in an area may or may not progress to similar or different endpoints.

Nonetheless, reviews of the literature on succession by McIntosh (1980), Miles (1987) and O' Neil (1986) show that until the 1970's, the Clementsian viewpoint was widely accepted and taught. For example, Miles (*op. cit.*) considers that the viewpoint is still apparent in the "systems approach" advocated by Odum (1969; 1971), who proposed that succession is directional, predictable and driven by the plant community. The emphasis of systems ecology is different to Clementsian ideas on succession because it looks at the flows of energy within an ecosystem, rather than a plant community. To Odum (*op. cit.*) however, each ecosystem develops towards a stable equilibrium stage, which is analogous to the climax concept. Some of Odum's ideas on trends that may be expected to occur during succession are used in this study (Section 2.2.2), but it is important that such ideas are examined critically in the light of modern ecological thought (Section 2.1.2), and can be testable scientifically.

2.1.1.2 Gleasonian succession: change through individualistic plant response

The "individualistic" viewpoint of Gleason (1917, 1926, 1927) at the other extreme to Clements, argued that plant species respond individually to variation in environmental factors such as topography, geology, climate, substrate and microclimate. A patch of vegetation is simply an assemblage of the constituent species that happen to arrive as propagules and establish due environmental conditions favourable to that species. The range of different combinations of environmental factors at any given point on the earth's surface is likely to vary continuously in space and in time. This is likely to give a unique combination of species in space and time, particularly because each species has a different tolerance range to each environmental factor. Plants must therefore be distributed in both space and time as a contiuum, not as distinct community entities.

Cooper (1926) argued that vegetation is constantly changing, and so there are many different types of change – e.g. physiological, seasonal and directional. Cooper thought that because vegetation is constantly changing it is impossible to determine the beginning or the 'climax' endpoint of a succession. He also pointed out that retrogressive change can occur, for example where a forest stand becomes dominated by moss communities in response to climatic change. He proposed that succession should therefore refer to the universal process of vegetation change.

These viewpoints challenge the Clementsian idea that plant succession is predetermined and that in any given region it will converge to a particular community. Both Gleason and Cooper (*op. cit.*) argued that factors such as stochastic (chaotic, unpredictable) processes, environmental conditions, and how individual species respond to these conditions are more important than the plant community itself in determining what happens during a succession.

2.1.1.3 Environmental gradients: the climax-pattern analysis

A third model of succession is also highly relevant to this study – the "climax pattern analysis" developed by Whittaker (1953, 1974). This theory to some extent linked the viewpoints of Clements' and Gleason, recognising that plant communities are distributed as continua along environmental gradients, but that mosaics of similar vegetation communities are repeated in space where environmental conditions are similar. However, Whittaker found no sharp boundaries between these communities, suggesting that Gleason's continuum theory of plant distribution patterns is more realistic. Modern studies such as Wilson and Chiarucci (2000) would also support this view.

The climax pattern analysis viewpoint is particularly relevant to this study, which aims to find out how the environment conditions present on the colliery spoil heaps may affect floristics (Section 1.1). This viewpoint shows that identifying the particular combination of environmental gradients present on the site through literature review (Section 2.3), and through data collection (Chapter 5) is as important as collecting information on the vegetation itself. Time-since-abandonment for example, can be thought of as one gradient that may influence species composition. Other gradients may be equally important such as substrate (Section 2.3.1), or microclimate (Section 2.3.2).

This study is particularly useful because few previous substrate or environmental analyses have been undertaken to identify the range of environmental factors and their gradients present in the Forest of Dean (J. Harvey, *op. cit*). It is difficult to predict how plant communities may respond to different management decisions if it is not known how they respond to existing gradients (Luken, 1990; Kessall, 1981).

2.1.2. Modern viewpoints on plant succession

This section reviews modern literature on succession to explain how the work of Clements, Gleason and Whittaker is perceived today (Section 2.1.2.1). The terms "succession" and "plant community" are also defined (Section 2.1.2.2) to distinguish the meaning of the words used in this research from their Clementsian origins. The research of Connell and Slatyer (1977), Tilman (1985,1988) and Grime (1979) is also reviewed (Section 2.1.2.3). This section describes the theories on the mechanisms of how succession may be expected to occur. These theories have also directed the programme data collection in this study (Chapter 5), and used to evaluate the results (Chapters 9 and 10).

2.1.2.1 Modern perceptions of Clements and Gleason

As models of succession, Clements' and Gleason's viewpoints both have strengths and weaknesses, but are useful starting points for the analysis of vegetation succession. Reviews by McIntosh, (1980) and Miles (1987) both recognise that each viewpoint has merits and limitations. O' Neill *et al.* (1986) consider that the Gleasonian viewpoint is reductionist, ignoring interactions occurring at a community level, e.g. competition and symbiosis (Miller, 1987; Gigon and Leutert, 1996). Succession is therefore analysed in this study at the level of the plant community rather than individual plants, to provide a broader understanding of habitat and diversity changes that may occur.

The research of Wilson (1999) however, has not found any evidence of repeated pattern within plant communities that would imply evidence of organisation in the Clementsian meaning. Perry (2002) argues that the classical Clementsian viewpoint concentrated on temporal pattern at the expense of spatial pattern. Over the past 20 years however, understanding of the importance of spatial pattern has increased. Spatial heterogeneity is particularly important to this study, due to the heterogeneous nature of colliery spoil (Section 2.3.1) and the method used to study succession (Section 3.1).

Meanwhile, research by Noble and Slatyer (1980), Austin (1981), Grubb (1977, 1986) and Grime (1979) has consolidated the understanding that successional change must be explained in terms of the individual niche properties and life-strategies of the constituent species. The historical viewpoints of Clements and Gleason are however, still considered useful today. They emphasise the fact that succession is a complex phenomenon, and that vegetation managers have to consider many different factors in order to predict the changes that may occur (Luken, 1990). These include the time-since-disturbance of an initial surface, soil pH, nutrient status, aspect, slope factors, distance from colonising source and properties of the seed bank.

2.1.2.2 A definition of the term succession

Like Cooper (*op. cit.*), Miles (1979) considers that succession is just one vegetation change phenomenon, to be considered alongside fluctuations, cyclical changes, or direct replacements. Successional changes are considered to be directional, causing cumulative changes in species composition, although it is a somewhat arbitrary distinction. In a later definition, Miles and Walton (1993) more succinctly write that succession is the replacement of one community by another over time.

Burrows (1990) argues that a constant (climax), vegetation community is unlikely to persist for more than a few generations of it's constituent plant species due to changes in environment, however subtle. Stability or permanence is therefore a relatively ephemeral property of any kind of vegetation. Communities may however, be considered mature where approximately the same floristic composition is maintained for more than one generation. Herbaceous communities may persist for a few years to a decade or more for example, whereas a mature forest might persist for more than a century.

"Plant community" is also used throughout this document, but more as a convenient term to use at the synecological level rather than implying organisation. It is defined here according to Southwood (1987), as an abstract "assemblage of plant species that exist and interact in an area".

2.1.2.3 Mechanisms by which succession may occur

Connell and Slatyer (1977) try to identify the mechanisms by which succession occurs. They argue that plants are not necessarily replaced sequentially as described in the Clements' model. Plant-environment and competitive interactions can result in other mechanisms of succession such as "tolerance" whereby early colonisers modify the environment, and are gradually excluded by competitive colonisers that invade or are already present. Egler (1954) for example, found that 95% of species dominating later stages of succession were also present in the initial stages.

Tilman's resource ratio hypothesis, and Grime's C-S-R continuum describe how species' strategies dictate plant response to biotic and abiotic factors, and cause long-term changes in community composition. These two particular schools of thought relating to succession are described here because of their relevance to describing patterns of change on colliery spoil.

Tilman (1985, 1988) views succession as resulting from a gradient through time in the relative availabilities of limiting resources. Two major gradients occurring through a primary succession are nitrogen and light. As illustrated in Figure 2.3, characteristics of primary succession are that light intensity on the bare substrate is high due to lack of vegetation, and soils are nitrogen deficient soil due to lack of accumulated organic matter (Jenny, 1980). As soil develops, it becomes nitrogen rich. Light availability is low at ground level due to increased light interception associated with biomass production (Crocker and Major, 1955). The plant species that are dominant in a plant community at any given time along the gradients are those best adapted to the environmental conditions present.

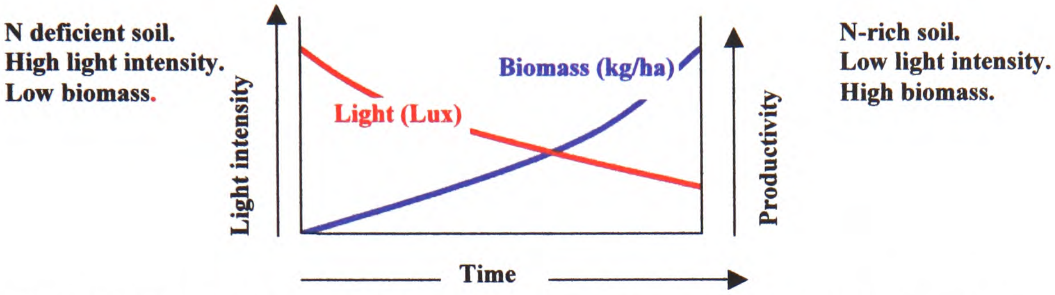


Figure 2.3: The hypothetical relationship between nitrogen availability, light intensity and biomass production during primary succession

Adapted from Tillman (1985)

Grime's C-S-R continuum is a theoretical three-way ‘trade-off’ in the different adaptations of plants to three main growth-limiting threats: competitive exclusion, chronic stress, and repeated severe disturbance. Each threat confers a selective advantage on different types of ecological specialization. Competitors prevail under conditions of low disturbance, low stress and therefore high competition. Stress-tolerators prevail in low disturbance but high stress environments. Ruderal species are able to tolerate highly disturbed conditions. The plants found at each stage of succession therefore depend on site conditions (Grime, 1977; Grime *et al.* 1988).

Table 2.1: A hierarchy of factors that may cause, or alter the path of successional change.

General causes of succession	Contributing processes or conditions	Modifying factors
Site availability	Coarse-scale disturbance	Size Severity Time Dispersion
Differential species availability	Dispersal	Landscape configuration Dispersal agents
	Propagule pool	Time since last disturbance Land use treatment
	Resource availability	Soil conditions Topography Microclimate Site history
Differential species performance	Ecophysiology	Germination requirements Growth rates Population differences
	Life history strategy	Reproductive timing Reproductive mode
	Environmental stress	Climate cycles Site history Prior occupants
	Competition	Presence of competitors Identity of competitors Within-community disturbance Predators and herbivores Resource base
	Allelopathy	Soil chemistry Soil structure Microbes Neighbouring species
	Herbivory, predation, Disease	Predator cycles Plant vigour Plant defences Community composition

Adapted from Pickett *et al.* 1987

Pickett *et al.* (1987) also compiled a useful and comprehensive hierarchical framework of factors that may influence the successional process (Table 2.1). This table emphasises the multidimensional processes and factors that could affect succession in the Forest of Dean, such as the availability of microsites on the spoil heaps, their size and configuration, what species surround the site and how effective the dispersal mechanisms of these species are. The environmental conditions however may not be suitable for all species, or other plant species may already exist on the site that are able to out-compete for resources.

The fact that there are so many processes and factors that can modify a succession, and that chance is involved in some of these processes (such as disturbance and dispersal) highlight the stochastic nature of succession.

2.2 Measuring plant succession

A series of trends is introduced in this section that ecologists such as Whittaker (1975), Odum (1971, 1969), Danserau (1974) and Grime (1979) have proposed as being indicators that succession is occurring. These trends have been used to direct floristic and non-floristic data collection within this study (Table 2.3), and to focus the literature review of studies previously undertaken on colliery spoil (Section 2.3).

2.2.1 Measurement of succession over time

The main difficulty of measuring succession is that changes may occur over decades or centuries (Pickett, 1989). The space-for-time substitution (SFT) method will be used in this study to overcome this problem (Section 3.1). A chronosequence of sites of different ages will be selected (Section 3.2) that have the same substrate and landform conditions. SFT substitution assumes that these sites have undergone the same sequence of vegetation changes (Burrows, 1990).

2.2.2 Quantitative indicators of succession

Whittaker (1975), Danserau, (1974), and Odum (1971; 1969) also listed generalised trends or progressive developments which may be expected to occur during the course of succession (Table 2.2). These trends can be used to quantify succession by measuring substrate, microclimate and vegetation parameters.

Table 2.2: trends that may be expected to occur within plant succession that may be used as quantitative indicators of succession within this study

	Time →		Measurable outcomes
Substrate	Immature	Mature	Increasing depth (1)
			Increasing organic matter content (1)
			Increasing differentiation of horizons (1)
			Moderation of drainage from excessive/deficient to regular (3)
	Low nutrient capital	High nutrient capital	Increasing fraction held in plant tissues (1,2)
			Mineral cycles from open to closed (2)
Microclimate	Extreme	Attenuated	Reduction of temperature extremes (3)
			Decrease of radiation and evaporation (3)
			Determined by community characteristics (1)
Non-floristic vegetation	Low productivity	High productivity	Biomass increases with soil development, community structure and resource use (1,3)
	Low height	High height	Increasing "massiveness" and stratification (1)
Diversity	Poor	Rich	Increased number of species found (1,2)
	uneven	Even	Reduced dominance by any one species (2)
Species strategies	r-strategists	K strategists	Species with strategies of rapid reproduction replaced by longer-lived competitors (1,2)
	Stress tolerant	Competitive	Species adapted to harsh environments replaced by those able to compete for increased resources (4)

Source: Whittaker, 1975 (1), Odum, 1971, 1969 (2), Danserau, 1974 (3), Grime 1979 (4).

Some of the trends listed in Table 2.2 such as diversity and biomass are however based on the 'systems approach' (Section 2.1.1.1), which assumes that succession develops towards a state of equilibrium. As discussed in Sections 2.1.1.2, 2.1.1.3 and 2.1.2, such viewpoints have been challenged. The theories behind each parameter have therefore been examined further in Section 2.3 in relation to modern viewpoints and in relation to studies on colliery spoil prior to using them to interpret results.

Table 2.3: data that will be collected in this study in order to measure succession

	Measurable parameter	Why measurement needed?
Time	Age-since-disturbance	Quantify time succession has had to occur
Substrate	PH	Identify potential factors other than time that may affect succession (e.g. acidity)
	Pyrites	As above
	Soil depth	Quantify substrate development
	Plant vigour	As for pH
Microclimate	Slope factor	Identify factors other than time that may affect succession (e.g. drainage, substrate stability)
	Aspect	Identify factors other than time that may affect succession (e.g. insolation, surface temperature)
	Canopy cover	Indication of % tree cover (massiveness of vegetation, stratification)
Non-floristic vegetation factors	Vegetation height (per layer)	Height, massiveness & stratification of vegetation.
	Biomass estimate (height x cover index)	Massiveness of vegetation
Species diversity	Number of species	Measure of species diversity in own right
	% cover-abundance	Information on eveness, required for diversity indices & distribution patterns of species
Life strategies	Life cycle (annual/perennial)	Indication of r-strategy or k strategy
	Reproductive strategies	As above
	Life form	Indication of stress-tolerant or competitive growth strategies
Floristics	Floristic composition	Indicate whether life-strategies change over time at plant community level

Table 2.3 lists the parameters that will be used in this study to quantify the successional trends, and to ensure that environmental factors other than time that may affect succession are identified. The methods used to measure each parameter are described in Section 5.

2.3 Primary succession on colliery spoil

To aid the interpretation of the results from the data collection programme outlined in Table 2.3, this section reviews previous studies that have been undertaken on coal wastes. In particular, studies that have measured similar environmental variables are reviewed, and where relevant the studies are used to further discuss and evaluate the successional trends introduced in Table 2.2.

Age-since-disturbance is one of the key variables listed in table 2.3. However, studies relating to age-since-disturbance are not reviewed under a specific section because time is a central theme to many of the studies reviewed, and it is therefore discussed where appropriate in the following sections.

2.3.1 Substrate factors

According to literature reviews on plant growth problems on colliery spoil by Bradshaw and Chadwick (1980) and Kent (1982), the environmental factors likely to affect substrate condition and suitability for plant growth include toxicity, low levels of plant nutrients, adverse particle-size and/or bulk density, and a harsh initial microclimate (Section 2.2.2). Furthermore, environmental factors can vary between tips on different sites, between sites within the same coalfields, or within different locations on the same site due to the heterogeneous nature of colliery spoil (Tasker and Chadwick, 1978). This highlights the importance of pre-selecting sites for inclusion within the study using criteria designed to minimise macro-scale differences between sites such as geology, topography, management and land-use

(Section 3.2). A rigorous substrate sampling regime should also be designed to ensure a representative sample is analysed (Section 5.2).

2.3.1.1 Substrate acidity

When coal shales are freshly tipped, they can have a relatively neutral pH of 7 or above, which falls to a pH level as low as 1.5-2.0 within five years. Acidity can remain low for 10-100years (Doubleday 1971, 1972; Bradshaw and Chadwick, 1980; Kent, 1982). However, in a chronosequence undertaken on the Somerset coalfields, Down (1975) found that pH rose steadily on his sites over time from pH 2.57 at 5 years, to pH 5.92 at 178 years since disturbance. The cause of pH change is often the presence of iron pyrites (FeS_2), which produces sulphuric acid on weathering. The occurrence, formation and weathering of pyrites is discussed further in Section 2.3.1.2.

Figure 2.4 shows the pH results from 648 samples taken from 34 sites in south and west Yorkshire (Kent *op. cit.*). This shows a bimodal distribution. The first peak, at pH 6-7, represents freshly tipped spoils prior to weathering of pyrites.

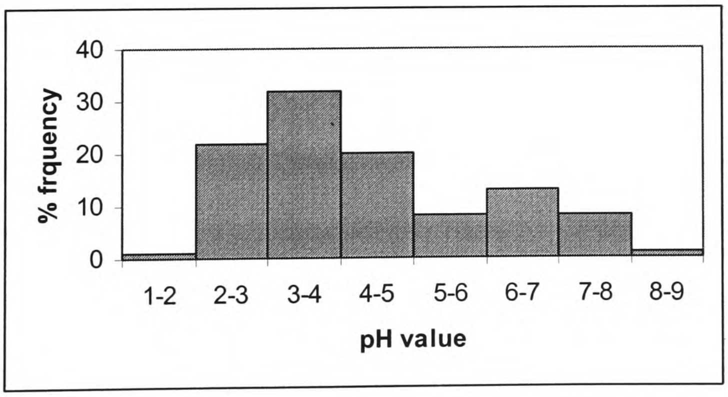


Figure 2.4: The % frequency of pH values taken from surface samples of 34 colliery spoil sites in Yorkshire, UK. Source: Kent (1982).

The second peak, at pH 3-4, represents spoils that contain actively weathering pyrites and have been tipped for 10 years or more.

Plants can be affected directly and indirectly by soil acidity. Below pH 4.0, the concentration of hydrogen ions begins to be directly harmful (Gemmell, 1977). At high acidities, metallic cations and toxic salts are made soluble, and thus available for plant uptake (Thornton, 1981). For example, Williams and Chadwick (1977) found Al, Mn, Cu, Zn and Fe to be present in toxic concentrations in colliery spoil in Yorkshire. Soluble Fe and Al salts cause phosphorous fixation and therefore nutrient shortages in plants, whilst heavy metals meanwhile can inhibit root growth and cause stunting (Section 2.3.1.4).

Tasker and Chadwick (1978) examined relationships between the micro-distribution of a common colonising plant, *Agrostis tenuis* and 17 spoil chemical characteristics. On very acid sites (pH < 4.0), samples taken from patches of vegetated spoil tended to have a higher pH, lower Cu and Fe concentrations and higher concentrations of K than samples taken from bare patches. On less acid sites (pH > 4), the differences between the samples were less obvious, but certain acid toxic patches were revealed from which plant cover was absent. The patchy colonisation patterns were thought to be a result of the differences in substrate chemistry.

Limited substrate analysis for pH was undertaken in the Forest of Dean on one site, Northern United at the request of the Forestry Commission when the site was undergoing restoration. Spoil pH values taken in 1996 ranged from 2.0 (coal slurry area), 3.0-4.1 (black shale) and 6.5 (red shale) (D. Fourt, Forestry Commission, *personal records.* 1994-2001). These results are less acidic than the pH of 1-2 reported by Bradshaw and Chadwick (*op. cit.*) for other coalfields such as

Yorkshire. The results also demonstrate that pH is not uniform across the site. As the bulked soil samples taken in this study (Section 5.2.1.1) provide an average soil pH result rather than the soil pH experienced by each plant, the plant health index (Section 2.3.1.4) may therefore be useful as an indicator of particularly acidic conditions within or between each quadrat.

2.3.1.2 Pyrites

Iron pyrites (FeS_2) is highly reactive with oxygen and water. Over time FeS_2 is metabolised by *Thiobacillus* bacteria, which derive energy from the oxidation of reduced sulphur or iron compounds. In the process sulphuric acid is generated, leading to high concentrations of hydrogen ions in the spoil and low pH levels (Bradshaw and Chadwick, 1980; Freedman and Hutchinson, 1981; Davis *et al.*, 1992). Depending on the amount of pyrites present (and whether neutralising carbonite minerals such as ankerite and siderite are present in the spoil), the weathering process can limit the growth of vegetation for over 100 years (Costigan *et al.*, 1981; Kent, 1982).

Table 2.4: "Typical" analyses of Forest of Dean Coals. Source: Ministry of Fuel and Power (1946)

Seam	T	CHD	CHD	CHD	W	Y
District	SW	S	E	NE	S	W
Carbon (MFD)	83.0	84.1	84.9	84.6	84.0	83.2
Hydrogen (MFD)	5.6	5.4	5.7	5.4	5.6	5.5
Nitrogen (MFD)	1.6	1.6	1.5	1.5	1.6	1.6
Sulphur (MFD)	0.8	1.0	0.9	0.6	1.3	1.1
Sulphur (total)	1.55	2.28	2.01	0.95	4.29	2.96
Pyritic sulphur	**0.86**	**1.37**	**1.16**	**0.41**	**3.19**	**2.03**
Chlorine (total)	0.05	0.08	0.1	0.05	0.06	0.03
Phosphorous (OB)	0.004	-	0.002	0.002	-	0.004

Seams: T = Trenchard; CHD = Coleford High Delf ; W = Whittington; Y = Yorkley
Analyses: MFD = Mineral-free dry basis; OB = original basis

Coal seams typically have a pyritic sulphur (FeS) content of 2% by weight (Burns, 1970), but this varies greatly. For example results from commercial analyses of Forest of Dean coal (Table 2.4) reveal that the pyritic sulphur content varies from 0.41-3.19% across the coalfield, and from 0.41-1.37 in one seam.

The relationship between FeS_2 content, pH and time is not straightforward. Costigan *et al.* (1981) found that younger coal spoils tended to have high pyrites content (1-3.7%) and high pH (5.9-6), as the pyrites had not weathered to form sulphuric acid. Older spoils had lower pyrites contents due to weathering (0.94-1.22), and low pH caused by the acids produced during this process (2.05-2.45). However, different forms of pyrites are thought to weather at different rates, and clay minerals present in the spoil may help to neutralise the acid.

According to Kent (*op. cit.*) the effects of pyrites on plants is closely related to the size of the FeS_2 grains (smaller grains have a larger surface area available for oxidation). Acidity caused by FeS_2 can also change markedly with horizontal depth due to the differential exposure to oxygen and water. This is shown in Table 2.5,

Table 2.5: Two profiles showing decreasing pH of colliery spoil towards the surface due to oxidation and weathering at two sites in Yorkshire. Source: Kent (1982).

Site 1		Site 2	
Depth (cm)	**PH**	**Depth (cm)**	**PH**
0-2.5	3.10	0-2.5	3.80
2.5-10.0	2.90	2.5-10.0	3.70
10.0-20.0	5.45	10.0-20.0	6.55
20.0-40.0	6.10	20.0-40.0	7.20
40.0-50.0	7.25	40.0-50.0	7.20

where changes in pH from 3.10 in the upper 10cm to 7.25 in the lower 40-50cm occurred. Disturbances to the substrate, such as excavation for clay, that have occurred on some of the Forest of Dean spoil heaps could therefore bring fresh, non-weathered FeS_2 to the surface. This highlights the importance of determining the land-use history and age-since-disturbance of each surface of a spoil heap rather than the spoil heap as a whole when selecting surfaces for study.

Combustion has occurred on many Forest of Dean spoil heaps. The preliminary surveys (Section 3.2) showed that patches of burned and unburned shales are often apparent on the same slopes. This is an important factor affecting plant growth differences between sites, because FeS_2 is burned off during the combustion process.

2.3.1.3 Soil depth

According to Whittaker (1975) and Odum (1971), substrates increase in depth, organic matter content, horizon differentiation and nutrient capital over time, with an increasing amount of nutrients being held in plant tissues. The measurement of the depth of the humus layer and any A/B horizons that have developed over the colliery substrate may therefore provide an indication of the amount of organic matter build-up and horizon differentiation.

The mechanism of substrate development described by Whittaker (1975), Jenny (1980), Titlyanova (1982), Tilman, (1985) and Jochimsen, (1996) is that pioneer plants will establish on a bare substrate, die, and thus provide nutrients for other incoming plants. Eventually the humus or organic soil layer accumulates, containing nutrients such as nitrogen that are released from plant tissues back into the soil. The increased nitrogen content of the soil allows more competitive plants to grow, which in turn release more nitrogen. The vegetation itself can be said to drive the development of soil in some situations, gradually modifying weathering, leaching and erosion processes that may otherwise remove soil and nutrients from a site. However, according to Billings (*op. cit.*) soil-forming processes are also affected by non-biotic factors such as climate, topography, weathering and drainage processes. Cooper (1926) describes several examples of where soil does not build up sequentially due to disturbance such as flooding.

Substrate development on colliery spoil may be very different from other primary successions due to toxicities and poor physical characteristics that inhibit plant growth. The development of the soil system can therefore be held up by a lack of nitrogen (Bradshaw, 1993). Very little nitrogen is thought to become present in plant-available forms through weathering of the parent material (Williams and Cooper, 1976; Kent, 1982; Palmer *et al.* 1985), although Cornwell and Stone (1968) found that conditions of high acidity in some black shales in Pennsylvania caused plant available N to be released.

Table 2.6: The gross annual input of total nitrogen onto colliery spoil heaps in Yorkshire via rainfall, after losses by runoff are taken into consideration

Nitrogen budget	**N (kg ha $^{-1}$)**
Net inputs of N through rainfall	8-9/year^{-1}
Losses of N through runoff	2.6-5
Gross N input	**3-6.4**

Source: Dennington and Chadwick (1978)

Whilst abiotic factors such as rainfall can contribute to the nitrogen budget (Table 2.6), biotic processes must contribute the majority of the resource needed for ecosystem functioning. For example, Smith *et al.* (1997), found that nitrogen accumulation under naturally regenerating forests on iron-smelting slag was accelerated in samples nearest the edges of the site, due to inputs from leaf litter that had blown in from surrounding areas. Although measuring soil depth cannot provide a reliable estimate of nutrient capital, a site with little or no accumulation of organic matter is therefore also likely to be lacking in nitrogen.

2.3.1.4 Plant vigour

Many studies have indicated that plant growth itself is the best indicator of the "total" effects of environmental factors (Doubleday, 1972; Chadwick, 1973; Mueller-Dombois and Ellenberg, 1974; Bradshaw and Chadwick, 1980; Kent, 1980, and DoE, 1996). Patches of substrate within a plant community where plant growth is absent or showing signs of stress may indicate areas where soil conditions are particularly poor.

Table 2.7: visual effects of nutrient deficiencies which may be seen in plants

Effect	Visual manifestation	Deficiency	Toxicity/physical
Stunting	Poor growth	All elements, but lack of N & Ca causes severe stunting	Low pH, heavy metals, nutrient fixation
	Poor leaf development	P	Nutrient fixation
	Poor root development	K	Heavy metals
Chlorosis	Lack of "greenness"	N, S, Fe, Mg, Mn	
Necrosis	Death of tissues (esp. directly on surface)		Temperature
	Inter-veinal necrosis		Heavy metals
Other	Mottled chlorosis	Fe, Mg, Mn	
	Small necroses	Fe	
	Ringing around stems		Temperature
	Leaves pale green, lighter areas around veins	S	
	Chlorosis of older leaves, veins greener	Mg	
	Chlorosis of younger leaves, veins green	Mn, Fe	
	Young leaves dark blueish green, older leaves reddish, poor rooting. Purpling	P	
	Necrosis of leaf tips, edges crinkled/distorted	K	
	Necroses of young leaves and roots	B	

Source: Bannister (1976); Kent (1982); Schramm (1966); Gemmell (1977)

There are specific symptoms that can be seen in plants, which are summarised in Table 2.7. It may be difficult to infer specific soil problems from these symptoms, as several soil deficiencies or toxicities may produce the same symptoms. As the nutrient requirements or toxicity tolerances of individual species are different species, symptoms seen in one species may not mean that other species in the area are similarly affected (Bannister, 1976). Mottling can be caused by disease or infection. Plant vigour is therefore not an alternative to soils or plant analysis, but will give an indication of particularly poor substrate conditions between sites, or within a site in the Forest of Dean.

2.3.2 Microclimate

The differences in microclimate within and between sites such as humidity, substrate moisture content, shade, and insolation can affect patterns of vegetation development and floristics (e.g. Sterling *et al.*, 1984). It is important to measure factors that can affect microclimate and vegetation development such as slope profile, aspect, and shade cover (Table 2.3) in a study of plant succession. Previous studies on colliery spoil relating to microclimatic effects on vegetation development have been reviewed to compare to the results of measurements in this study. It is also necessary in a space-for-time substitution (Section 3.1.1) to examine how the variation of microclimatic factors between sites may be minimised.

2.3.2.1 Slope factors

Slope can affect factors such as soil creep, erosion, stability, water flows and drainage. It is therefore important to select study areas that are from similar slope zones (Section 3.2) to minimise variation in vegetation development between sites.

Figure 2.5 demonstrates how differing areas on the slope profile experience different drainage, water flows and soil movement patterns. Sites on the crest of hills and steep slopes actively shed water into low-lying areas. Low-lying areas receive more water, and therefore remain wetter for longer as water drains from soils higher upslope (Bridges, 1987).

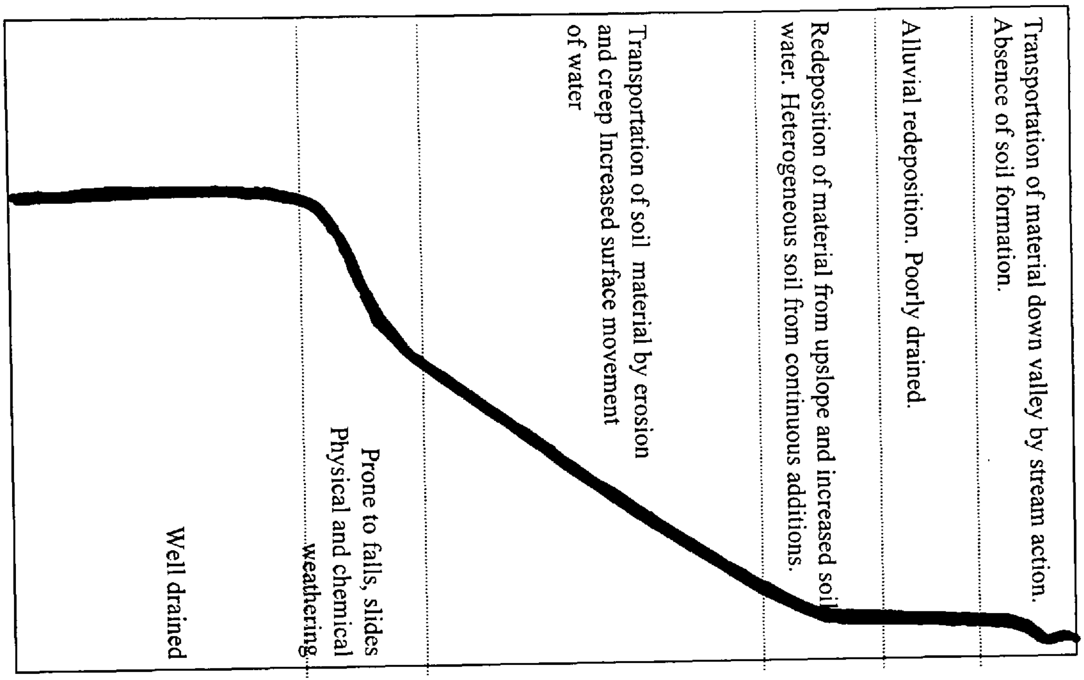


Figure 2.5: soil drainage and movement processes on slopes. Adapted from Conacher and Dalrymple, 1977 in Bridges (1997)

Instability of surface substrate can particularly affect vegetation trying to establish on loosely tipped colliery spoil. This is exacerbated on sloping areas of a spoil heap by erosion and soil creep, particularly as tipping methods on conical and fan tips in the Forest of Dean often created steep slopes of 40° or more (Table 4.1).

Down (*op. cit.*) investigated movement on the coal shale slopes by measuring the displacement of plaster of paris cubes fashioned to resemble spoil particles lightly embedded in the spoil.

Table 2.8: mean distance moved in 7 days down-slope of plaster-of paris cubes lightly embedded in spoil heaps of different ages in Somerset (UK). Adapted from Down (1975a).

	In Gully	Outside gully
Spoil Age	**Distance (cm)**	**Distance (cm)**
5 years	363.4	7.9
21 years	254.9	4.6
45 years	414.5	0.8

Table 2.8 shows that in the gullies material was washed down slope by 363cm a week and outside the gullies 7.9cm a week. This demonstrates the difficulties that plant propagules and seedlings would face in colonising an unstable substrate.

Prach *et al.* (1999) found that the vegetation cover on flat areas of colliery spoil increased from 0 in year 1 to 100% by 15th year, with substrates able to support forbs, shrubs and small trees. However, on steep slopes of the same age, vegetation cover was only 40%, dominated by Coltsfoot (*Tussilago farfara*), which was able to establish through vegetative spread.

Differing particle size can further affect drainage patterns on colliery spoil heaps. Large shale particles increase the rate of water percolation through the spoil, and water-stress in summer may occur. A large proportion of fine shale particles can retard water percolation and lead to water-logging (Down, 1974a).

Sterling, *et al.* (1984) demonstrate floristic differences that can result from even small-scale differences in drainage due to slope. In a 2-30 year chronosequence of abandoned agricultural pastures, very different species assemblages appeared in the furrow depressions to the plough ridges on the younger sites due to differences in edaphic moisture and nutrient accumulation. This study illustrates the fact that even slight variations in slope can have discernable effects on floristic composition.

The studies reviewed above show the importance of using a selection procedure (Section 3.2) to minimise macro-topographical differences between sites. It is also important to measure the slope factor of each site, and create a slope profile, as differences within sites or between sites may affect drainage patterns, soil creep or settlement patterns and substrate stability, and therefore affect floristic pattern.

2.3.2.2 Aspect

Aspect can greatly affect the amount of solar warming received, especially in temperate climates such as the UK, where south facing slopes have higher

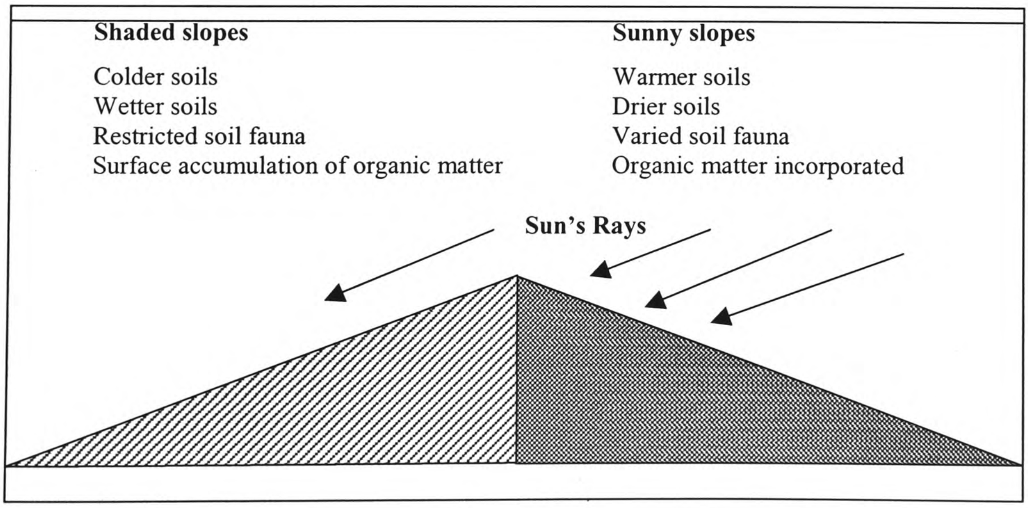


Figure 2.6: the effect of aspect and relief on soils situated on shady and sunny slopes. Diagram modified from Bridges (1997)

insolation than north-facing slopes. Differences in soils will develop in response to the different conditions prevailing on slopes that face the sun compared to slopes shaded from the sun as shown in Figure 2.6 (Bridges, 1997).

Figure 2.6 demonstrates that north facing (shaded) slopes in temperate climates can be less productive and diverse than south facing slopes due to the effects of colder conditions and wetter soils on soil fauna and nutrient cycling. However, on colliery spoil heaps, the effects of increased insolation on south facing slopes can have negative effects on vegetation due to heat damage. Richardson (1958) made daily temperature recordings on pit heaps in Durham. On bare spoil, July temperatures were found to be regularly above 50° C, causing plant mortality. The black colour of the spoil was thought to absorb light rather than reflect it, and heat up more quickly than lighter substrates would. Temperature readings taken on vegetated substrate surfaces were however, cooler at only 26°. The temperature range was also less extreme. Schramm (1966) found that north-facing banks re-colonised better than south banks or flat surfaces because of the higher insolation received on south-facing slopes.

Table 2.9:The % of soil moisture tension recordings at wilting point (4.2 pF) or above taken from 4 different aspects of a 23 year-since-disturbance spoil heap in County Durham.

Aspect	Surface	2cm	3.3cm
SW	69	25	19
SE	63	37	30
NE	64	15	5.5
NW	65	17	13

Source: Richarson and Greenwood (1967).

Richardson and Greenwood (1967) examined pF values (soil moisture tension) on one Durham spoil heap of 23 years-since disturbance, by season, aspect and depth. The study found that aspect critically affected the surface pF values. A higher number of recordings showing values above the wilting point were recorded on the south-east and south-west aspects than the north-east and north-west aspects, (Table 2.9), particularly during the summer months. This resulted in a non-uniform pattern of colonisation, as shown in Figure 2.7, where cover was much denser on the north-east section of the tip than on the south-east and south-west and north-west sections. Aspect also affected species composition. Early colonists included *Agrostis tenuis, Dactylis glomerata, Holcus lanatus, Hieracium* spp. *Senecio viscosus* and *Tussilago farfara.* Mosses did not arrive until later, and first appeared on the north-east slope. This was thought to be because of the cooler and wetter microclimatic conditions occurring on northern slopes.

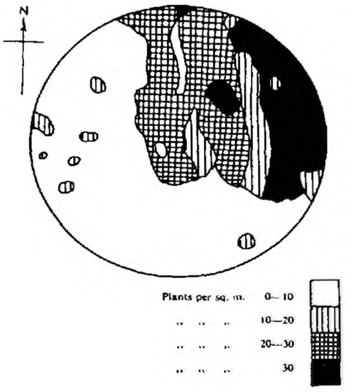


Figure 2.7: patterns of plant colonisation on a conical spoil heap in County Durham of relatively uniform substrate composition at 23 years since disturbance.

Source: Richardson and Greenwood (1967)

This research highlights the importance of limiting differences in aspect recorded for each site as the resulting differences in floristic composition may obscure any patterns that may be attributed to time (Section 3.2).

2.3.2.3 Canopy cover

Canopy-cover has been included in microclimatic factors rather than vegetation factors as an indication of shade patterns that may affect vegetation development within or between sites (Section 5.3.3).

In a study of floristic composition on a garden lawn, Austin and Belbin (1981) found that shade profoundly affected floristic composition even in a small garden area. Shade does not just affect the level of insolation received on different parts of the site, but also humidity, moisture regime and light levels.

Measuring canopy cover will give an indication of the amount of light reaching the understorey layers. It is therefore useful in this study for identifying possible differences between and within sites that may affect floristic composition.

As well as collecting information on shade, the canopy cover parameter also gives information on the percentage tree cover occurring on each site. This information is useful for measuring succession. Tilman's Resource Hypothesis (Section 2.1.2.3) predicts that light levels will drop as succession proceeds. As higher levels of nitrogen accumulate in the soil, higher plants can be supported, which intercept more light. The assumption is thus similar to that of Whittaker (1975) that as a succession develops, the height, massiveness, and differentiation of strata of the plant community increase (Section 2.2.2). By measuring canopy cover it may be possible to see whether the assumption holds true for the Forest of Dean spoil heaps.

2.3.3 Non-floristic vegetation factors

This section describes how the measurement of vegetation factors such as vegetation height, biomass estimates, and species diversity (Table 2.3) may be complimentary to floristic data in the study of plant succession. Studies relating to specific trends outlined in Table 2.2. such as changes in species diversity over time (Section 2.3.4.1) are also examined where relevant.

2.3.3.1 Vegetation height and biomass

Alongside information on canopy cover (Section 2.3.2.2), measuring the height of different vegetation layers in the Forest of Dean may help to determine whether the massiveness and stratification of a plant community changes during succession (Section 2.2.2).

Vegetation height measurements will also compliment the % cover-abundance measurements to provide an estimate of biomass (Section 5.7.1). The estimation of biomass may also allow Tilman's resource ratio hypothesis to be applied to the data (Section 2.1.2.3). It may also help to provide an indication of whether vegetation is protecting the surface substrate from insolation. This is particularly relevant because of the findings of Richardson (1958) described in Section 2.3.2.2.

2.3.4 Species Diversity

Species diversity has two components, species richness and species evenness. Species richness is defined as the number of species per unit, whereas species evenness related to the abundance of each species (Magurran, 1988). Both components are important in determining and comparing species diversity between sites or between different samples taken within a site. For example, if floristic information was recorded from two quadrats, and both were found to contain 15 species, the species richness is the same. However, if *Pteridium aquilinum* dominated one quadrat with a cover-abundance of 90%, species are much less evenly distributed (and therefore less diverse), than a sample where all 15 species have cover-abundances of 6-8% each (Kent and Coker, 1992).

2.3.4.1 Changes in species diversity over time

According to Whittaker (1975) and Odum (1969, 1971) (Section 2.2.2), species diversity is expected to change during succession from species-poor to species rich as the height and complexity of the plant community increases, and from being un-evenly distributed to evenly distributed (Section 2.2.2). However, Whittaker (*op. cit.*) himself noted that these changes are complex, and in many plant communities such as temperate woodland, plant diversity may decrease in the later stages of succession.

Tilman (1982) considers that decreases in diversity in the later stages of a succession may be caused by increases in biomass production over time (Figure 2.3, Section 2.1.2.3), leading to the dominance of those species most effective in competing for light, and the suppression of less competitive species. Gough *et al.* (2000) however, argue that diversity and biomass are not significantly correlated, warning that a number of environmental variables are responsible for diversity.

The "intermediate disturbance hypothesis" of Connell and Keough (1985) argues that diversity is maximized in sites where disturbance such as grazing occurs that is sufficient to prevent the development of dominant species, yet insufficient to cause regional destruction. Proulx (1998) confirmed that grazing pressure is an important factor influencing species diversity in temperate ecosystems. A literature review study was undertaken that provided 44 comparisons of species richness under low and high grazing pressure in nutrient rich, or nutrient poor plant communities. As simplified in Figure 2.7, the study found that nutrient poor communities exhibited significantly lower species richness under high grazing than under low grazing. Nutrient rich ecosystems exhibited significantly higher species richness under high grazing rather than low grazing.

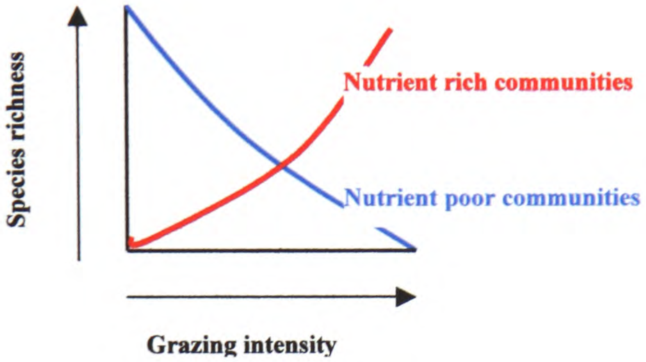


Figure 2.7: Proulx (1998) reviewed 30 grazing studies and found that plant species richness tends to decrease with high grazing in nutrient poor ecosystems, and but increase in nutrient rich ecosystems.

According to Kent (1987), grazing can reduce diversity of vegetation establishing on substrates that are extremely nutrient poor such as colliery spoil, as the disturbance places too much additional pressure on the plants, which are already under stress from the poor environmental conditions of the rooting medium.

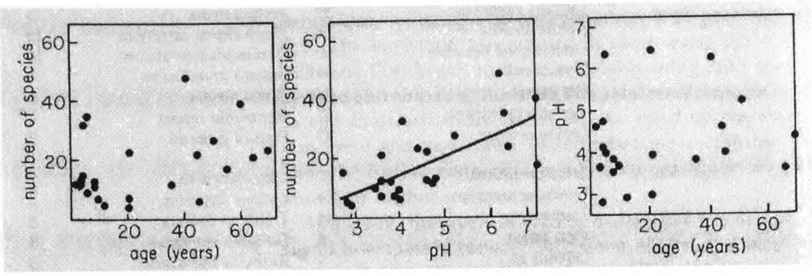


Figure 2.8: The relationship between age, pH and species richness on colliery spoil heaps in Yorkshire (Bradshaw and Chadwick, 1980)

The environmental gradients present on a site may therefore influence diversity as much as the grazing pressure. Bradshaw and Chadwick (1980) for example, found that species richness was correlated with pH (Figure 2.8). Age and pH were not correlated, supporting the view that there are many environmental gradients other than age that are likely to influence diversity.

However, the expected trends outlined in Section 2.2.2 for species diversity were found to occur in Prach's (1987) study of the colonisation of lignite spoil heaps. Species richness was highest in the fifth year of succession, the community was dominated at that point by one main species. Species diversity was considered greatest in the 12th-15th year, as evenness was highest at this time. However, diversity had decreased slightly by the 30th year.

The results found by the studies reviewed above show that there are many environmental factors that may influence diversity. Diversity may increase over time in the initial stages of a succession as species colonise a site and develop into a more closed community, as shown by Prach (*op. cit.*) However, factors such as substrate nutrient status, pH and grazing pressure may be as equally important in determining diversity between or within sites. Harris *et al.* (1996) further point out that the vegetation types that may develop on colliery spoil, such as acid grasslands and heathlands naturally have very low species diversity, and therefore the type of community that has developed must also be taken into consideration.

Increases or decreases in species diversity cannot therefore be used to indicate that succession is or is not occurring. However, it is a useful means of comparing samples or sites to investigate the effects of differing environmental gradients, as required by Objective viii (Section 1.1).

2.3.4.2 Island biogeography and the species-area relationship

Island biogeography and the species-area relationship may also have implications for the species diversity of colliery spoil heaps in this study due to the differing sizes of the spoil heaps and the differing sizes of the sample plots (Section 5.1).

The island biogeography theory (MacArthur and Wilson, 1967) hypothesised that on islands, an equilibrium stage is reached where the rate of species invasions is counterbalanced by the rate of extinction. The size of the island and the number of species arriving are inversely related and the relative isolation from propagules will affect species diversity. If primary substrates such as spoil heaps are thought of as virtual islands due to substrate differences from the surrounding area (Gray, 1982), it may be hypothesized that the bigger the spoil heap the more chance propagules have of landing on the site. However, this does not always hold true. Studies on the re-colonisation of primary volcanic substrates on Mount St. Helens found that the central patches of large areas of bare substrate were less diverse than the edges. It was thought this was because they are further away from a colonising source. Large areas may therefore be less diverse (del Moral and Wood, 1993).

The species-area relationship states that the larger an area surveyed, the more species are likely to be recorded. This is due to the increased environmental variation likely to be found over larger areas than smaller areas, which affects floristic variation (Hopkins, 1955; Connor & McEvoy, 1979; Leps & Stursa 1989).

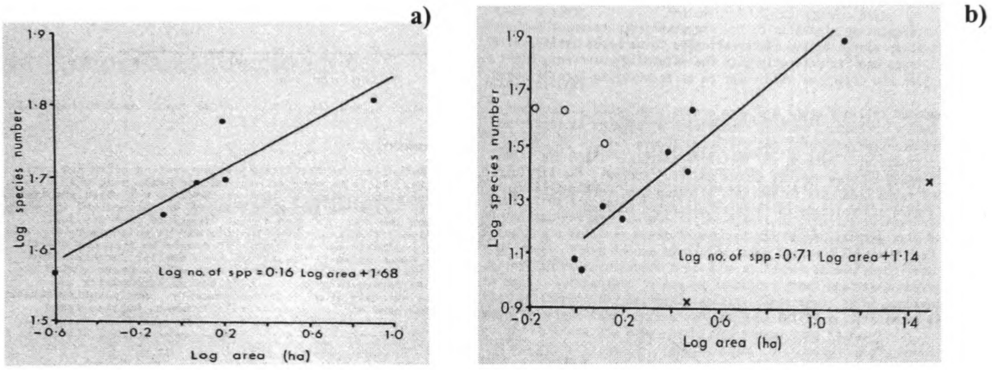


Figure 2.9: The regression of log species against log area for a) Leblanc wastes and b) unwooded colliery spoil (o = sites of 100 years or more; ! = sites aged between 50-30 years). Reproduced from Gray (1982)

Gray (*op. cit*) examined the differential area of three different categories of waste tip (Leblanc waste, non-wood habitats on colliery spoil, and wooded habitats on colliery spoil) in relation to species richness, as shown in Figure 2.9. The habitats that developed on Leblanc wastes (Figure 2.9a) and wooded colliery spoil sites (not shown) fitted the species-area hypothesis, with species number increasing with area. However, other factors such as age were found to affect species richness on non-wood habitats on colliery spoil tips (Figure 2.9b). The three 100+ year old sites had relatively high species numbers but were small in area. The main group of tips aged 50-30 years however, produced a high correlation co-efficient between area and species richness.

This research shows that the number of species arriving on a spoil tip is likely to be affected by the area of that spoil heap as well as the environmental factors present on that site (Section 2.3.4.1). This finding is particularly relevant because the differential sizes of the spoil heaps selected for use in this research range from 600ha to 1ha in size (Section 4.1), and sample plot sizes were also different in area (Section 5.1).

2.3.5 Species strategies

If the Gleasonian idea that every plant species responds to different environmental gradients in different ways (Section 2.1.1.2) is developed, it may be possible to categorise different types of species that have particular strategies or attributes, and predict the ways in which they may respond to various environmental changes (Duckworth *et al.*, 2000). Species composition may be expected to change over time, as environmental conditions such as light and nutrient status change (Section 2.2, Section 2.1.2.3). Different species strategies may therefore be better able to compete at different temporal stages during a succession. This section examines the type of changes theoretically expected during a succession, how these changes have been measured in previous studies, and whether the expected changes were recorded on colliery spoil.

2.3.5.1 Models of species-strategy changes during succession

The *r* and *K* hypothesis predicts that *r*-strategists will be amongst the first species to colonise, as they are adapted for rapid growth and survival in disturbed conditions. As the ecosystem develops, these will be displaced by *K*-strategists, plants adapted for a longer life, who divert resources from reproduction to storage and defence. For example, Harper and Ogden (1970) grew *Senecio vulgaris*, a common annual present on some Forest of Dean sites under various conditions designed to simulate a stress gradient. Whilst these different treatments were found to affect plant size, each plant still allocated 21% of it's energy to seed production. Biennials and perennials on the other hand need to reach a critical plant size before flowering is initiated When environmental conditions are not favourable, the onset of reproduction is delayed. In theory then, annuals are likely to be successful in colonising primary substrates with fewer available nutrient resources because they are able to reproduce under conditions of environmental stress. However, because so much energy is allocated to seed production rather than sustained plant growth, these plants may become less competitive as edaphic conditions improve, and a more closed sward develops, allowing the species that devote more energy to growth to flourish.

Grime's C-S-R continuum (section 2.1.2.3) predicts that species with mechanisms allowing them to tolerate stressful conditions will be found in low-disturbance/high-stress environments. Species with mechanisms that tolerate disturbance (ruderals) will be found in highly disturbed conditions such as pathways. Species with competitive strategies will prevail under conditions of low disturbance and low stress (Grime, 1977; Grime *et al.* 1988). Stress-tolerant species and ruderals may therefore be found at the beginning stages of succession when soil substrates may not be well developed, and nutrients are scarce. More competitive species may be found on sites where these conditions have been ameliorated over time.

2.3.5.2 Species-strategy changes over time on colliery spoil

Figure 2.10 shows the relative dominance of annuals, biennials and perennials over a 30-year period on lignite dumps in the Czech republic, as studied by Prach, (1987). It was found that annuals and biennials did dominate the first 5-10 years of the succession, and perennials rapidly increase in dominance after 5 years.

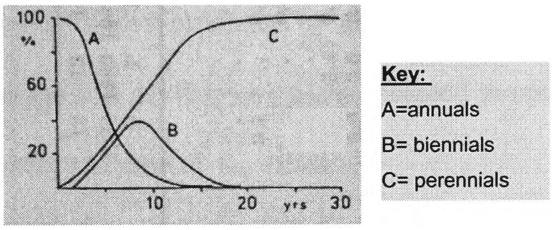


Figure 2.10:Dominance of growth-forms over 30 years (Prach 1987).

Brierley (1956) found a similar phenomenon on a 10-80 year chronosequence of the Nottingham-Derbyshire and south Yorkshire coalfields. On the 10 year-old pit heaps, 89 % of species were annuals or biennials, and only 11% perennials. By 80 years, 91% of all plant species were perennials. These results support Grime's hypothesis, suggesting that the shorter life-span and fast reproduction mechanisms of annuals are well adapted to initially open conditions found on coal wastes, but that longer-lived species eventually predominate as the community becomes more closed and competition for resources becomes more important.

Of the more specific mechanisims that enable plants to survive on colliery spoil, Down (1973) examined the life-form of plants on a chronosequence of the

Somerset coalfield (12-98 years), described according to Raunkier (1937). Therophytes initially comprised 23% of the flora, but declined to 9% on older tips. This life-form category consists of plants that usually live from spring to autumn, and over-winter as seeds – i.e. ruderal plants adapted to disturbed conditions by allocating energy into annual reproduction rather that growth. Rosette species also declined from 32% - 11% over time. These species can be described as stress-tolerant as they have long tap roots that may help the plant to anchor itself in the unstable colliery spoil, and forage for water and nutrients. The decline of species displaying both these strategies is also predicted by Grime (*op. cit.*), as they are likely to be out-competed as the soil develops by plants adapted to competition for resources, allocating more energy to growth

Gilbert (1989), found that species producing many wind-dispersed propagules were the most successful colonists of disturbed ground in urban areas, as the propagules saturate substrates, and are therefore able to rapidly colonise any site that becomes available. This may be relevant to the Forest of Dean as substrates in urban areas, like colliery spoil, can be skeletal and have low nutrient status (Gemmell, 1977).

Prach *et al.* (1999) meanwhile noted the importance of vegetative expansion on steep conical spoil heaps in the Czech republic. Here, colts-foot, known to exhibit rapid clonal growth mechanisms, reached 40% cover-abundance in 15 years, and no further successional changes occurred over the 20 years studied. Vegetative expansion may therefore be an important strategy for colonising unstable spoil heap environments. Schramm (1966) for example, noted that vegetative spread from species surrounding the spoil heaps was important on the margins of spoil wastes in Pennsylvania, but clonal species had not colonised the tops of spoil heaps.

However, in a study of clonal growth forms on a variety of habitats, Prach and Pysek (1994) found that species with clonal mechanisms of growth formed the dominant component of vegetation on all habitats. Without extensive studies on other types of habitat in the Forest of Dean it may therefore be difficult to ascertain whether any patterns of change that may be found over time in the strategies of species establishing on the sites are different to those of other substrates (Section 10.4.3).

Of other plant growth mechanisms, Schramm (*op. cit.*) found that despite large quantities of seed rain reaching the coal wastes, seed-dispersed species were not successful site colonists, whereas woody plants with large seeds (containing more resources to encourage growth) such as oak and aspen, were more successful.

Legume species also be expected to occur on colliery spoil in the early stages of succession, as these are stress-tolerant species able to fix the atmospheric nitrogen deficient in colliery spoils via symbiotic bacteria contained in root nodules. However, the soil gradually becomes enriched by these nitrogen-fixers, facilitating the growth of non-nitrogen fixers. Once established, these other species have a competitive advantage, as they do not have to give up energy to support bacteria in their roots (Davies *et al.*,1992). Studies such as Marrs and Bradshaw (1982) suggest that the accumulation of nitrogen in primary succession on industrial wastes is directly correlated with legumes.

2.3.6 Further factors affecting floristic composition

Previous sections in this chapter describe how factors such as pH, pyrites content, nutrient status, aspect, slope factor, shade, area, and species response to environment may affect floristic composition. However, studies that have been undertaken on colliery spoil have found that factors that were not predicted in Tables 2.2 and 2.3 may also influence species composition, such as propagule source, distance from the propagules source or other physical barriers. Edaphic conditions can be very different from those of surrounding habitats, meaning that propagules that do reach the site may not be suitable or able to survive. Finally chance factors can also influence floristic composition.

Hall (1957) studied a chronosequence of colliery spoil heaps from different coalfields in the UK. A relationship between colonization by woody species and the number, distance and bearing of tree species available as seed source was found to exist. In North Staffordshire, pits on the south and west of the coalfield were well wooded, whereas on the north and east there were few if any wooded heaps. Woodland was prevalent south and west and the prevailing wind was southwest. On the east and north, however, there was a physical barrier of industrial towns in between the seed source and the heaps. He concluded that the flora of the area surrounding the heap had a profound influence on species composition but that physical barriers could also influence colonisation by preventing propagules from reaching the site.

Ash *et al.* (1994), and Gray (1982) both report on an experimental approach to test the main factors affecting primary succession on colliery spoil, Leblanc (alkali) and blast furnace slag in North West England. The 100-year old sites of all wastes still had a very open (50% cover) and restricted flora. Most species were pioneer ruderals that are common in the surrounding areas. However, on the Leblanc wastes, a more specialised flora had developed because of the strongly alkaline substrate. The nearest propagule source for some species was coastal dune systems 30-40km away. The reasons for poor vegetation cover were hypothesised as being a) extreme edaphic conditions, and b) the difficulties of immigration encountered by appropriate species. To test these hypotheses, locally collected wild seed mixtures were sown which contained species known to be adapted to the characteristics of each site, but currently absent. Survival rates of species were recorded after 6 years. Seventeen species out of 36 introduced became permanently established on the Leblanc wastes and 21 out of 41 on blast furnace slag. As these species successfully colonised the sites after introduction, it was concluded that there were vacant ecological niches for these species, despite edaphic conditions, and that immigration clearly was a problem.

Del Moral and Wood (1993) studied primary succession on the volcanic substrates formed by the Mount St Helens eruption, 1980, Washington State, USA using permanent plots & seed traps marked out and sampled since eruption. They note that floristic composition is qualitatively very different on isolated sites compared to sites near intact vegetation. Evidence indicates that even short distances combined with hostile substrates are barriers to the establishment of some species, and that species that do exist are therefore common in surrounding areas or arrive and establish by chance.

Demonstrating the role that chance factors may play in succession, Einarsson (1973) and Fridriksson (1987) describe the primary colonisation of the volcanic island Surtsey, Iceland. In the first few years after the eruption started, vegetative and seed material was found from over 30 species of plants. The only individuals that managed to establish were however, halophytic coastal species common in the region. These had sea-borne seeds able to float and withstand immersion in salt water. However, individuals tended to establish near to the high tide line where they were prone to being washed away by severe coastal erosion. By 1986, the 64% of the species colonising the island has propagules that were brought to the island by birds. The colonising species are not necessarily the ones that are best fit for being pioneers, but are the ones that by chance have arrived on the island.

Mueller-Dombois (2000) also found that chance factors influence the recolonisation of volcanic material. The primary succession started with mosses, ferns, lichens, and a few seed plants. A short lived perennial mat-forming shrub eventually began to spread, but no further species were able to colonise the site for many years until a species of goose started to use the site, spreading seeds of native heath shrubs that are disseminated only by berries. Time since material deposition was a less important factor in the speed of succession than the availability of favourable microhabitats for initial colonisers, and animal activity that functioned as a propagule dispersal agent.

2.4 Summary

The historical development of the succession concept is explored to set the applied studies into context. Clements (1916) thought that succession occurs as a pre-determined systematic process, from lower to higher plants, and ending at a stable, climax, vegetation type. Gleason (1917; 1926; 1927) argued that every assemblage of plants is likely to be unique, because each plant species responds individually to biotic and abiotic factors. There is likely to be different combinations of these factors at any given point on earth, therefore a different plant assemblage at each. The climax pattern analysis of Whittaker (1953; 1974) recognised that plant communities are distributed as continua along environmental gradients, but that vegetation does form mosaic patterns that are repeated in space where environmental conditions are similar. Modern viewpoints recognise that biotic interactions occur within assemblages of plants. However, change is thought to occur at the level of the individual, and the niche properties of the constituent species are therefore an important element of succession.

Theories on the mechanisms of succession are reviewed to enable results from this research to be placed within the context of theoretical ecology. Connell and Slatyer (1977) argue that successions do not necessarily occur sequentially, with waves of different plant communities replacing each other, but can also occur by other mechanisms such as the gradual exclusion of initial colonists by slower-growing competitors. Tilman (1985, 1988) and Grime (1979) both assert that those species likely to be dominating a plant community any given time are those best adapted to the environmental conditions present. Picket *et al.* (1987) emphasise the complexity and stochastic nature of the successional process, with a multitude of factors likely to influence species composition, including chance.

Whittaker (1975) and Odum (1969, 1971) both list generalised trends that may be expected to occur during succession, such as substrate, microclimate, species diversity, and species strategies. These have been adapted for use within this study as quantitative measures of succession.

Previous studies undertaken on coal wastes are reviewed. These studies show that pH on colliery spoil heaps can be low at 1.5-2.0, a level directly harmful to plants, due to the presence of FeS_2. FeS_2 causes acidity because it reacts with oxygen and water, and this process generates sulphuric acid. Pyrites is likely to be present in the Forest of Dean wastes, as pyritic sulphur is known to range from

0.41-3.19%. If plant growth is retarded by substrate acidity, ecosystem development can be held up for many years. The lack of nitrogen can be a particular problem, as very little nitrogen is thought to be available in colliery spoil (Williams and Cooper, 1976; Kent, 1982; Palmer *et al.* 1985), and therefore nitrogen resources are mostly built up in the soil through biotic processes - vegetation growing, dying and rotting to provide organic matter and nutrients for new plants.

Slope can influence substrate stability, drainage, and the movement of water and soil. Plant growth can be retarded on spoil heap slopes as the instability of the surface, combined with soil creep and heavy surface water flows can prevent seedlings from establishing. Even small-scale differences in micro-climatic factors such as drainage pattern or shade can affect floristic composition. Aspect can also affect floristic composition and vegetation development. The increased insolation received on south-facing slopes can retard vegetation growth, as in summer months the black substrates absorb heat, and surface temperatures can rise above 50°C.

Species diversity does not necessarily increase with age. It tends to decrease with increasing biomass unless the competitive species are suppressed by a continuous moderate-intensity disturbance such as grazing. Grazing may reduce species diversity in ecosystems such as colliery spoil heaps that are nutrient poor, as it exerts additional pressure on plants communities already under stress from the poor substrate conditions. Different areas of spoil heaps may affect species-diversity. The species area effect means that more species will be recorded from larger sites than smaller ones. This has the potential to affect results taken from the Forest of Dean. If spoil heaps are considered virtual islands, the theories of island biogeography suggest that bigger spoil heaps may also be more species rich as there is a higher chance of propagules landing on the site.

The *r* and *K* hypothesis outlined in Table 2.2 predicts that shorter lived *r* strategists such as annuals will be the first type of species to colonise a bare site, followed by longer lived *K* strategists such as perennial species. Evidence from two studies undertaken on colliery wastes have found annuals to be more prevalent at the beginning of a succession, with perennials increasing over time. Grime's CSR continuum predicts that plants which are stress-tolerant will be present in conditions of high stress at the beginning of a succession, and that species with more competitive strategies will increase in dominance as conditions ameliorate. Down (1973) however, found that rosette species to be higher at the start of the succession, possibly due to their long tap-root that will aid against drought and instability. Prach *et al.* (1999) found that clonal growth strategies were important strategies on colliery spoil due to the instability.

Evidence from previous studies indicates that succession does not tend to occur by the Clementsian facilitation mechanism in the Forest of Dean, as higher plants such as birch have been found to be amongst the first colonists. Chance factors play a much greater role in influencing succession such as the vegetation type surrounding the spoil heap, and whether there are physical barriers to propagules arrival.

Chapter 3.0: Selection of a chronosequence in the Forest of Dean

Space-for-time substitution (SFTS) is used in this study as a method of studying succession. Sites are selected that have the same substrate and landform conditions, but the surfaces are of different ages (e.g. tipped at different times). Provided that time can be isolated as a factor, this method allows the short time-frame of the research period to be overcome. The method is discussed further in Section 3.1. Section 3.2.1 explains how suitable sites were identified and information on them found. The site selection methodology is outlined in Section 3.2.2, showing how the environmental variance between sites was minimised. Sections 3.1 and 3.2 together fulfil objective ii (Section 1.1.2).

3.1 Space-for-time substitution

As introduced in Section 2.1.1, if succession is to be studied, time must be included as an environmental factor. One of the main difficulties of studying succession is that the time-frame of the research is relatively short, whilst successional change may occur over decades or centuries (Major, 1974). The methods used to solve this problem are outlined in Section 3.1.1, whilst Section 3.1.2 examines why the method was considered suitable for use in this study.

3.1.1 The choice of a method to study succession: space-for-time substitution theory

There are several methods of studying vegetation change over time, but only two of these are suitable for studying plant succession: fixed-plot sampling and space-for time substitution (Pickett, 1989). Pollen analysis, for example, was used to examine vegetation change over 6,000 years on the Somerset Levels (e.g. Coles and Hilbert, 1975). The relative frequency of species occurring in each peat layer was counted, and from this information vegetation types were inferred. Rackham (1986) and Moore (1962) meanwhile, used historical maps to show how the shape and extent of habitats changed over hundreds of years. Neither method however is suitable for the aims of this study, which needs to collate in-depth information necessary to examine relationships between plant communities, environmental gradients and time, to enable management recommendations to be produced (Section 1.1).

Pickett (*op. cit.*) considers that fixed-plot studies, whereby plots are revisited annually or biannually, provide the best detail for the study of succession. Einarsson (1973) made annual observations on the colonisation of Surtsey (Section 2.3.6). Fridriksson (1987) later re-visited the data. The studies were able to investigate the year that different species arrived on the island, how each species arrived, and how successful each method of establishment was. Fixed-plot studies on grassland habitats have been undertaken at Rothamstead (UK) since 1856, and have shown how species composition changes over time when different treatments are applied. This has also enabled fluctuations and cyclical changes to be monitored (e.g. Harper, 1971).

The limited time-frame of this study however, mean that the fixed-plot method was not considered appropriate for this study. Unlike Fridrikkson (*op. cit.*), no previous data-sets were available to re-visit in the Forest of Dean either. The alternative method for studying succession, space-for-time substitution (SFTS), was therefore investigated.

Table 3.1: Advantages of using space-for-time substitution

Advantage	Reference
Enables successional change that has occurred over centuries to be measured during a short time-period	Pickett (1989)
Seasonal fluctuations eliminated	Bakker *et al.* (1996)
Provides accurate prediction of floristic change	Foster and Tilman (2000), Norland and Hix (1996)
Used in previous vegetation and soil studies over time on colliery spoil.	Brierley (1956), Hall (1957), Down, (1973, 1975a, 1975b)
Shows how time affects broad-scale changes in vegetation patterns over time on different substrates (glacial moraines; sand dunes; mine wastes)	E.g. Matthews (1978, 1979), Lichter (2000), De Kovel (2000); Knoche *et al.* (2000).

Table 3.1 summarises the advantages of using the SFTS method in this study. It is for the reasons outlined in Table 3.1 (and Section 3.1.2) that the SFTS method was used in the Forest of Dean. In particular, Bakker (*op. cit.*) points out that the SFTS method reduces noisy data on fluctuations and cyclical vegetation change, which can be an advantage where longer-term trends are sought. Foster and Tilman (*op. cit.*) compared fixed-plot data with data collected over the same time-frame using SFTS, and found that the SFTS method did provide an accurate prediction of floristic change in an old-field (prairie) succession.

Pickett (*op. cit.*) however, warns that if using the SFTS method, care must be taken when selecting sites because of the assumption made: that sites within the chronosequence have only been affected by time. Matthews (1978, 1979), for example, investigated the spatial variation of vegetation on glacial moraines using a chronosequence of over 10,000 samples and 638 sites. The study found that spatial variation is extremely complex. Variations in vegetation could be broadly interpreted by age, highlighting the advantages of the SFTS method. However, micro-scale topographic variations and environmental variation also affected spatial pattern, as described in Section 2.3.2.1.

Pickett (*op. cit.*) also warns that biased results may be produced if plots or quadrats are selected on a subjective basis (Table 5.2), particularly if sites are picked to fit presupposed ideas on succession (e.g. Section 2.1.1.1). A site selection procedure was therefore used in this study (Section 3.2) not only to help isolate time as a factor (Section 3.1.2), but also to ensure that sites were not selected on a subjective basis.

3.1.2 Suitability of the space-for time substitution method in the Study Area

The first requirement of the space-for-time substitution (SFTS) method is that a series of sites of different ages are available that can be ordered to form a chronosequence. According to Burrows (1990), if using the SFTS method, the time factor must be isolated as much as possible by minimising environmental differences between sites, such as substrate, landform and environmental conditions. By minimising environmental variance between sites, it can therefore be assumed that the vegetation occurring at each site has been affected by similar environmental conditions. There are therefore advantages of using the Forest of Dean as a study area:

a) Colliery spoil heaps spanning two centuries (Section 1.3.3) are present within a relatively small area, presenting an ideal opportunity for forming a chronosequence
b) All sites are located on the plateau of the Dean Plateau and Wye Valley Natural Area (English Nature, 1999). All sites will therefore be initially

similar in terms of climate, geology, and regional species pool (defined according to Partel *et al.*, 1996).

One of the problems of using the SFTS method on colliery spoil heaps is that the substrate is an anthropogenically-altered waste product which is heterogeneous in nature. It may therefore be difficult to minimise within-plot variation of environmental factors such as substrate chemistry (Tasker and Chadwick, 1978), moisture regime (Richarson and Greenwood, 1967), and substrate physical characteristics (Down, 1974, 1975a).

The SFTS method has however, been used in previous studies on colliery spoil heaps to study vegetation changes over time in the UK. Brierley (1956) for example, used the method to study changes in the attributes of plant species colonising the Nottingham-Derbyshire and South Yorkshire coalfields over an 80-year period (Section 2.3.5.2). Hall (1957) used the space-for-time substitution method to describe broad-scale vegetation changes over time on coal spoil heaps of different ages from seven different coalfields (Figure 2.1). He concluded that due to the differences seen in vegetation type over the different coalfields that age is a far less important factor in determining vegetation development than spoil heap configuration, pH, and the vegetation of surrounding areas. (Section 2.3.6). The number of environmental and human factors found by Hall to influence vegetation also highlights the importance of using selection criteria to reduce the number of variables within this study.

The SFTS method has also been used to examine substrate and ecosystem development as well as vegetation development. Down (1975 a, 1975b) studied chemical and physical substrate changes over a 178-year time period. Definite trends were found to occur over time in surface instability, gully erosion, substrate vertical stratification, pH, nutrient status, and organic matter. Fyles *et al.* (1985), also found space-for-time substitution a useful method for examining the development of coal mine substrates prepared and seeded over a much shorter 6-year time scale for agricultural use. The sites were compared with naturally re-colonised sites of 15 years-since-mining, and unmanaged sites to determine how ecosystem function differed with the different treatments.

Whilst this brief literature review illustrates some of the problems associated with the space-for-time substitution method such as substrate heterogeneity, the method was used in this study because of the many advantages (Table 3.1). The method has been successfully been used to describe trends in vegetation development and substrate development by previous studies on colliery spoil despite the drawbacks. There are also advantages of using the Forest of Dean as a study area, as a chronosequence of sites is available for study, and all sites are located within the same Natural Area (English Nature, *op. cit.*).

3.2 Finding and selecting suitable study sites

This section describes the processes by which the vegetation plots were identified and selected for inclusion within the experimental design. The plots that were selected are described further in Section 4.1. Mapping information on plot location is provided in Appendix 1.2.

3.2.1. Site identification

As the study area is some $85\mathrm{km}^2$ (Section 1.2), finding potential sites for inclusion within this large study area was a vital part of the research. The strategy described in Figure 3.1 was therefore used for finding and locating study sites.

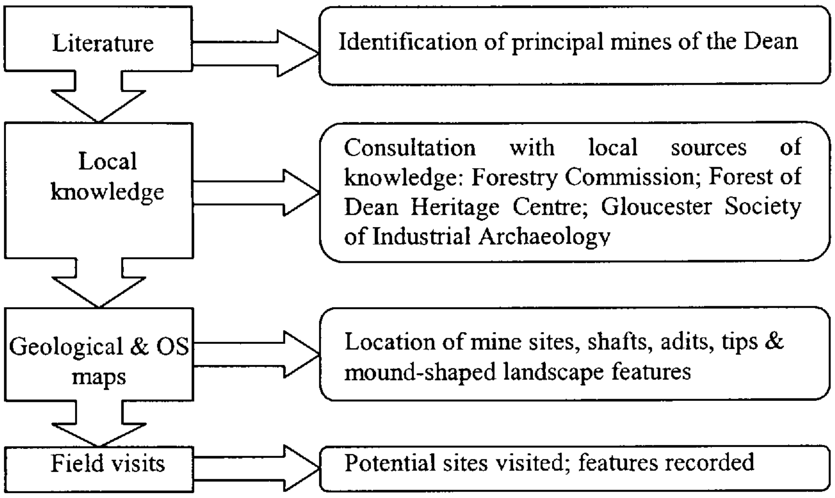


Figure 3.1: Flow chart to describe the process of locating spoil heaps for potential inclusion within the research

3.2.2 Site selection criteria

The results of the site identification process are shown in Appendix 1.1 and summarised in Table 3.2. These sites could not all be included within the study because many are very different in terms of size, management and origin. According to Kent (1980), this is a common problem on coalfields. He recommends that ecological criteria are applied to the sites in a selection process. This process can help to ensure that the sites used in a study are all comparable in terms of key variables, and therefore suitable for use with the SFTS method (Section 3.1).

Table 3.2: Summary of coal waste sites located in the Forest of Dean that were considered for inclusion within this study. The main characteristics of the sites are given, with red text denoting unsuitable characteristics, and therefore reasons for exclusion. Appendix 1.1 contains further details of each site.

Site name	Enclosed	Habitat	To be removed	Age	Loosely tipped	Opencast/other waste	Slope factor	Biking	Walking	Other
Baileyhill	N	grassland/scrub	N	70-90	Y	N	20	N	Y	small area
Barnhill Coalpit	N	heathy scrub	N	?	Y	N	0-10	Y	Y	
Bixlade valley mines	N	conifer	N	?	Y	N	30	N	Y	
Bowson House	N	grassland	N	?	Y	N	23	N	N	small area
Baileyhill	N	grass/heath	N	70	Y	N	25	Y	Y	too small
Barnhill Coalpit	N	heath/scrub	N	55	Y	N	flat	Y	Y	
Bixlade mines	N	woodland	very disturbed	120	Y	N	various	N	Y	aspect
Bowson House	Y	grassland	N	400?	Y	N	20	N	N	too small
Cannop	N	Various	Y	40/15	Y	N	35	Y	Y	
Castlemain	N	conifer	N	62	Y	N	10	?	Y	
Cinderford Linear Park	some	parkland	N	14	N	Y	flat	Y	Y	
Crumpmeadow	N	conifer/grass	N	71	Y	Y	20	N	Y	
Eastern United	N	conifer	Y	41	Y	N	20	N	Y	
Foxes Bridge A	N	conifer	N	69	Y	N	35	N	Y	
Foxes Bridge B	N	bare	Y	0	Y	N	n/a	N	Y	
Foxes Bridge C	N	conifer/heath	N	15	N	N	flat	N	Y	
Flourmill	N	Conifer	N	?	Y	N	15-35	N	Y	
Hawkeswell	Y	bare	being removed	35	Y	N	15	N	N	
Haywood level	N	grass	Y	?	Y	Y	flat	N	N	
Lightmoor	N	grass/scrub	N	60	Y	N	40	Y	Y	
Mirystock bridge	N	conifer	N	?	Y	N	30	N	Y	
Moseley Green	N	grass/conifer	N	?	Y	N	20	Y	Y	too small
New Fancy	N	grass/conifer	N	55	Y	N	30	N	Y	
Northern United	Y	conifer/bare/grass	N	35/5	Y	N	17	N	N	
Parkend	N	braken/grass	N		Y	N	10	N	Y	
Princess Royal	N	Conifer	N	35	Y	N	34	N	N	
Quidchurch gale	N	marshy grass	N	?	Y	Y	flat	N	N	
Steam Mills	N	grass	N	29	N	Y	flat	N	Y	
Strip-and-at-it	N	conifer	N	?	Y	N	30	N	N	
Trafalgar	Y	conifer/grass	N	75	Y	Y	15	N	Y	
True Blue	N	heath	N	100	Y	N	20	N	Y	
Waterloo	N	conifer	N	40	Y	N	35	N	Y	
Woorgreen	N	lake/planted	N	15	Y	Y	flat	N	Y	

▨	Shaded rows denote sites that failed the selection criteria and were excluded from the study
☐	Non-shaded rows denote sites that passed the selection criteria

Kent (*op. cit.*) used variables such as slope form, aspect, spoil type, mineralogy and geology. Fyles *et al.* (1985) used age, altitude, slope and spoil type. Down (1975a &b) used geological divisions, spoil type, age, aspect and topography. Similar criteria have therefore been used in this study to define suitable sites: current site management, future site management, age, spoil type tipping methods, and minimum size. Combustion history was also included, as this affects spoil chemistry. Aspect, slope factor, and relative homogeneity were also used to define suitable plots within each site (Section 3.2.3).

The small size of the coalfield meant that climate, relief and altitude were already comparable for all sites, as they are located within a synclinal basin, at 200-250m above sea level. The Dean Plateau and Wye Valley Natural Area (English Nature, 1999) was selected on the basis of land management and cultural history, which also helps to minimise the effects of human factors, although further selection criteria are described below. It was decided not to include stratigraphic geology in the site selection process, because many mines produced coal from more than one seam, and more than one different stratigraphic division (Hart, 1971). The chemical analysis of different seams undertaken by the Ministry of Fuel and Power (1946), as described in Section 2.3.1.2 also reveals that for example, the pyritic sulphur content of the seams varies considerably within seams as well as between seams. It is therefore doubtful whether applying a geological criteria would help to produce sites as similar to each other as possible. The 4 criteria used to select sites from Table 3.2 are outlined overleaf:

i) Current site management

a) Conifer plantations

The vegetation that has colonised the sites should not be influenced by forestry operations such as conifer plantations. These were considered inappropriate in a study of natural colonisation. Planting schemes and management on plantations are designed to suppress the natural growth of any plant species that may compete with the planted trees (John Harvey *pers. comm. 3.11.00*). This is also likely to create microclimate conditions such as shade that are very different from sites that have naturally colonised.

Sites that were entirely forested were therefore excluded. Sites that were partially forested were included for further consideration if some slopes were available that were not planted. One further site, Northern United was included for further consideration as the trees were sufficiently small (<1m) and at such a low density not to have affected natural colonisation by other vegetation at the time of sampling.

b) *Grazing.*

Vegetation on the selected sites should be managed in the same way. All sites selected should have similar grazing or mowing regimes. Enquiries to the Forestry Enterprise (who owned and managed the majority of sites) and private landowners were therefore undertaken to ascertain management practices. None of the sites except New Fancy were under direct management, except for grazing by forest sheep (Section 4.3).

An enclosed plot on New Fancy was chosen alongside a grazed plot to study the effects of grazing exclusion – particularly relevant as all forest sheep were removed from the Forest of Dean between April 2002-April 2003 due to the Foot and Mouth epidemic of 2002.

ii) Future site management

Sites should be free from severe disturbance during sampling. All sites scheduled for shale reclamation or other works were therefore excluded to prevent experimental sites from being disturbed during the period of data collection.

iii) Age

Sites should form a time- or chrono-sequence, so that the space-for-time substitution method can be used (Section 3.1.1).

iv) Source of waste material

The parent waste on all sites should consist of waste materials from deep mining such as argillaceous sandstones, arenaceous sandstones, mudstones, clays and coal wastes. Opencast mining sites, spoil washery yards, and rail-head loading yards were therefore excluded.

v) Tipping methods

All sites should have been created via the same methods, formed via loose tipping before 1970. After 1970, compaction and landscaping were common (Kent, 1987). Small 'free-mines' were therefore excluded, as tipping-methods were difficult to ascertain. These are private sites, owned and mined by local Forest of Dean men. Today they are typically small-scale, employing 1-2 people, and there are many such mines to be found in the Dean area (Section 4.2.1).

vi) Size

All sites should be large enough in area to ensure that the flexible experimental sampling design can be applied (Section 5.1.2).This requires slopes to be a minimum area of 15m by 15m.

vii) Combustion

All sites should have been subject to similar combustion processes. As many of the sites were found to have been subject to burning in the past, this category was picked over sites that had not combusted. All sites were therefore a mixture of burnt and black shales.

3.2.3 Plot selection

As explained in Section 3.3.2, to gain an accurate representation of the vegetation communities present on the spoil heaps, sampling of all sites should be undertaken within a six week period. This meant that the amount of time spent on each site was limited, and it was therefore decided to sample selected plots rather than entire sites. The selection criteria i-iii outlined below ensures that data from each of the sites is comparable.

i) Topography

The plots should all be of similar slope factor (Section 2.3.2.1). They were therefore all selected from the slopes of the spoil heaps, which provide the largest area for study, ensuring that the shedding area at the top of the slope, and the deposition area at the bottom of the slope were excluded.

ii) Aspect

Plots should have a similar aspect due to differing insolation affecting surface temperatures (Section 2.3.2.2). It was not possible to find enough plots to undertake a chronosequence of exactly the same aspect that still fulfilled all other

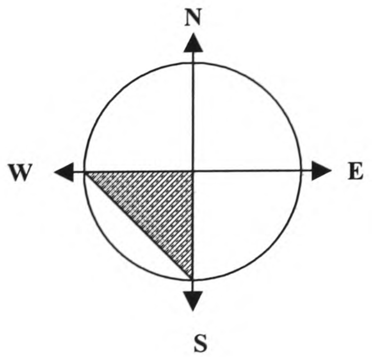


Figure 3.2: Minimising the effects of aspect as an environmental factor: plots selected from between 180°S – 270°W.

criteria. Plots were therefore limited to being south-westerly in aspect (Figure 3.2), as there were sufficient plots of this aspect that did meet other criteria.

iii) *Homogeneity.*

According to Muller-Dombois and Ellenberg (1974) and Krebs (1989), study plots should be chosen that are relatively homogeneous in terms of vegetation cover to minimise environmental 'noise', and therefore maximise statistical precision. As 'homogeneity' is a subjective assessment until the results are gained, selecting particular areas of vegetation for study plots can bias the results of a study, for example by selecting plots thought to be typical of a plant community or typical of particular stages of succession (Jongman *et al.*, 1995; Muller-Dombois and Ellenberg, *op. cit*).

In the study area, sites meeting criteria i) and ii) were found to be too small to require specific study plots to be chosen from each slope anyway. The plots were therefore only separated to meet homogeneity requirements if management differed, or where human activities on one part of a slope had obviously altered vegetation – causing it to be excluded under criteria 3.2.2i. This meant that homogeneity requirements could be met without deliberately selecting particularly 'favoured' or less 'favoured' areas of spoil heaps to sample.

3.3 Summary

One of the main difficulties of studying succession is that time-frame for the research is relatively short, whilst successional change may occur over decades or centuries (Major, 1979). Some studies therefore study succession in real-time using fixed-plots which are observed annually. This method was not suitable for use in this study due to the limited time-frame of the study. The space-for-time substitution (SFTS) method is one way to get around this problem. Other advantages of using SFTS in this study are that the method reduces noisy data on fluctuations and cyclical vegetation change, focussing on longer-term trends. Foster and Tilman (2000) compared fixed plots with a chronosequence of plots, and found that SFTS does provide an accurate prediction of floristic change. The method has also been used successfully in previous studies undertaken on colliery spoil.

The sites must be of different ages to create a chronosequence, but must be initially similar to ensure that environmental heterogeneity between sites is minimised. The main advantage of using the Forest of Dean as a study area is that both of these requirements can be met.

Over 30 potential sites were found within the study area, through a literature review, local knowledge, map-based observations and follow-up field visits. To ensure that the sites used met the homogeneity requirements of the SFTS method, selection criteria were applied to the list of sites. Current and future site management, age, source of waste material, tipping methods, combustion history, topography, aspect, and vegetation homogeneity were used in this study as site selection criteria.

Chapter 4.0: Site descriptions and management at the time of survey

This chapter adds to information provided in Section 1.3. Section 4.1 provides details of the sites selected for use in Section 3.2. Information from local knowledge, previous studies, and photographs are included where they help to identify environmental gradients present on the sites (Objective v, Section 1.1), or evaluate results (e.g. Section 10.1.4.6.2). Much site information for example, was gained from local knowledge including reports written by local industrial archaeology experts such as Hobday (1994) (Section 4.2.2). Appendix 1.3 provides further details of local sources of information and site visits.

Section 4.2 explains why this study, with it's focus on conservation management of spoil heaps in the Forest of Dean, is important. It is argued that the Forest of Dean spoil heaps are unique compared to other coalfields and have ecology, landscape, amenity and cultural interest. Section 4.3 examines management at the time of survey, problems resulting from management methods, and threats to management. This section shows how this study may aid future management decisions (Section 10.2), and help to conserve or improve the nature conservation value of the spoil heaps.

4.1. Site descriptions

Each site is described in Sections 4.1.2—4.1.7 starting with the age of the youngest plot in the chronosequence sampled on that site (Table 4.1). Maps showing the location of the study plots on each site are shown in Appendix 1.2, as well as additional photographs relevant to the study.

4.1.1 Plots that passed the selection criteria

Tables 4.1 and 4.2 provide a summary of the plots that passed the selection criteria described in Section 3.2, and were therefore included within the experimental design of this study (Section 5.1). Figure 4.1 shows where the sites are located within the Forest of Dean.

Table 4.1: List of sites that meet the site selection criteria applied in Section 3.2

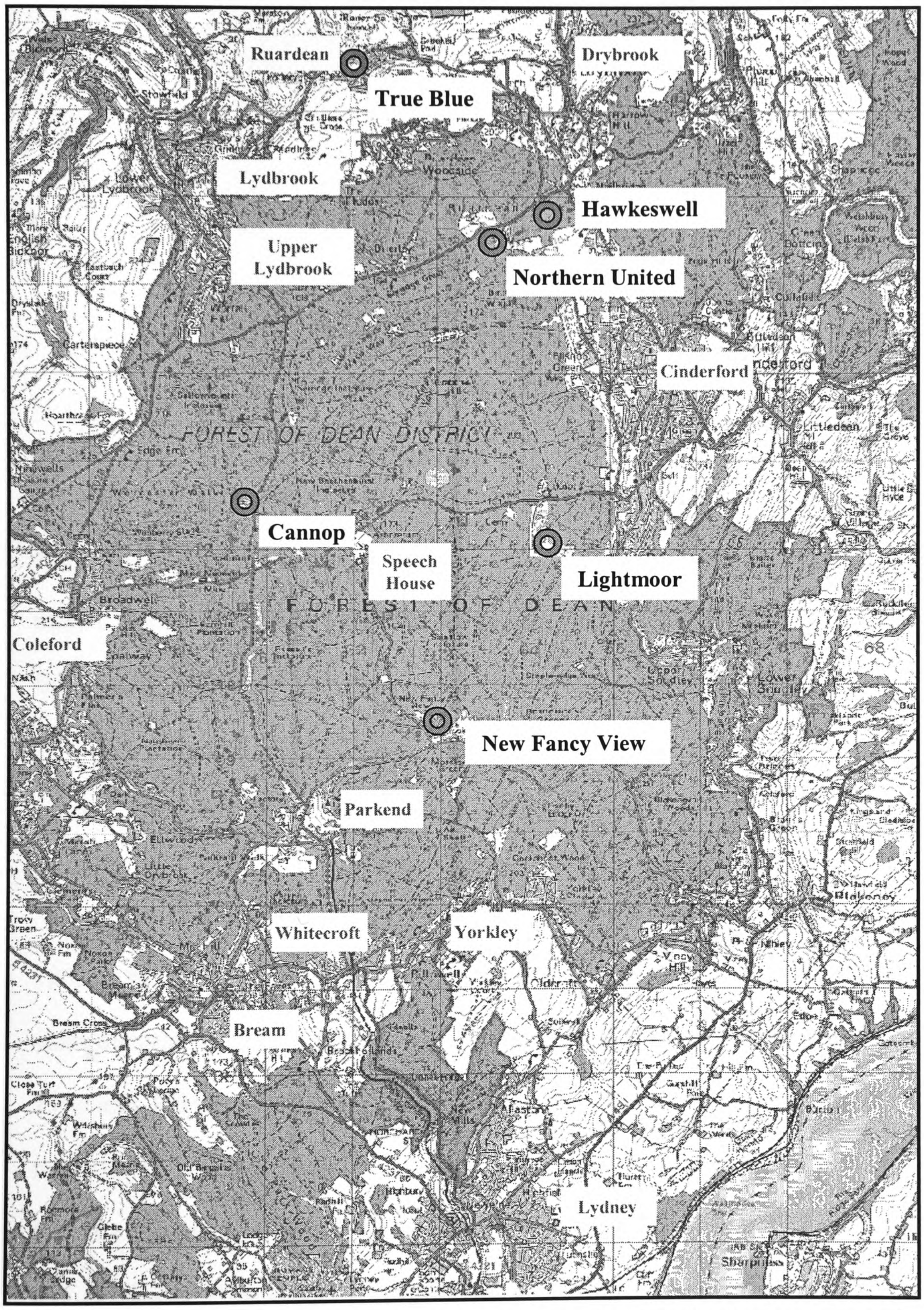
Site	Grid Ref.	Slope °	Age	Aspect	Habitat	Tipping	Management
HW	SO643159	0	0	180	Bare	Loose	Reclamation
NU	SO636155	17	6	183	90% Bare	Loose	Forestry
CPA	SO607121	35	16	260	Birch	Loose	Grazed
NFA	SO629095	30	36	263	U1 grassland	Loose	Grazed
NFB	SO629096	30	36	270	U1grassland	Loose	Enclosed
CPB	SO605121	35	41	240	Birch	Loose	Grazed
LM	SO643124	40	60	220	U1grassland	Loose	Grazed
TB	SO624167	20	100	255	Heathland	Loose	Grazed

Table 4.1: Abbreviations used in this study to describe the study plots

Abbreviation	Site name
HW	Hawkeswell
NU	Northern United
CPA	Cannop site A
NFA	New Fancy site A
NFB	New Fancy site B
CPB	Cannop site B
LM	Lightmoor
TB	True Blue

4.1.2 Hawkeswell

Hawkeswell represents age "0" in the chronosequence as it was being reclaimed at the time of survey for remaining coal content. Figure 4.2 shows the 1ha site before reclamation. The tip serviced Northern United Colliery, and closed



Source: © DEFRA, www.magic.gov.uk

Figure 4.1: Location of study sites, within the Forest of Dean, marked by ◎

in 1965. The site was almost bare before reclamation, as shown in Figure 4.2 although some vegetation was starting to colonise the edges of the spoil tip.

Figure 4.2: Hawkeswell from SO643158 looking northwest, 2000

The site is not enclosed, but no sheep were observed on or around the site during site visits. The site is located in the heart of the Forest, and is surrounded by mixed woodland. It was classified as derelict land in 1988 (Department of the Environment, 1991). No relevant literature or surveys were found for this site.

4.1.3 Northern United

The 6ha Northern United spoil heap was planted with *Pinus sylvestris* in 1965 at the time of pit closure. The selected plot is however, only 6 years of age since disturbance ceased because much of the site was partially reclaimed between 1990 and 1994 for remaining coal content (Figure 4.3). Recommendations were made to the developer to ameliorate pH using deep lime incorporation (D. Fourt, Forestry Commission, *personal records.* 1994-2001), but were not undertaken by the developer. The site was classified as derelict land (Department of the Environment, 1988).

Figure 4.3: Northern United from SO637154 looking north towards the study plot, 1999.

The site was replanted in 1996 with mixed conifers. At the time of data collection however, the development of the trees remained slow on the study plot (Figure 4.4), with 90% below 1m tall and internal spacing up to 3m wide. The low height and density of the trees was felt not to inhibit natural colonisation of the field layer or influence drainage or surface substrate stability.

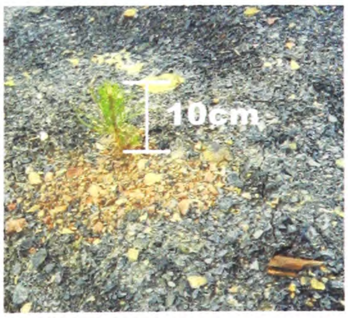


Figure 4.4: A Pinus Sylvestris specimen of 10cm planted in 1996, typical of those surviving on the Northern United study plot in 2001.

Figure 4.1 and maps provided in Appendix 2.2 show that Northern United is located within the heart of the Royal Forest, and is surrounding by mixed woodland.

4.1.4 Cannop

The Cannop spoil heaps (c.5ha) were in use until 1960, when Cannop Colliery closed (Hart, 1971). Figure 4.5 is taken at plot CPB.

Figure 4.5: Cannop B, looking up the slope of Transect 3. SO606121 facing northeast. 2001.

Moore (1952) notes that tipping started on the eastern fan in 1923 and ceased in 1944. Tipping was still occurring in 1952 however, on the western fan where plot CPB is located. It is likely that this part of the tip was used up until colliery closure, giving an approximate age-since disturbance date of 40 years for plot CPB. Moore (*op. cit.*) also noted that all slopes were prone to erosion, and deep gullies had formed. Figure 4.5 and Appendix 1.2.4 show that the site still has erosion problems. A list of the plant species growing on the tip in 1952 is given in Appendix 1.1.5.

Figure 4.6 shows the area in which plot CPA is located. This 0.1ha patch of the spoil heap was disturbed during a trial coal reclamation programme ceased in 1985 (J. Harvey, Forestry Commission, *pers. comm.* 1999).

Figure 4.6: Cannop A, looking towards the study plot at a distance of 30m. SO607122 facing northeast. July 2001.

The habitat surrounding the spoil heap is predominantly mature oak woodland surrounding the site, as illustrated in Appendix 1.2.3. Conifers were planted on some parts of the tip; mixed broadleaf woodlands and scrub have developed in areas where planting did not occur. Several footpaths cross the site, and a mountain-biking centre is located nearby. Some areas of the site showed signs of erosion from biking and walking (Appendix 1.2.4).

According to Hobday (1994) the conical-shaped fans of tip form a distinctive landmark typical of the tipping method. The site is considered to have landscape interest as well as amenity value from the pathways running across it. Scoring information from the report is provided in Section 4.2.2.

4.1.5 New Fancy

New Fancy consists of two sister spoil heaps - New Fancy East and New Fancy View (3ha). New Fancy East was excluded from the study as it is extensively planted with conifers (Appendix 1.20). New Fancy View (Appendix 1.19) was selected for use, and is referred to as New Fancy in this study. The photographs in Figure 4.7 show plots NFA and NFB. A map of the location of these plots is provided in Appendix 1.2.5, and other relevant photographic evidence is provided in Appendix 1.2.6.

New Fancy is maintained as public open space by the Forestry Commission. It is a popular viewpoint, with public footpaths traversing the site. According to the Forestry Commission, parts of the site are maintained by mowing, but the study plots are either fenced off or managed only be grazing (Section 4.3.1). The site is surrounded by a mixture of deciduous woodland and conifer plantations.

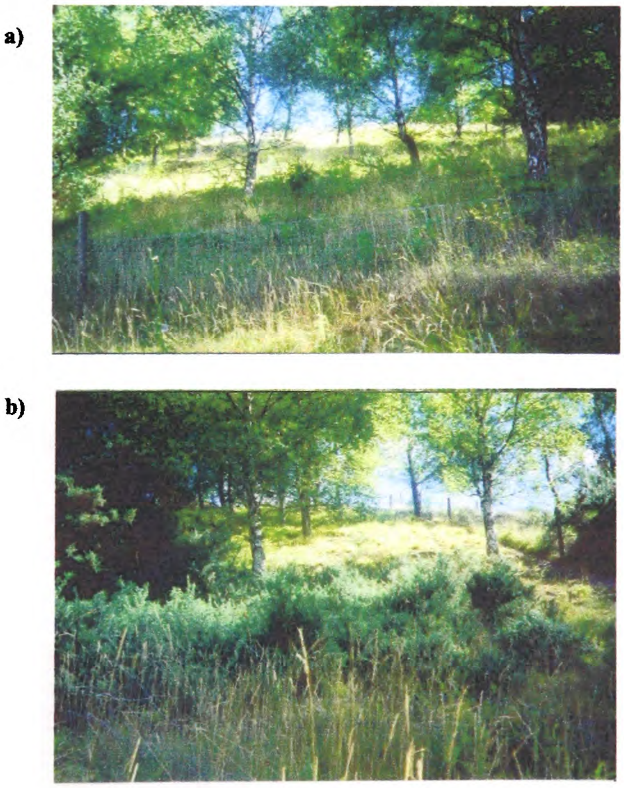


Figure 4.7: a) New Fancy A, looking up the slope of Transect 2, facing east; b) New Fancy B looking up the slope of Transect 1, facing east, August 2001.

Hobday (1994) rated New Fancy second of the 19 tips assessed (Section 4.2.1), due to the amenity value and the "wealth" of mining artefacts that remain in the vicinity. The ecological value was given a score of 3/5 however, due to heavy grazing.

English Nature also surveyed New Fancy in 1994-1995 (English Nature, 1996; Appendix 1.19). The report confirmed that the site is grazed heavily by forest sheep. It is described botanically as being a mosaic or a transitional grassland site as it was difficult to define the plant communities in terms of the National Vegetation Classification (NVC). Patches were encountered for example, that fitted both the acid U1 and calcareous CG7 NVC grassland types.

4.1.6 Lightmoor

The 10.5ha Lightmoor site lies approximately 1 mile from Cinderford. This is one of two main settlements in the Forest of Dean, and the site is used informally by the public for fishing, walking and mountain biking. The vegetation is disturbed in some places by mountain bike runs.

Figre 4.8: Westerly-facing slope of Lightmoor taken from SO642120, August 2001

Lightmoor was recorded as being a calcicolous CG7 *Festuca ovina-Hieracium pilosella-Thymus praecox* community (English Nature, 1996; Appendix 1.16). A short grass-sward grassland dominates much of the site including the study plots. No photos are available of the study plots, but Figure 4.8 shows the westerly aspect of the same slope. Appendix 1.2.7 show the location of the study plots, and Appendix 1.2.8 provides further photographic information.

Hobday (1994) found that few industrial archaeological features remain around the site, but felt it provided a good viewpoint over Cinderford. It was regarded as being of only moderate ecological value, although the fishing pools are noted as being important for dragonflies. Scores are noted in Section 4.2.2.

4.1.7 True Blue

Unlike the other sites, this spoil heap is located to the north of the main Forest (Figure 4.1) in a hamlet surrounded by forestry, farmland, gardens, and heath-scrub. Public rights of way pass across the site, and the site is well-used by local people as open space. During conversations that arose with local people during site survey, questions were asked as to the tip's history and management. The spoil heap serviced the True Blue colliery, and has been in the village for as long as local memory (c. 100 years). Although open to grazing, the site is not apparently used by the forest sheep.

Figure 4.9: True Blue taken from SO62351669 looking north towards the study plot at a distance of 50m, September 2001.

Despite the long age-since-disturbance of the spoil heap, the area of the plot location has only recently developed a closed-sward plant community in the past 15-20 years, as shown in Figure 4.9. Bare patches still remain at the south-western end of the tip, and in other places the footpaths have caused erosion.

4.2 Perceived value of Forest of Dean coal spoil heaps

This section follows on from Section 1.3, and explores literature relating to colliery spoil heaps in the Forest of Dean to explain why these features are of interest in terms of culture (Section 4.2.1, 4.2.2), amenity (Section 4.2.3), ecology (Section 4.2.4), and as features integral to the industrial landscape (Section 4.2.5). Photographic material is also used where relevant.

4.2.1 Cultural Heritage

It is argued in this section that as remnants of industrial activity, spoil heaps should be preserved as part of the cultural heritage of the Forest of Dean, because they are often the only remaining visual features of an industry that profoundly affected the lives of local people.

Mining heritage is important to people within the Forest of Dean. As noted in Section 1.3.2, in the Forest of Dean the common right to mine coal is a tradition that has spanned at least 700 years; mining has had a profound influence on local culture. As late as 1945, half of the Forest's male population worked in the mining-industry (Bick, 1980), so the decline of the industry was a big loss (Appendix 1.4). Mining still affects people today through the prevalence of respiratory diseases in the older population (Anon., 1974; K. Biggs, *pers comm.*, 2001), and high unemployment from the decline of the industry – particularly as it formed such an important economic base within the area (Land-Use Consultants, 1999).

It is therefore not surprising that mining is still a part of the collective memory of the residents of the Forest of Dean, and its people are still proud of their mining heritage (K. Biggs, *pers comm.*, 2001). Appendix 1.4 for example, summarises newspaper clippings found in two local papers between 1959-1998. These also show that mining did not just make an impact on the local economy and landscape, but on people - who still define themselves as miners, are proud of their heritage, and for whom mining may even influence politics (e.g. Blake, 1992).

According to Box (1994), writing about the mining landscape of Telford, Shropshire, colliery spoil heaps and other mining remnants can add cultural value to the landscape for local people, as they provide visible links with mining and with a past way of life. The views of a local historian, D. Bick (Graham, 1998, see Appendix 1.4) would support this view in the Forest of Dean: "People visit the Forest of Dean because of it's old industries, not in spite of them".

There is also a growing recognition both within the Forest (e.g, Graham, 1998) and nationally that industrial landscapes are part of our cultural heritage, and as such need to be preserved alongside other components of cultural heritage such as buildings and peoples' memories. Cossons (1975) for example, believes that interest in industrial landscapes was low in the past, because industry was associated in the minds of the nation with unemployment, decay, and 'landscapes of destruction'. He argues that people do not value derelict landscapes, but the preservation of cultural heritage, including landscape features, has become more important in the post-industrial era now that the process of regeneration has started in former industrial areas. The recent UNESCO World Heritage Site designations of Blaenavon Industrial Landscape, South Wales (2000), and Ironbridge Gorge, Shropshire (1986) illustrate the increasing importance of industrial landscapes at a national and international level.

4.2.2 The Hobday Report

The Hobday Report (1994) is explained in more depth here. It is a locally produced report that supports this study because it argues that the preservation and management of Forest spoil heaps is important for local people. The report considers that the management of vegetation on the spoil heaps is an important issue that had not been resolved, demonstrating the value of this study.

The Hobday Report (*op. cit.*) was commissioned by the Forestry Commission in recognition of the need to preserve some of the spoil heaps in the Dean rather than allow all of them to be re-worked (e.g. for aggregates). It helped evaluate the Forest spoil heaps, and prioritise which were of most interest. The 'evaluation panel' consisted of archaeological consultants and local stake-holders.

The report identified 19 coal spoil heaps (criteria for inclusion not given) which were visited, and given scores on visual/landscape appeal, association with other colliery/industrial archaeological remains, ecology, recreational and amenity value, and economic value for forestry. Table 4.2 summarises the scoring information where relevant to sites included in this study. Specific comments on each site are discussed in Section 4.1. It can be seen that New Fancy and Cannop were both amongst the top 5 most important tips in terms of the criteria applied.

Table 4.2: The Hobday (1994) scores for the three sites also used in this study, and ranking out of 19 sites (1= highest rank).

Criteria	**New Fancy**		**Cannop**		**Lightmoor**	
Landscape	5	Viewpoint	4	Obvious in landscape	4	Viewpoint
Industrial archaeology	4	Screen wall, railway track	3	Adits; Free mines nearby.	2	Little near the tip.
Ecology	3	Heavily grazed by rabbits	3	Old oak forest below tip	3	Very open grazed tip
Amenity uses	5	Picnic site	4	Mountain biking	3	Fishing pools
Forestry	0	None	1	Corsican Pine	0	None
Total score	**17**		**15**		**12**	
Rank	**2**		**4**		**7**	

In terms of cultural heritage (Section 4.2.1), the report argues that where spoil heaps comprise the only remnants of the mining industry, it can be easy to dismiss them as being unimportant. If the spoil heaps form part of a site together with other remains such as pit buildings or artefacts, they can however help to form a "glimpse into a past way of life" (Hobday *op. cit.*).

4.2.3 Ecological interest

This section highlights the importance of spoil heap habitats as part of the biodiversity of the Forest of Dean. Open, semi-natural habitats have been maintained on some spoil heaps by Forest sheep. As woodland habitats are widespread within the Forest, these open patches are particularly important for biodiversity. This study can help meet the nature conservation targets of the area by increasing information on colonisation and successional processes and promoting an understanding of the wildlife value of spoil heap communities, as well as making recommendations to improve biodiversity (Section 10.2).

An English Nature (1996) grassland survey conducted in the Forest of Dean (see Appendix 1 for species lists) summarised the ecological interest of open spoil heaps that have naturally colonised:

a) Patches of semi-natural vegetation remaining within a largely wooded landscape.

b) Botanical or ecological interest in the plant colonisation and successional processes on disturbed land

According to Gloucestershire County Council (1986), some 80% of the Statutory Forest area is woodland (40% coniferous). Grazing by Forest sheep

(Section 4.3) has however, maintained characteristic open grassland habitats along roadside verges, some spoil heaps and 'common areas' (English Nature, 1996). These open grassland patches add variety to the overall woodland matrix (Forman, 1995). According to Gloucestershire Trust for Nature Conservation (1981), the acid grassland, heathland and birch scrub habitats that have naturally developed on colliery spoil are not 'island habitats' (Section 2.3.4.2), but are similar to habitats that naturally occur on acidic sandstone substratum underlying the Forest of Dean (Figure 1.2). Lowland heathland is also a nationally and internationally valuable habitat (Farrell, 1989; English Nature, 1997).

English Nature (1997) views the grasslands and heathlands of the Forest of Dean as a sensitive habitat that have suffered a dramatic decline this century, due to loss to improved agriculture and forestry, decline of traditional management, fragmentation and isolation, and the loss of spoil heap communities through mineral reclamation. One of the main aims for the Wye Valley and Forest of Dean Natural Area is therefore to prevent further loss of the habitat and seek to expand the resource where possible.

Land Use Consultants (1999) recognise that former industrial workings in the Forest, such as quarries, mine-workings, ponds and spoil heaps add to the biodiversity of the area as they provide habitats for bats, dragonflies, and unusual plant communities.

4.2.4 Amenity value

Whilst undertaking the vegetation survey, the number of people passing by each of the study plots was noted on the quadrat sheets. This was done because it was noticed that although pathways traversed many of the sites (Section 4.1), there was a big difference in the number of people encountered. For example at least 10 people per day were seen walking up New Fancy View during the 2-week fieldwork period; around 1 person per day crossed True Blue, and parts of Lightmoor were used daily by dog-walkers. Only 5 people were encountered on Cannop however, during 4 site visits and 2 weeks of fieldwork, despite pathways being heavily eroded (Appendix 1.2.4). One person was encountered on Northern United in a similar time-frame, and none on Hawkeswell.

As the amount of time spent on each site varied due to the size and number of plots, Table 4.3 has been compiled, to formalise the observations over a comparable time-frame. The survey sheets for two days per plot in July or August were randomly selected from the pile, and visitor numbers calculated. As no literature could be found on visitor numbers to sites within the Forest, these results provide a 'snapshot' of amenity use, showing the wide variation in numbers of people observed.

Table 4.3: The number of people recorded on spoil heaps over randomly selected two day periods when vegetation recording on each site was being undertaken.

	Mountain-biking	Walking	Total
Northern United	0	0	0
Cannop	0	0	0
New Fancy	0	34	34
Lightmoor	3	0	3
True Blue	0	2	2

New Fancy was felt to attract more people because it is a Forestry Commission-run site with parking, picnic facilities and managed pathways to a viewpoint. It is also visually attractive (Appendix 1.2.6, Section 4.2.5).

4.2.5 Value of spoil heaps within the industrial landscape

This section argues that in the Forest of Dean, spoil heaps form an integral part of the post industrial landscape. The Forest of Dean may be one of the only coalfields in the UK where spoil heaps are not intrusive in the landscape, and can even be positive features. Reasons why the Forest of Dean is different include the small size of the spoil heaps, combined with the basin-shaped topography of the Forest and a woodland landscape that is able to 'hide' sites that remain visually unattractive. These differences are important because for many coalfields, a study promoting nature conservation on spoil heaps may not be a useful contribution to local or regional strategies (e.g. if these aimed to regenerate a landscape still considered to be derelict). Managing spoil heaps for nature conservation is however, considered an appropriate aim for the Forest of Dean, as argued in Sections 4.2.1-4.2.4, and as outlined below.

4.2.5.1 Perceptions of coal spoil heaps – a definition of terms

Perceptions of, and feelings about, landscapes and landscape features are personal and subjective. Allan *et al.* (1997) however, conducted a survey of attitudes to spoil heaps in South Scotland, and found that spoil heaps considered as 'negative' by local people tended to be visually unattractive, whereas those regarded as 'neutral' or 'positive' tended to be visually inoffensive or attractive features within the landscape. The survey found spoil heaps that were vegetated and had wildlife interest were often those described as 'positive'. Spoil heaps that were poorly vegetated were often those considered unattractive and 'negative', because they were more visually obtrusive within the surrounding landscape.

This study complements the arguments of Cossons (1975) that people do not value landscapes considered derelict (Section 4.2.1). Spoil heaps that are not vegetated may be visually intrusive and contribute to a feeling that an industrial landscape is still derelict (e.g. Hawkeswell, Figure 4.2). Spoil heaps that are vegetated, form interesting or neutral features, and blend in with the landscape, can add to the landscape (Figure 4.10). This study may help to identify barriers to vegetation succession on the sites in the Forest of Dean that are still considered to be derelict land, and make recommendations for their management to promote succession.

4.2.5.2 Spoil heaps as an integral part of the industrial landscape

Sections 1.3.1 and 1.3.2 explain that iron, stone and coal have been worked in the Forest of Dean for over 2000 years, and the results of activities such as mining, quarrying, brick-making, and iron-working can be seen in the landscape today. Table 4.4 summarises the types of earthworks recorded in the Sites and Monuments Records (SMR) in 2001 relating to the working of the iron, coal, stone and clay resources. Modern colliery spoil heaps can be seen as industrial archaeological remnants representing the later stages of this long industrial history, and it can therefore be argued that they are an integral part of this former industrial landscape.

Table 4.4: a summary of the types of sites associated with different periods of industrial activity, that are still apparent in the landscape today (SMR 2001).

Period	Resource	Landscape remnant
Bronze-age (BC2500-700)	Ochre	Ochre pit (reported)
Iron-age (BC800-AD43)	Iron	Iron-workings
Roman (AD43-410)	Iron	Iron-stone mine
		Iron-workings
	Clay	Clay pit
Early Medieval (410-1066)	stone	Quarry
Medieval (1066-1540)	Coal	Bell pits
	Iron	Iron-workings
Post-Medieval (1540-1901)	Coal	Bell pits
		Colliery sites & mines
		Spoil-tips
		Ponds
	Iron	Mined cave complexes
		Slag heaps
	Stone	Quarries
	Clay	Clay pits
Modern (C20)	Coal	Colliery sites & mines
		Spoil-tips
		Ponds
	Iron	Mined cave complexes
		Slag heaps
	Stone	Quarries

4.2.5.3 Is the Forest of Dean colliery landscape unique?

Figure 4.10 shows views of 4 coal spoil heaps in the Forest of Dean, illustrating that many of them have become positive or neutral features within the landscape (Section 4.2.5.1). This may be partly because they are vegetated, and partly because they are visually unobtrusive (or form interesting features) within the forest landscape.

The Forest of Dean colliery landscape is very different however from colliery landscapes seen in the South Wales valleys, Durham, or Central Scotland. There may be several reasons for this, including mining history, the size of the

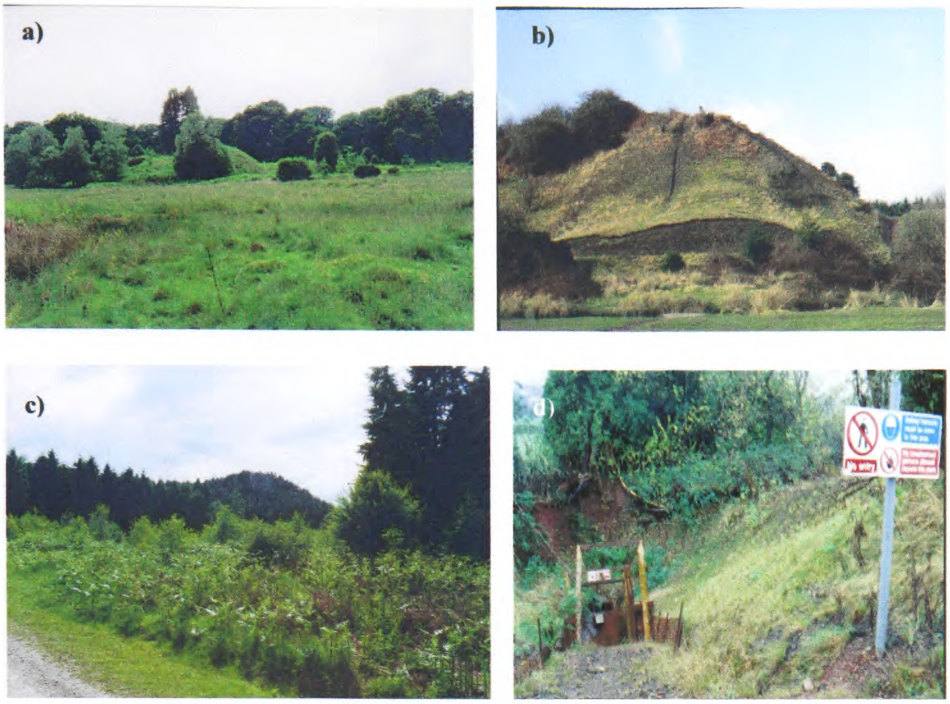


Figure 4.10: views of 4 Forest of Dean spoil heaps, blending into the Forest landscape: a) Moseley Green (0.1ha) taken at a distance of 50m; b) part of the Lightmoor site (10ha), taken at a distance of 50m; c) spoil heap at Mirystock Bridge (4ha) taken at a distance of 0.5km; d) entrance to a free-mine operating at Bream.

coalfield, the size of spoil heaps, and other topographical and landscape features. The Ayrshire coalfield in Mid-Scotland is still operating for example, with as many as 6 opencast sites of more than 200ha operating at the time in 2004 (Scottish Coal, *pers. comm.*, 2004). The landscape is still considered to be derelict in some places, exacerbated by the open-cast coal sites (Figure 4.10a; CEI, 2004).

In South Wales, the scale of mining was also greater than it was in the Forest of Dean. According to GTJ (2003), 53 mines operated in a 26km long area in the Rhonnda valleys at the height of production during the 19th Century. This compares to 30 mines recorded in 1895 in the 85km^2 Forest of Dean area (Her Majesty's Inspectorate of Mines, 1895). The South Wales valleys also experienced massive migrations of people to work in the pits during the 19th

Figure 4.10: the impact of mining in the Ayrshire and South Wales coalfields: a) shows opencast mining at the 600haGasswater site, Ayrshire; b) shows a 20th Century coal pit dominating the heart of Abertillery, South Wales; c) the scale of coal wastes left at Pwll Du, Blaenavon, in 1999

Century. Towns therefore grew up around the pits, and coal mining could dominate the whole town visually as well as economically, as shown in Abertillery (Figure 4.10b). Mining continued at some pits until the 1980s, and the resulting waste tips can cover 100ha or more, as shown at Pwll Du (Figure 10.4c).

One obvious difference between the Forest of Dean and these larger coalfields is that spoil heaps are much smaller, and the impact of mining is much less visually intrusive than it is in other coalfields. The largest spoil heap found in the Forest of Dean is Lightmoor, at 10ha (Appendix 10.2.8). This may be due to the pattern of local mine ownership in the Forest of Dean (Section 1.3.2) as free-mines are very small in size compared to the South Wales deep-mines (e.g. compare Figures 10.3d and 10.4b). Geological and technical difficulties such as thin seams, faults and water flows and flooding, also curbed mining production in the Forest throughout the 19th and 20th Centuries (Hart, 1971).

Furthermore, the Royal Forest of Dean was part of the Norman Royal Forest system (Rackham, *op. cit.*), and the district is still the largest tree covered area within Gloucester (GCC, 1996). This forest matrix means that spoil heaps are often hidden in the landscape rather than having an immediate visual impact (Figures 4.10 a-c).

4.3 Management of naturally colonised spoil heaps in the Forest of Dean

As explained in Section 4.2, spoil heaps in the Forest of Dean are of interest culturally, archaeologically and ecologically, have amenity value, and are an integral feature of the industrial landscape. It is therefore worth managing these areas to preserve and enhance these values. This section looks at the current method of management, and its limitations to help formulate recommendations for the future in light of the results found in this study (Section 10.2)

4.3.1 Management at the time of survey

One of the key questions when considering the different habitats that have formed on different spoil heaps such as open grassland on Lightmoor, heathland on True Blue and woodland on Cannop. Why has natural succession towards woodland not occurred on all sites? Will this happen over time? And what is preventing succession from occurring?

English Nature (1997) suggest that open habitats tend to occur where the spoil heaps are close to settlements, and are treated as commons managed by light grazing. The traditional form of grazing in the Forest of Dean is through customary rights or privilege, whereby local people are licensed to let sheep roam freely throughout the forest. It is therefore difficult to ascertain exact grazing densities on each of the sites, as sheep tend to be "hefted" (accustomed to particular territories), which means that the forest area is not grazed evenly. During the Foot and Mouth outbreak in February 2001, 5800 roaming sheep were culled in the Forest - an area of 85km^2 (Hart, 2002) giving an approximate pre-Foot and Mouth stocking density of 68 sheep/km^2.

Compared to the 0.15 sheep/km^2 guidelines for the maintenance of semi-natural habitats such as heathland (Gimmingham, 1992), it can be seen that this stocking density is very high. As the sheep are hefted, and have their own territories and grazing patterns, some areas are also likely to be grazed much more heavily than others. For example, Hobday (1994) found that New Fancy was heavily grazed but not Cannop. Without further intensive study, it would be difficult to tell how heavily grazed any particular site is (Section 10.4.2.2.1), and what impacts this may have on plant succession.

4.3.2. Threats to management

There were two main threats to the management of the spoil heaps for open space at the time of survey:

a) A lack of control over the grazing patterns and grazing density of the sheep (Section 4.3.2.1), which means that the effects of grazing on a habitat is hard to ascertain

b) The severe reduction of sheep numbers in the Forest of Dean following the cull of all forest sheep during the 2001 Foot and Mouth epidemic (Section 4.3.2.2).

4.3.2.1 Lack of grazing control

English Nature (*op. cit.*) suggest that due to the uneven grazing patterns of the sheep, in some cases the spoil heaps are undergrazed, and bracken scrub starts to encroach. This has occurred on parts of Lightmoor. Sites such as Cannop, which are further away from settlements, may also be under-grazed, and this may be a factor in the development of birch scrub.

Lack of grazing control also affects people and forestry operations, and there has been continued conflict over sheep for several decades. According to Jeffcoate (1999) for example, the RSPCA had to shoot one sheep per week in 1999 because of untreated injuries following traffic accidents. Sheep are also a problem for the Forestry Commission (Hart, 2002) because they prevent natural regeneration within broadleaved and conifer plantations unless land is fenced off, which increases the cost of silvicultural management. Land Use Consultants

(1999) summarise that sheep are an integral part of managing the traditional Forest landscape, but more effective control of grazing patterns and straying sheep is needed.

The current system of sheep grazing means that for vegetation succession, sheep cannot be kept away from sensitive areas that may benefit from lower grazing but may not graze other areas enough to prevent scrub development if open spaces are required. If valuable open habitats (Section 4.2.3) are to be maintained, ensuring adequate grazing regime is therefore necessary.

4.3.2.2 Loss of traditional grazing

On 28th February 2002, the Forest of Dean was declared to be within a Foot and Mouth Infected Area, and all sheep were culled. The Foot and Mouth epidemic followed both years of conflict over the role of sheep in the modern Forest (Section 4.3.2.1) and poor economic prices for sheep.

Since the Foot and Mouth epidemic, some Foresters have re-introduced sheep into the forest. New controls over these sheep were also introduced in 2001. Sheep can still roam freely through the forest, but better measures for identifying the owners have been introduced, and only 5,100 sheep are allowed by a new legal agreement (Hart *op. cit.*). However, sheep numbers may not reach previous levels for a number of years, and it is still difficult to use sheep grazing as a management tool for controlling natural succession in the grassland and heathland habitats.

4.4 Summary

Eight plots from six sites passed the selection criteria, providing a chronosequence ranging from Hawkeswell at age '0' to a 100 year old plot on True Blue. Further site information is provided for each of the sites.

It is argued that this study is important because spoil heaps have cultural and archaeological interest, ecological interest, amenity value, and are an integral part of a landscape that has been heavily influenced by industry. This study will increase understanding of successional processes on spoil heaps and promote management for nature conservation, which will help to increase their interest.

Mining heritage is important to people within the Forest of Dean. The common right to mine coal is a tradition that has spanned at least 700 years and so mining has had a profound influence on local culture. Mining is still a part of the collective memory of the residents of the Forest of Dean. Colliery spoil heaps can add cultural value to the landscape for local people, as they provide visible links with mining and with a past way of life. The Hobday Report (1994) certainly argues for the need to preserve some of the spoil heaps in the Dean for this purpose. In terms of amenity value, sites such as New Fancy attract visitors because it is a site managed for amenity use with parking, picnic facilities and managed pathways to a viewpoint.

As woodland habitats are widespread within the Forest, the open vegetation patches that have been maintained by Forest Sheep are particularly important for biodiversity. This study can help meet the nature conservation targets of the area by increasing information on colonisation and successional processes and promoting an understanding of the wildlife value of spoil heap communities, as well as making recommendations to improve biodiversity. .

Colliery spoil heaps can be seen as industrial archaeological remnants representing the later stages of this long industrial history, and it can therefore be argued that they are an integral part of this former industrial landscape. The Forest of Dean is one of the only coalfields in the UK where spoil heaps are not intrusive in the landscape, and can even be positive features. Reasons why the Forest of Dean is different may include the small size of the spoil heaps, combined with a woodland landscape that helps to make spoil heaps seem visually unobtrusive. These differences are important because managing spoil heaps for nature conservation is considered an appropriate aim for the Forest of Dean, whereas it may not be appropriate for all coalfields.

Sheep-grazing is currently the only management method used to control vegetation growth on the spoil heaps. This is not a reliable method because grazing has declined following a cull sheep during the Foot and Mouth epidemic in February 2001. Sheep grazing is also un-managed, with sheep allowed to roam freely. It is therefore difficult to increase or decrease grazing numbers, and the differing grazing patterns of the sheep may be the reason why some sites have developed a woodland habitat and some sites have remained open. This study will help to examine successional processes in more detail and examine the impacts of grazing on the vegetation.

Chapter 5.0 Data collection techniques

This chapter addresses objective ii) by describing the experimental design that has been implemented at each of the selected study sites. The sampling design is described to show how floristic data was collected from within the framework of the experimental design as required by objective iii). The environmental variables that are measured at each site are also summarised, and the methods used to collect data on each is described to address objective iv). Sampling methods for collecting the substrate samples, microclimate data, floristic and non-floristic data are described, and the choice of methods justified.

5.1 Experimental design

The experimental design forms the framework or logical structure within which the vegetation and environmental data is collected to ensure that the questions being asked can be answered (Krebs, 1989).

5.1.1 Overview of the experimental design

Figure 5.1 provides an overview of the experimental design by summarising the process by which the research has been undertaken. The site selection process is described in Section 3.2, the sites themselves in Section 4.1, and the methodology used to find the sites is provided in Appendix 1.3.

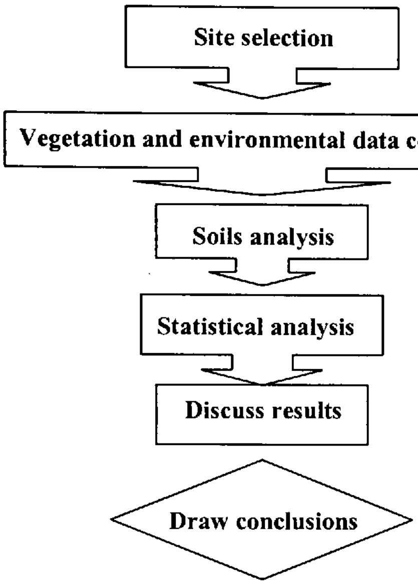


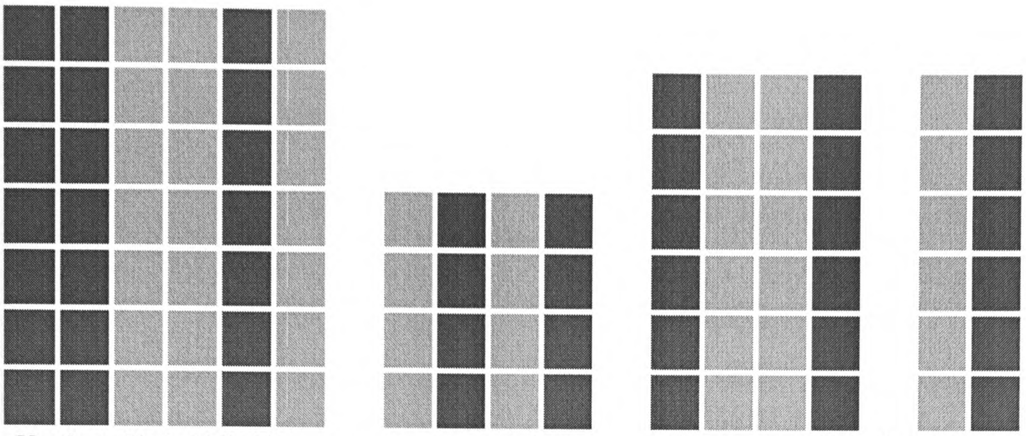
Figure 5.1: Flow-chart illustrating the process by which the research has been undertaken

5.1.2 Sampling design for vegetation and environmental data collection

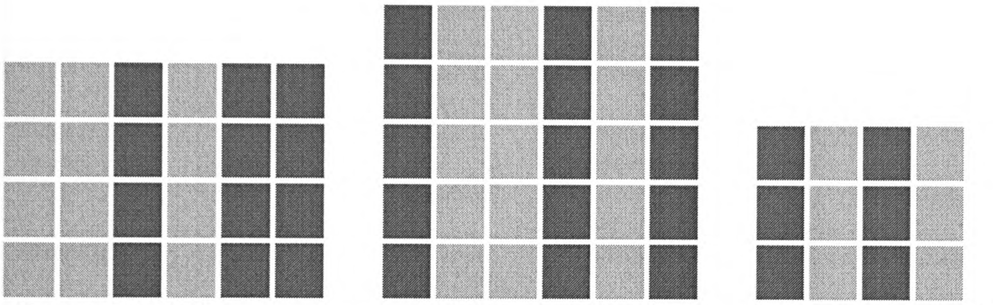
The design shown in Figure 5.2 was developed for use in this research. Quadrats were randomly sampled within subplot blocks placed to form transects. This design was developed for two main reasons:

a) So that the research could be expanded into a randomised block design to test treatments should that be required at a later date

b) To allow the vegetation to be sampled in a stratified but random fashion along the slope of each site.



Northern United (6): 84 Cannop A (16): 32 New Fancy A (36):48; B (36):24



Cannop B (41): 48 Lightmoor (60): 60 True Blue (100): 24

Key: ▨ sampled subplots ($5m^2$); ░ unsampled subplots; (x) age since disturbance; x number of quadrats.

Figure 5.2a: Flexible transect design used to sample 7 sites of different ages and sizes. A constant sampling density of 12% per plot is mantained. Transects are randomly allocated along plot length.

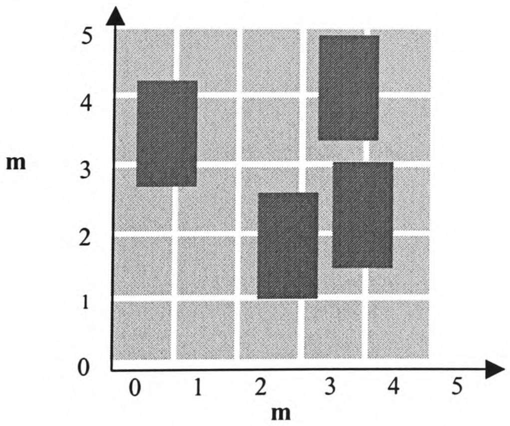


Figure 5.2b: Each transect is sampled using $5m^2$ blocks (sub-plots) containing 4 1x1.5m randomly allocated quadrats.

Table 5.1 summarises the environmental information that was collected within the sampling design, why each parameter was measured, and the level at which the data was collected.

Table 5.1: parameters to be tested, and justification for their selection

	Parameter	Level of information	Justification for information collection
Substrate	pH value	Plot	Indirect measure of toxicity caused by pyrites
	Iron pyrite (index)	Plot	Indication of FeS_2 level
	Soil depth (cm)	Quadrat	Measure of the depth of soil that has developed over the spoil surface over time
	Plant vigour (index)	Quadrat	Indirect indicator of effects of all environmental factors combined via assessing plant health
Microclimate	Slope factor (°)	Subplot	Measure of slope steepness; indicator of slope stability, drainage, soil creep patterns
	Aspect (°)	Transect	Indicator of differential insolescence received, affecting soil temperature, annual light/shade
	Canopy cover (%)	Quadrat	Indicator of light availability
Vegetation factors	Sward height (cm)	Quadrat	Measures height of 3 different layers of the sward, estimate of biomass
	Biomass (index)	Quadrat	Height multiplied by cover gives rough estimate of the quantity of vegetation present.
Floristics	Cover (%)	Subunit (20x30cm)	Estimate of abundance of each species present
Diversity	No. species	Subunit (20x30cm)	Combined with abundance data gives measure of species diversity

Sources: Doubleday (1971); Bradshaw and Chadwick (1980); Bridges (1997).

5.1.3 Specifications considered when forming the experimental design

Table 5.2 lists problems both generic to ecological sampling and specific to this study that were considered when formulating the design. For example, whilst seasonality is a constraint on the time available for vegetation sampling, sufficient

Table 5.2: Generic ecological problems and site-specific problems that were considered when developing the experimental design.

Problem	Result	Solution
Generic		
Seasonality	Floristic composition differs with season	Sample all plots within same season
Biased plot selection	Sample unrepresentative of community	Plots selected through applying criteria, transects selected randomly
Replicates insufficient	Samples unrepresentative of community	Increase samples taken
Biased sampling	Samples unrepresentative of community	Randomised assignment of samples
Background noise	Natural floristic variation not separated from variation along an env. gradient	Increase samples taken/ concurrent sampling of environmental factors
Specific		
Different plot size	Samples not comparable across all sites	No. replicates proportional to area.

Source: Cochran & Cox (1992), Krebs (1989, 1978), Hurlbert (1984), Muller-Dombois & Ellenberg (1974)

replication of quadrats is essential for gaining an accurate and representative sample of the plant community.

5.1.3.1 Seasonality

In a study of succession along an environmental gradient of shading, Austin and Belbin (1981) studied the vegetation dynamics of a lawn over two years. It was found that seasonality had a marked effect on the species and their abundances sampled. In order to obtain an accurate picture of a plant community at a point in time and also to ensure that a plant species has an equal chance of being found in any sample, all plots should be sampled within as short a time frame as possible (Krebs, 1978). To incorporate the effects of seasonality in this study, a sampling design was created that could ensure all sites could be sampled within an 8 week period.

5.1.3.2 Randomisation

According to Krebs (*op. cit.*), the spatial randomisation of samples ensures that results are more accurate because:

i) Every part of the sample area has an equal chance of being selected
ii) Observer bias is minimised
iii) Each sample is representative of the community

Randomisation was therefore built into the design in the random spatial allocation of transects within the selected plots, and quadrats within each subplot. Each plot was divided into 5m sections numbered from 1-n. A dice was thrown to select in which section the transect would be located. To allocate quadrat location, random number tables were used to create x and y co-ordinates used to place the bottom left-hand corner of the quadrat randomly within the block.

5.1.3.3 Replication

Replication of samples increases the efficiency of a project, because statistical variance between samples is reduced with every sample taken in a homogeneous plot, thus reducing the statistical error of the mean (Cochran & Cox, *op. cit*, Krebs, *op cit.*, Goldsmith *et al.* 1986). A large data-set is also needed in community ecology, to distinguish recurrent patterns from noise (Gauch, 1982; Kent and Coker 1982), a problem discussed further in Section 3.5. Kent and Coker (*op. cit.*) therefore recommend that at least 10% of the selected study area should be sampled to ensure that a representive sample of the plant community is gained.

A sampling density of 24% per transect and per block, and 12% per plot was therefore used in this study to ensure that sufficient quadrats were sampled to gain an accurate, representative sample.

5.1.4. Differential site size

The spoil heap slopes in the Forest of Dean are not all the same shape and size, causing plots to vary from 15m^2 to 35m^2. Plot sizes cannot be standardised vertically because quantifying the effects of slope factor means that the length of the slope must be sampled. However, this does not mean that data is un-comparable between sites. Cox and Cochran (1992) for example note that where data analysis techniques use the mean values of a result, the different sample size can be prevented from giving biased results if prior to the analysis, the mean from each site is summed, and divided by the number of samples. Krebs (1989) and Greig-Smith (1983) however, recommend that the proportion of area sampled is kept constant – which is a further reason for ensuring that one transect is sampled for every 10m of plot length.

Solutions to the problem of species-area, whereby the number of species tends increases with increasing area are discussed in Section 6.2.

5.2 Substrate factors

5.2.1 Soil sampling methodology for pH and pyrites

The pH and pyrites tests were undertaken in laboratory conditions due to the health and safety considerations of transporting and using strong chemicals such as 6M HCl into the field. Bulked soil samples were collected from the 8 plots on 12th December 2001. These were immediately transported to the laboratory and tests undertaken to prevent detrimental soil changes occurring. Table 5.3 lists procedures

Table 5.3: Sampling requirements to minimise ensure that any results analysis

Purpose	Requirement	Action
Minimise effects of spatial soil variation	Area sampled should be relatively homogeneous	See selection criteria (3.2.2, 3.2.3)
	Sub-samples taken randomly	Sub-samples collected from random co-ordinates across plot
	Sufficient sub-samples taken to be representative of area	
	Sub-samples bulked	Sub-samples mixed thoroughly & divided according to Jackson (1958) prior to use
Sub-samples representative of soil volume	Auger should not be wider at the top than bottom.	Cylindrical auger used
	Sub-samples of same volume	Same auger used to collect samples
	Sub-samples from same depth	Specified depth marked on auger

Source: Jackson (1958); Townsend (1973); Jeffrey (1987); Hesse (1971) which were incorporated into the soil sampling regime to ensure that the soil tests were undertaken on sub-samples that were representative of this chosen soil volume. According to Jackson (1958), and Hesse (1971) samples not being representative is the main source of error in soils analysis because soil is heterogeneous and soil chemistry may vary over short distances. The two main ways of avoiding this are firstly to collect sub-samples which are bulked and mixed thoroughly prior to use, and secondly to ensure that sufficient sub-samples were taken from the chosen soil volume.

5.2.1.1 Bulking

Because soil chemistry within a site can be heterogeneous, if analysis is undertaken on individual sub-samples the results may not be relevant even to the individual plant growing above it, as roots may spread over a much wider area. Bulking these sub-samples gives a much better idea of the mean soil chemical quantity, far more relevant to the vegetation growing above it (Hesse, 1971). This is particularly important for this study where the purpose of substrate analysis is to describe the average pH and average pyrites characteristic from each plot of the chronosequence, so that between-site substrate differences can be compared.

In this study, sub-samples were therefore collected according to Section 5.2.1.2, placed in a large receptacle, and the samples mixed thoroughly. Each bulked sample was spread onto a tray and quartered according to Jackson (1958) until the required sample size used for the experiment is reached.

5.2.1.2 Collecting sub-samples

Townsend (1973) recommends bulking 10-15 sub-samples for areas below 6 hectares (60,000m^2). Based on studies that compared the efficiency of several soil sampling programmes (Ball, and Williams, 1971), Ball (1986) recommends bulking 10 random sub-samples per 6m^2 plot to give a reasonable assessment of soil chemistry. Jackson (*op. cit.*) recommends 20-30 sub-samples per homogeneous plot at random or in a criss-cross pattern across the plot to be representative.

In this study the plots range in size from 225m^2 in area to 1225m^2. Collecting 10 sub-samples per 6m^2 proved impractical. Therefore 1 sub-sample was taken per 20m^2, as outlined in Table 5.4, to give bulked samples proportional to area. Each bulked sample will contain between 11-61 sub-samples – the lower limit of which is still within the Jackson and Townsend recommendations. Random numbers were

Table 5.4: No. sub-samples bulked per plot, proportional to area

Plot name	**Size (m)**	**Area (m^2)**	**No. sub-samples bulked**
Ruardean Woodside	15m^2	225	11
New Fancy B	10x 25	250	13
Cannop A	20x20	400	20
Cannop B	30x20	600	30
New Fancy A	20x 30	600	30
Lightmoor	30x 25	750	38
Northern United	35x35	1225	61
Hawkeswell	35x35	1225	61

used to generate co-ordinates to ensure that every 10cm area within the plot has a chance of being sampled. Where the random numbers coincided with the placement of a quadrat, the sample was taken outside the bottom left hand corner of the quadrat to ensure that vegetation was not disturbed.

Observations of exposed soil horizons, and the soil horizons excavated during preliminary sampling showed that the herbaceous plant roots tend to utilise the top 5-10cm of the substrate surface only on the spoil heaps. Substrate samples were therefore taken from 0-15cm, the level encountered by colonising plants and the level just below, to ascertain any growth limiting factors. Ball (1986) also recommends sampling this level in studies where the relationships between soil chemistry and plant distribution are analysed.

5.2.2 pH

The method given for pH measurement in Bradshaw and Chadwick (1980) is for spoil to be mixed with a weak salt solution (0.01M $CaCl_2$ – calcium chloride). The addition of a neutral salt releases the available hydrogen ions. This method gives lower values than mixing spoil with water. It is considered as being closer to the pH of the spoil *in situ*. Fresh material in the field can be measured, or dried material in the lab. It must be noted however, that the degree of dilution with the salt water will influence the pH measured (rising as dilution with salt water increases). The $CaCl_2$ method is also recommended by Kent (1980), and Williams and Chadwick (1977).

In this study the fresh spoil was mixed at a ratio of 1:8 with dilute (0.01M) calcium chloride. The spoil mixture was filtered through standard Whatman no. 1 filter papers, and a pH meter used to read values.

5.2.3 Pyrites

The literature was examined to source suitable methods for determining iron pyrites FeS_2. Burns (1970) also describes the methods used to find pyritic sulphur (FeS) in coal, although Dacey and Colbourne (1979) consider this unreliable for determining FeS_2 in coal spoil due to the possible interference of the results by clays and other minerals present in coal spoils but not in coal itself. Three more robust methods were found, described below.

5.2.3.1 The Dacey and Colbourne method

Dacey and Colbourne (1979) examined several experimental methods to determine the iron pyrites content of colliery spoil, based on literature reports and experimental observations. Sequential nitric acid oxidation (from Burns, 1970) was selected as the best laboratory method on the criteria of accuracy, simplicity, speed and cost. This involves extracting a spoil sample first with HCl, and then with HNO_3. Pyrite (%) is obtained from the HNO_3 extract.

5.2.3.2 The Pulford and Duncan method

Pulford and Duncan (1975) describe a rapid, qualitative method for "fingerprinting" the acid production potential of colliery spoils based on assessments of sulphate (2.5% acetic acid soluble) and acidity (Table 5.5).

Table 5.5: "fingerprinting" the acid production potential of colliery spoil

1.Fresh material (high potential acidity)	High pH, Low sulphate	Time ↓	Fresh coal wastes usually have a neutral or slightly alkaline pH, which falls as pyrite oxidizes to pH values of 2-3. Under acid conditions, iron is soluble, but sulphate is held as jarosite (insoluble). Above pH 4, jarosite becomes unstable, and therefore sulphate is released. Sulphate is not easily leached, and therefore remains in the spoil for many years
2.Young material (high potential acidity)	Medium pH, Low sulphate		
3.Acid material (medium potential acidity)	Low pH, High sulphate		
4.Oxidised material (low potential acidity	Medium pH, High sulphate		
5.Old material (low potential acidity)	High pH, High sulphate		

The advantages of this method are that it is fast and would only require sulphate and pH to be tested. However, two problems may make the method unsuitable for use in the Forest of Dean:

i) It can only be applied to unburnt spoil - if combustion has occurred, pyrite will have oxidised without the production of acid.

ii) "High" or "low" levels of sulphate are relative, and results would therefore be qualitative rather than quantitative, making it unsuitable for use with direct gradient analysis.

Also, because the results are relative to each other, they cannot be compared with results from other coalfields.

5.2.3.3 The Neckers and Walker method

Kent (1980) recommends using a rapid field method based on colourimetry to estimate pyrites content, as tested for suitability by Neckers and Walker (1952) on spoil heaps in Illinois, USA. The procedure followed is described below:

1. 2-3g spoil material placed in 20-150mm test tube and mixed with 1g granular zinc.
2. Insert spiral of copper wire halfway down the tube to disperse potential bubbles
3. Add 2-3ml 6N HCl.
4. Wait for 5 seconds for fumes to displace the air in the test tube
5. Place a small filter paper impregnated with lead acetate over the mouth of the tube
6. Wait for 5 minutes, then remove filter paper
7. The colour of the filter paper is indicative of potentially active or active pyrites in the sample as follows:

Slight tan colouration:	Very weak pyrites content
Tan colouration:	Weak pyrites content
Brown with tan edge:	Moderate pyrites content
Brown with silver edge:	Very strong pyrites content

This method was thought to be the most appropriate method for this research due to its simplicity of use, rapidity and effectiveness. Because the results are not relative to each other it is not qualitative like the Pulford and Duncan method, and a numerical index or rank can be assigned for statistical tests (Section 7.1.1). The health and safety considerations of transporting and using strong hydrochloric acid meant that the test was not undertaken in the field as designed. The samples were instead taken directly to the laboratory from the field and processed (Section 5.2.1). Standard lead acetate impregnated filter papers could not be sourced commercially, so these were made up in the laboratory by soaking standard Whatman no 1. filter papers in 15g lead acetate dissolved in water, leaving the papers to air-dry overnight. As Neckers and Walker (*op. cit.*) did not specify the strength of the lead acetate mixture, the mixture used in this study may have differed from the original method.

5.2.4 Soil depth

Soil depth was measured at each quadrat, using a direct measurement technique, whereby a soil auger was used to take a substrate sample at the bottom left-hand corner of each quadrat, or as close as possible to this point if quadrats overlapped, so as not to disturb vegetation to be surveyed. On all spoil heaps there was distinct differentiation between the disturbed man-altered coal spoil horizon, and, where present, an overlying organic humus layer. The depth of this overlying humus layer was measured at each quadrat to give an indication of the amount of humus built up over time.

5.2.5. Plant vigour

A subjective assessment of plant vigour was carried out at each quadrat alongside the floristic survey to provide an indication of the total soil condition and reveal areas where plants are under stress. A standardised assessment table for assessing the plants in each quadrat was devised based on appearance, colour, rooting and necrosis, with space on the recording form to note specific signs of nutrient

Table 5.6: symbols used in the field to indicate the health of individual plants & flowering information

Symbol	Meaning
⊙	Dead
oo	Very feeble
o	Feeble
	Normal
*	Vigorous
•	Flowering

Adapted from Mueller-Dombois & Ellenberg (*op. cit.*)

deficiency or lack of health seen on individual plants, as discussed in Section 2.3.1.4. The assessment is by nature subjective because it is based on opinion, and because it relies on the observer being able to spot unusual growth form due to substrate conditions in a species from the "normal" appearance and growth habit of that species. Tables 5.6 and 5.7 show the assessments used to standardise the task, meaning that numerical values could be used to summarise information from each quadrat for statistical purposes.

Table 5.7: Rapid numerical assessment of plant vigour used to assess whole quadrats, based on colour (indicator of nitrogen deficiency/sufficiency), leaf health, (toxicity/nutrient deficiency), root anchorage, appearance

Foliage blue-green in colour	1
No blotches, galls, lesions, signs of discomfort.	
Firmly rooted.	
General appearance: exceptionally vigorous	
Foliage mainly green-blue, some discolouration	2
Some blotches or other signs of discomfort	
Firmly rooted	
General appearance: healthy	
Foliage green in colour, some yellowing	3
Foliage blotchy, showing signs of discomfort	
Not firmly rooted, gives some resistance	
General appearance: surviving	
Foliage yellowy-green in colour	4
Foliage showing signs of discomfort	
Unstable rooting: would be easy to pull up	
Growth may be stunted	
General appearance: surviving but not healthy	
Foliage yellow	5
Foliage dying	
Barely rooted	
Stunted growth	
General appearance: barely surviving	

5.3 Microclimate

5.3.1. Slope factor

Slope factor was recorded every 5 metres (subplot) using a hand held clinometer, and a ranging pole. This was clearly marked at the eye level of the observer driven into the spoil to a fixed level. The information was collected so that slope profiles could be produced to aid vertical plot selection (Section 3.2.3), and examine potential drainage patterns (Section 2.3.2.1). The slope factor between the top and bottom of each transect was also recorded.

5.3.2 Aspect

The aspects of several potential plots on each site (Table 3.2) were recorded for plot selection purposes (Section 3.2.2) using a hand-held compass. A second, more precise, recording was taken on each transect after plot selection.

5.3.3 Canopy cover

A visual estimate of the percentage canopy cover above each quadrat was undertaken at the same time as the vegetation survey. This provides an indication of the level of direct shading at ground level by any overhead trees (Section 2.3.2.3).

5.4 Non-floristic vegetation factors

5.4.1 Vegetation height

The height of the ground layer (mosses, liverworts and lichens), the herb layer (all non-woody flowering plants) and the shrub layer (woody plants and trees 2m or under) were measured for each subunit of the quadrat. Table 5.8 summarises the methods that were considered for gaining these measurements.

Table 5.8: Three methods considered for measuring sward height alongside comments on advantages and disadvantages

Method	**How it measures vegetation**	**Advantages**	**Disadvantages**
Weighted-disc	Light disc dropped over stick, allowed to settle on vegetation	Gives reliable estimate of mass (4)	Ground irregularities influence results (1). Unsuitable in short turf (3).
Sward stick	Sleeve on ruled stick lowered. Height of 1st green non-flowering plant measured.	More sensitive to sward height than drop disc (1)	Gives consistently higher results than other methods (1,3).
Direct measurement	Height measured below which ≈ 80% of vegetation estimated to be growing.	Suitable for measuring variation in short turf. Most rapid method.	Subjective measure

Sources: Dowdeswell *et al.* (2000) (1); Frame (1993) (2); Stewart *et al.* (2001) (3), O'Riordan (2000) (4)

Stewart *et al.* (2001) points out that each of the methods have advantages and disadvantages depending on the purpose of the measurements. The sward stick method was found to be preferable over the weighted-disc by Diack *et al.* (2000) due to its greater portability and because ground irregularities were found to bias results gained by the weighed-disc method. Stewart (*op. cit.*) however, found that the weighted-disc was unsuitable for measuring height variations on short turf, because again, it was found to measure micro-topographical differences rather than vegetation height differences, underestimate short-swards (<4cm), and over-estimate tall swards (>10cm).

In this study, four of the seven sites consist largely of irregular surfaces and short open grass/herb swards of <4cm, where the weighted-disc and sward sticks did not perform so well. The direct measurement method was therefore used because of rapidity of use and accuracy over a wide range of vegetation types.

5.4.2 Biomass index

According to Frame (1993), sward height and abundance are the two main characteristics influencing biomass, and the measurement of one or both can therefore provide a reliable estimate. Jones (1979) meanwhile considers dry-weight biomass to be the only accurate measure of plant productivity. However, this was not considered to be appropriate for use in the Forest of Dean because it is a destructive measure, and plants cannot be re-sampled that have been removed (should further studies be undertaken on the spoil heaps at a later date).

In a study examining how indirect height measurement methods of measuring biomass compared with dry-weight biomass, Dowdeswell *et al.* (2000) found that the relationship between sward stick measurements and herbage mass on agricultural grass swards was not reliable. Although close relationships occurred between height and mass at low sward heights, above 15cm, the relationship was largely lost. O Riordan (2000) however found that the weighted-disc method produced close correlations between sward height and sward mass (r^2 = 70-90%).

As vegetation height and cover abundance figures are available in this study, a biomass index was formed whereby vegetation height data is combined with cover abundance to give a more accurate indication of the mass of the vegetation than vegetation height alone. The biomass index per quadrat was formed via the following calculations:

Biomass Index = (sc x sh) + (hc x hh) + (gc x gh), where:

sc = mean % shrub layer cover	sh = mean shrub layer height
hc = mean % herb layer cover	hh = mean herb layer height
gc = mean % ground layer cover	gh = mean ground layer height.

5.5 Species diversity

One of the main benefits of using the Braun-Blanquet method of floristic data collection (Section 5.7) is that diversity data on many levels are collected indirectly. The number of species and abundance of species are recorded at three levels at no extra time-cost: a) per 20 x 30cm sub-unit, b) per quadrat, and c) per sample. The diversity information may be useful in this study because the plots are of different sizes, which may affect species richness (Section 2.3.4.2). Mean species richness per subunit and quadrat may provide standard-sized units comparable across all sites that are not as affected by area. The data recording sheet is provided in Appendix 2.

5.6. Species strategies

In order to compile information on the life-strategies of key vascular species present in the Forest of Dean data-set, Table 5.10 was used to compile a data matrix. This table comprises questions asked by previous studies undertaken on colliery spoil (Section 2.3.5), so that comparisons between this study and previous studies in different locations can be drawn. Information on each species was found using information in Grime *et al.* (1988) and Stace (1997). Binary coding was used within the matrix to signify a positive (1) or negative (0) response to each possible answer so that the positive responses could be counted numerically and therefore quantified statistically.

Table 5.10: Basis for data matrix on plant species present on the Forest of Dean colliery spoil heaps

Strategy	Potential responses	Use in previous studies
Life-form	Annual Biennial Perennial	(Brierley, 1956) (Prach, 1987)
Competitive strategy	Competitor (C) Stress-tolerator (S) Ruderal (R) C-S-R Other	Grime (1979)
Raunkaier life-form	Phanerophyte Chamaephyte Hemicryptophyte Protohemicryptophyte Semi-rosette hemicryptophyte Rosette hemicryptophyte Geophyte Therophyte	(Down, 1973)
Reproductive Strategy/ies	V – Vegetative spread S – Seasonal regeneration W- seed production Bs – persistent seed bank Bj persistent juveniles	(Prach & Pysek, 1994, 1999)
Special attributes	Clonal Tap root Legume	(Prach & Pysek, 1994, 1999) (Down, 1973) (Palmer & Chadwick, 1985)
Capacity for lateral spread	Assigned categories 1-5	(Prach & Pysek, 1994, 1999); Grime *et al.*(1988)
Optimum pH range	3.0-3.9 4.0-4.9 5.0-5.9 6.0-6.9 7.0-7.9	e.g. Chadwick (1973); Williams and Chadwick (1977); Tasker and Chadwick (1978); Bradshaw and Chadiwick (1980)

5.7 Floristic vegetation factors

5.7.1. Vegetation sampling techniques

Table 5.11 summarises three common methods of sampling vegetation abundance and distribution. Cover-abundance will be used in this study because floristic rather than population data is the focus of the study, and it can be seen that cover-abundance provides more floristic information per quadrat than density or frequency.

Table 5.11: Comparison of different vegetation parameters for measuring abundance

Parameter	Method	Advantages	Disadvantages
Cover-abundance	Estimation of the quadrat area occupied each species when viewed from above.	Measures floristic composition, species distributions, diversity & biomass estimation (via plant height). Rapid. Absolute.	Cover visually estimated (therefore subjective) or point frames used (time consuming)
Density	Count of individuals within quadrat area.	Accurate, qualitative, and absolute.	Individuals often hard to recognise. Time consuming.
Frequency	Presence/absence data to find % of quadrats that contain a species.	Rapid	Non-absolute: dependent on quadrat size, plant size and patterns of vegetation growth

Sources: Goldsmith *et al.* (1986), Kent and Coker (1992), Kershaw (1973), Mueller-Dombois and Ellenberg (1974).

The visual estimation method as developed by Braun-Blanquet (1932) will be used in this research as it is a rapid means of collecting accurate information. The pin-frame method one of the main alternatives - this is a quantitative method unlike the visual estimation method, but is highly time consuming (Greig-Smith, 1983). It is therefore inappropriate here, where the aim is to collect maximum amount of accurate information in a limited 8 week period (Section 5.1.3.1).

The main disadvantage of the visual estimation method is that estimations are subject to personal error. As Greig-Smith (*op. cit.*) notes, the same person may give different assessments on different occasions. For example, rare species tend to be rated lower when the observer is feeling tired than when feeling fresh. Table 5.12 highlights some of the main problems with the method and the best solutions for this study – which were incorporated into the sampling regime.

Table 5.12: errors involved in cover-abundance estimation

Type of error	Problem	Solution
Personal subjectivity	Different people give different assessments of cover-values	One person only records data
	Different assessments of cover-values given on different occasions by same person	Take break every few hours, ensure tiredness not a problem
	Tiredness affects judgement	Take break every few hours
	Misidentification of species	Seek botanical training; always check easily confuse-able species such as grasses; get expert advice when in doubt.
Errors associated with certain species	Large amount of wood-leaf	Divide quadrat into smaller cells for increased accuracy. If one person only records data, type of errors kept constant. Count species rooted in quadrat, not species with shoots in quadrat.
	Compound leaves	
	Variable leaf size	
	Creeping stems	
	Infrequent distribution, in small numbers	

Source: Greig-Smith (1983); Kennedy & Addison (1987)

5.7.1.1 The determination of optimum quadrat size

In this research, the species-area method was used to find the Minimum Methodological Area (MMA). This is defined by Barkman (1989) as the area-size above which the number of species in a homogeneous area of vegetation does not rise, or slows down, meaning that the species composition of the plant community will be adequately represented in each sample.

The main theoretical problem associated with the species-area curve is that it originated with the Braun-Blanquet method of community vegetation analysis, which assumes vegetation to be distributed in discontinuous units or communities (Mueller-

Dombois and Ellenberg, *op. cit.*). It is therefore based on the premise that a maximum can be prescribed for the variability of each community unit, and therefore that a minimum size to satisfy the conditions can be found (Clapham, 1932). If vegetation is considered as a contiuum however, the concept of minimum area becomes untenable (Barkman, *op. cit*). The method does however, have a practical application in modern ecological studies. Table 5.13 lists the type of advice given in ecological methodology texts for determining quadrat size, demonstrating the often arbitrary or qualitative nature of other methods available. The species-area curve is a rapid way to gain quantitative information on the most efficient quadrat size for the vegetation of the study plots (Goldsmith *et al.* 1986; Mueller-Dombois and Ellenberg, *op. cit.;* Kent and Coker *op. cit.;* Krebs, *op. cit.*).

Table 5.13: Range of advice given in ecological methodology texts for the determination of quadrat size

Author	**Advice on choosing a quadrat size**
Kenkel *et al* (1989)	Should be a size somewhat larger than the mean size of vegetation clumps
Kent and Coker (1992)	Should be appropriate to morphology of vegetation
Krebs (1989)	Should be statistically efficient to maximising information and reduce variance
Greig-Smith (1952); van Dyne *et al.,* (1963); Brummer (1994)	Err towards a larger quadrat size because larger quadrats reduce variance and increase efficiency
Kent and Coker (1992)	Should be small enough to observe differences in the numbers of individuals

The data for the species-area curves was collected in the Forest of Dean according to the nested sampling technique described in Mueller-Dombois and Ellenberg (1974), whereby a patch of visually homogeneous vegetation is chosen for sampling, with sample size starting at 25cm x 25cm, and progressively doubling until

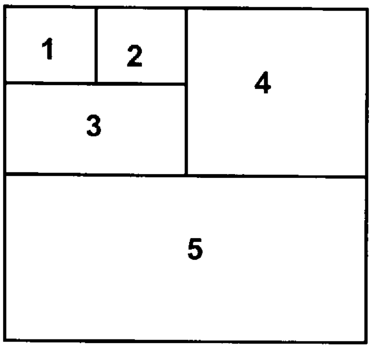


Figure 5.3: The nested plot technique

no or few new species are found (Figure 5.3). Due to the differences in vegetation occurring on the sites of different successional ages, species-area data was taken for two different plots, Northern United, the youngest site due to be surveyed, with sparsely distributed vegetation, and New Fancy A, a short-sward grassland.

At each plot, the nested sample was allocated using randomly selected co-ordinates. Whilst Barkman (1989) recommended that each sample should be taken at random, rather than nested to minimise the subjectivity of the method, a recent study by Levesque (1996) on arctic plant communities compared the results gained using both techniques, and found that the sampling method did not noticeably influence the results of that study.

The data are shown in Figures 5.4 and 5.5. According to Cain (1938), the optimum quadrat size is taken to be the tangent of the species-area curve, and the line representing the rate of increase of 10% of the total number of species for an increase of 10% total sample area. On the basis of this data, it can be seen that the optimum quadrat size that can be used to sample both communities should therefore be at least

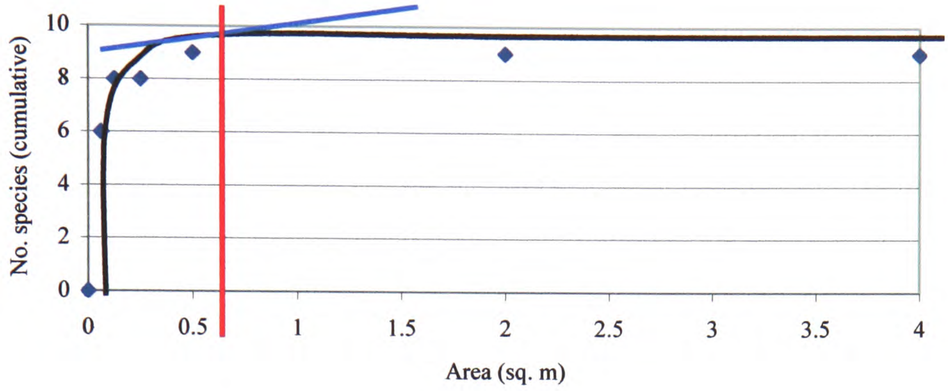


Figure 5.4: Species-area curve, Northern United

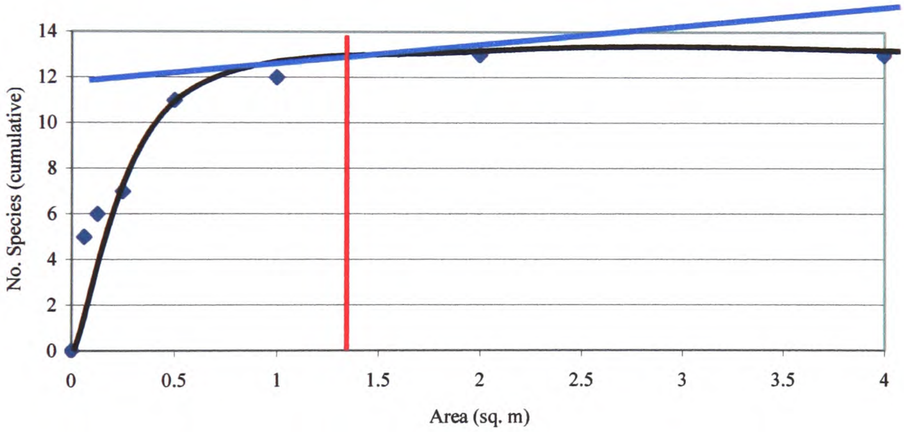


Figure 5.5: Species area curve, New Fancy View

1.25m^2 in area, or 1 x 1.5m for ease of data collection. Although there is a disparity of 0.75m^2 between the sites, the advice given in Table 5.3 indicates that making the quadrat size slightly larger than the MMA of Northern United would increase efficiency, whereas making it smaller than the MMA of New Fancy would decrease efficiency. The quadrat size of 1m x 1.5 was therefore chosen.

5.7.1.2 Quadrat design

The quadrat size of 1x 1.5m used in the Forest of Dean as shown in Figure 5.6, deliberately forms a rectangle shape, as well as satisfying Minimal Methodological Area requirements. This is because research by Clapham (1932) shows that the rectangle shape increases sampling efficiency if placed parallel with slope, and care is taken to count rooted density, rather than shooted density. Clapham used variance of the likely deviation of observations within a quadrat from the mean to measure efficiency. He found that long thin quadrats (50cm x 400cm) were found to be significantly less variable than squares of the same area, and contained almost twice as much information if placed parallel to any discernable pattern (such as slope). This is because long quadrats tend to cross more patches or clusters of vegetation (Krebs, 1989). Experiments by Greig-Smith (1983) and van Dyne by Greig-Smith (1983) and van Dyne *et al.*, (1963) also confirm Clapham's conclusions. However, errors due to edge effects have been found to increase with increased edge/area ratio (Clapham, *op. cit.;* Krebs, *op. cit.;* Kenkel *et al.*, 1989) which leads to possible counting errors due to the need for personal judgement in deciding whether the individual is outside or inside the area to be counted (Greig-Smith, *op. cit.*). Such errors decrease the efficiency of long-thin quadrats, a further reason for using a more practical 1 x 1.5m design.

The quadrat was designed to be light for carrying to and from sites, flexible for sampling over rough terrain/scrub, be dismantled for ease of storage, but fast to

Figure 5.6: quadrat design as shown on Northern United

assemble, as shown in Figure 5.6. It was therefore made from four lengths of 4cm diameter plastic piping cut to form a rectangle with an inside measurement of 100cm x 150cm. The plastic lengths were held in place with four 90° U-bend fixtures. 5mm holes were drilled at every 10cm along the 100cm lengths and every 15cm along the 150cm lengths, through which 4mm diameter metal rods could be pushed to form smaller 20 x 25cm sampling units for increased accuracy. The flexibility of the rods make the quadrat ideal for sampling rough terrain, or heather/shrub habitats (Johnston, 1998).

5.8 Summary

Objective ii is addressed by describing the overall experimental design that was implemented on each study site. This enables Objectives iii and iv to be undertaken, by setting out a suitable sampling design and data collection methods. A flexible sampling design was developed to enable sites of different sizes to be sampled. Vegetation, soil depth, plant vigour, canopy cover, sward height and biomass data was collected from transects placed parallel to the slope gradient of each spoil heap. Pyrites and pH analysis was undertaken on bulked soil samples which were collected at random, the number of samples being proportional to site size. Aspect was measured per transect, and slope factor by 5m subplot. Species strategies information was compiled on each species found using sources such as Grime *et al.* (1988) to enable this study to be compared with the results from previous studies. Floristic vegetation factors and diversity were measured by the Braun-blanquet visual estimation technique. The quadrat was designed to be of optimum size, as determined by taking a series of species-area curves on 2 sites, and was rectangular to increase sampling efficiency.

Chapter 6.0: Statistical analysis techniques

This chapter outlines the appropriate statistical methods needed to analyse floristic and environmental data, as required by objective v) (Section 1.1.2). It was decided that both univariate and multivariate techniques were required to fully analyse the data. Univariate techniques such as correlation analysis (Section 6.1) were investigated to help analyse relationships between the environmental and vegetation data-sets (Table 5.1). Univariate statistics were also used to analyse species-strategies data. This helps to fulfil one of the aims of this study (Section 1.1.1), to examine how environmental factors may influence vegetation factors. Objective viii) requires that suitable methods of analysing the species diversity of each plot are researched so that diversity may be used as a means of comparing sites (Section 6.2). Multivariate techniques were considered more appropriate for analysing floristic data (Section 6.3) than univariate techniques, due to the bulkiness of the data collected.

6.1 Substrate, microclimate, and vegetation factors

This section evaluates techniques that are available for analysing the relationships between data-sets outlined in Table 5.1 (Section 5.1.2). The specific methods that were chosen as being the most suitable for the type of data collected are examined further. Methods for analysing species-strategies data-sets outlined in Table 5.10 (Section 5.6) are also described.

6.1.1 Univariate techniques available for analysing relationships

Correlation analysis and regression analysis are described by Kent and Coker (1992), and Fowler (1998), as being the two main univariate statistical techniques used to examine relationships between data. Correlation analysis determines the strength of the relationships between variables by quantifying the amount that one variable decreases as the other increases (or vice versa). Regression analysis takes correlation analysis one step further by identifying the nature of the relationship. Multiple correlation and regression analyses can also be undertaken.

Clarke (1980) however, warns that neither correlation analysis nor regression analysis can be used to infer the cause and effect of a relationship. For example if pH rank was shown to significantly decrease as the pyrites rank increased, neither technique can prove that the increases in pyrites have caused the soil to become more acid. Kent and Coker (*op. cit.*) suggest that only further examination of the data, experimentation or the knowledge of the observer can determine cause and effect.

Given that both techniques have this limitation, and that multivariate techniques are also being used in this study to identify the potential relationships between vegetation data and environmental data (Section 6.3), correlation analysis was chosen for use in this study. It is the simpler of the techniques to use, and therefore provides a quick method of establishing which data-sets tend to vary with each other. The results of the multivariate analysis (Chapter 8) can be checked against the results of the correlation analysis (Chapter 7) for significance to establish which parameters should be examined further in Chapter

9. The results of previous studies (Section 2.3) may also help to assess possible cause and effect.

6.1.1.1 Properties of the data

Table 6.1 summarises the properties of the univariate environmental and vegetation data collected in this study, to ensure that the method of correlation analysis selected for use is suitable for the type of data available. Three data-sets are measured on the ordinal scale. The pyrites and plant vigour data are based on non-numerical qualitative observations of colour or health.

Table 6.1: Summary of the properties of data collected within this study to determine suitable methods of correlation analysis

	Value		**Sampling density**			**Scale of measurement**		
	QL	*QT*	*P*	*SP*	*Q*	*Ordinal*	*Interval*	*Ratio*
Substrate								
pH		✓	✓				✓	
Pyrites	✓		✓			✓		
Depth		✓			✓			✓
Plant vigour	✓				✓	✓		
Microclimate								
Slope factor	✓			✓				✓
Aspect (°)		✓	✓				✓	
% Canopy cover	✓				✓			✓
Vegetation								
% cover	✓				✓			✓
Sward Height (cm)		✓			✓			✓
Species richness		✓			✓			✓
Biomass index		✓			✓	✓		
Other								
Age		✓	✓					✓

Key:

QL: Qualitative QT: Quantitative P: Plot SP: Subplot Q: quadrat

The biomass data has a numerical basis (Section 5.4.2) but is an estimated index rather than a direct measurement such as dry-weight biomass.

Full statistical analysis cannot be undertaken on this type of data because the relationships between the ranks are not mathematically precise (Fowler *et al.*,1998). A quadrat ranked at plant vigour level 2 is not necessarily twice as healthy as a quadrat ranked at level 3. A quadrat with a biomass index score of 1500 may not be precisely twice as productive as a quadrat with a score of 750. Statistical tests that are based on the mean or assume a normal distribution cannot be used. For example, 'mean health rank' or the 'distribution of data around the mean health rank' are not scientifically meaningful.

6.1.1.2 Choice of correlation analysis technique

The Pearson Product Moment technique is parametric and requires data to be on the interval or ratio scale because means and variances are used in the calculations. The technique also assumes that data is normally distributed around the mean (Kent and Coker, *op. cit.*; Fowler *et al., op. cit*; Quinn and Keough, 2002). The ordinal data-sets (Table 6.1) cannot fulfil these assumptions. None of the frequency distribution analyses of three randomly selected interval and ratio scale data-sets (Sections 7.1.3, 7.3.2, 7.3.4.3) were found to have a normal distribution around the mean, indicating that Pearson-product moment is not suitable for use.

Spearman's rank correlation co-efficient was therefore chosen as being the most suitable method for all of the data-sets collected in this study. It is non-parametric and therefore does not assume a normal distribution. It can also be used on data-sets that are ordinal as long as the data can be ranked using a numerically meaningful method (Dytham, 1999; Fowler *op. cit.*).

However, there are some disadvantages of using the Spearman rank method. All data-sets will have to be reduced to the lowest common sampling density (Table 6.1), such as mean result per plot for numerical observations and the mode result per plot for nominal data. This means that a large amount of information is lost from data-sets collected at the level of the quadrat. Fowler (*op. cit.*), Dytham (*op. cit.*) and Quinn and Keough (2002) give three main warnings that need to be addressed when analysing the results (Chapter 7):

a) The method is more conservative than the Pearson's Product-moment method. This increases the chance that significant relationships are not picked up.
b) If over half of the observations are tied, the method becomes unreliable.
c) The method does not pick up non-linear relationships.

6.1.1.3 Determining the strength and significance of correlations

Correlation analysis produces a co-efficient that lies between 1 and –1, where r_s = -1 describes a perfect linear negative correlation between two data-sets, r_s = 1 signifies a perfect linear positive correlation, and r_s = 0 describes no correlation (Quinn and Keough, *op. cit.*). Fowler *op. cit.* provides a guide to the relative strength of the figures that lie in-between 1 and –1, shown in Table 6.2.

However, the correlation co-efficient does not determine whether the correlation is statistically significant. The co-efficients should therefore be checked against special tables that show pre-calculated values of the correlation co-efficient which differ significantly from 0 at the 5%, 1% and 01.% levels for the particular number of observations contained within that data-set.

Table 6.2: the Strength of a correlation

Value (+/-)	**meaning**
0.00 to 0.19	very weak
0.20 to 0.39	Weak
0.40 to 0.69	modest
0.70 to 0.89	strong
0.90 to 1.00	very strong

Adapted from Fowler (*op. cit.*)

Kent and Coker (*op. cit.*) suggest that the t statistic should be used on the data prior to using the tables, and that a one-tailed significance test is more appropriate for correlation data, as the hypotheses formed are directional. However, Clarke (1980) suggests that the t statistic is only needed where the number of items ranked is more than 10, and it is therefore not used in this study where the number of observations is 8. Fowler (1988) provides a table for checking r_s using a one-tailed test, summarised in Table 6.3 for the Forest of Dean data.

Table 6.3: expected values of r_s for relationships to be considered statistically significant

No. observations	**1 tailed test**				
	10%	**5%**	**2.5%**	**0.01%**	**0.005%**
8	0.600	0.643	0.738	0.833	0.881

Given that the Spearman rank method is less likely to pick up significant relationships than the Pearson product moment method, the 5% probability level may be more appropriate for use in this study than the more conservative 1% or 0.01% levels, and it has therefore been used in significance testing in this study. .

6.1.2 Univariate statistics for analysing species-strategies data

The species-strategy information (Table 5.10) are based on nominal categories. In this study a data-matrix was compiled (Section 5.6) to show how many of each species found on each plot belong to each category. This numerical count data transforms category information into ratio data. Calculations were undertaken to determine the mean percentage of species on each plot that possess each of the different strategies, as outlined further in Table 7.23. Given the large quantity of data gathered on these strategies, and the fact that analysing species-strategy data is not a key objective of the study, further tests such as correlation analysis were not undertaken within this study (Section 10.4.3).

6.2 Species diversity

This section evaluates the techniques that are available for analysing species diversity data taken at the level of the plot, quadrat and sampling subunit (Section 5.5). The methods chosen as being the most suitable for the type of data collected are examined further.

6.2.1 Purpose of analysis

The analysis of species diversity can be used to describe or compare a plant community at different landscape scales, as summarised in Table 6.4. The precise definition of scale and purpose is important because different approaches and procedures are used for calculating different types of species diversity (Magurran, 1988).

Table 6.4:The different scales and purposes of species diversity as described by Whittaker (1975)

Descriptive (inventory) diversities	Comparative (differentiation) diversities
Internal: diversity of a sample taken from a "homogeneous" assemblage	Internal β (beta) diversity: difference between samples of a homogeneous assemblage
α (Alpha): within-habitat diversity including all samples the "homogeneous" assemblage	β (beta) diversity: differences along a gradient or between assemblages in a landscape
γ (landscape) diversity: total diversity from all assemblages in a landscape	δ (geographical) diversity: the differences along geographical gradients, or between landscapes in a geographical region.
ε (regional) diversity: total for differing landscapes in a large geographic region	

The main objective of using species diversity in this study is to describe and compare samples and plots to see if there are any changes which occur along environmental gradients such as time, pH or slope factor. Between-plot β diversity is an important focus of the analysis to see if changes over time (Table 2.2) occur (Section 3.1). Internal or within-plot β diversity may also be important to examine whether parts of a plot are more diverse than others.

6.2.2 Species diversity indices

According to Magurran (*op. cit.*), a widely used method for calculating diversity is an index. Several indices have been developed, that are recommended

Table 6.5: Summary of comments on the use of six diversity indices

Index	Advantages	Disadvantages
Simpson	Weights abundant species more heavily than rare species; Widely used and understood	Less sensitive to detecting subtle differences between sites
Shannon	Useful method for comparing Beta diversity of habitats (permits the use of parametric statistics to test significance of differences); Widely used and understood	Assumes that all species within a population are represented in the sample; Less sensitive to detecting subtle differences between sites
Berger-Parker	More frequently adopted after comments by May (1975)	Subject to bias caused by fluctuations in the abundance of the commonest species; Less sensitive to differences between sites
Log series α	Good at detecting subtle differences between sites	Complicated to calculate
S (no. spp.)	Good at detecting subtle differences between sites	Provides no measure of evenness
Brillouin	None relevant to this study listed	Used where randomness cannot be guaranteed, or where whole plant community has been sampled

Sources: Magurran *op. cit;* Barbour, 1998

by some authors, and criticised by others. The comments on a range of indices are summarised in Table 6.5.

Because there are so many indices to choose from, Magurran (*op. cit.*) recommends testing the response of several indices to the data being used. Criteria used to test the index should include:

i) able to discriminate between sites
ii) independent of sample size
iii) suitable for component of diversity being measured
iv) widely used and understood.

Research by Magurran concluded that indices weighted towards species richness (S) are more sensitive for detecting differences between sites than measures which emphasize dominance and evenness (e.g. Simpson, Shannon, Berger-Parker, or Brillouin). However, the Simpson and Shannon indices are more sensitive to sample size than log series of (S). Krebs (1989) recommends using an index that provides a measure of evenness, despite the limitations. Evenness is important information for this study, as some sites may contain many species, but be dominated by just one or two species.

Four indices were tested for use in this study, so that the results could be examined, evaluated and compared: species richness (S), Simpson 1/D, Shannon H and Shannon evenness. Shannon H' and (S) were picked as they emphasise species richness. The Shannon evenness index was picked because it emphasises evenness of abundance, and the Simpson dominance (1/D) index because it is weighted towards the abundances of the commonest species. It may therefore be less sensitive to sample size. Of the two dominance indices discussed in Macgurran (*op. cit.*), the Simpson index was chosen for testing in this study over the Berger-Parker index due to its better discriminatory abilities. This is particularly important because the Shannon indices are criticised in Table 6.5. as being insensitive to subtle differences between sites.

6.2.3. Rank-abundance diagrams

Alongside species indices, Krebs *op. cit.*, Magurran *op. cit.*, and Kent and Coker (1992) recommend that rank-abundance diagrams are constructed as well as diversity indices. A criticism of indices relevant to this study is that too much of the original floristic or species information is lost or obscured in the process of calculation to make the ensuing single-figure results useful, transparent and understandable (Kent and Coker *op. cit.*; Peters, 1991). As discussed in Section 6.2.2, there is no consensus as to which indices should be used for different tasks. Rank-abundance diagrams can help with the interpretation of diversity data because they display richness and evenness information visually (Magurran *op. cit.*).

6.2.4 Measuring β diversity along gradients

Wilson and Mohler (1983) review specific measures of how floristic composition may change over a gradient (a coenocline). Whittaker (1960, 1965) developed a method whereby compositional differentiation is measured via units of half change (HC). A coenocline of 1HC has endpoints which are 50% similar, and a coenocline of 2HC has endpoints which are 50% similar to the midpoint.

According to Magurran (*op. cit.*) however, classification and ordination may also provide β diversity information, such as the degree of association or similarity of sites (Sections 6.3.1.2, 6.3.2). Association analysis techniques (Section 6.3.3.3) also provide information on the % similarity or dissimilarity between sites or samples. In this study, β diversity will therefore be indirectly determined using the multivariate methods and association analysis techniques described in Section 6.3. These techniques may provide information on floristic change and similarity between or within plots through measured gradients (Table 5.1) such as slope, time, pH, shade and aspect.

6.2.5 Methods for standardising data-sets of different sizes

According to Huggett (1998), Dale (1999) and Wilson & Chiarucci (2000), the species-area relationship, whereby the number of species is likely to increase with increased sample size, is a fundamental bio-geographical pattern. In this study, (Section 3.2) the decision was made to sample plots that are not of the same area, to ensure that the slope factor gradient could be incorporated into gradient analysis. Results may therefore be affected by the site size.

Rarefaction is a method which can be used to standardise data-sets of different sizes by estimating the "expected" number of species per standardised sample (Magurran, *op. cit.*). However, Magurran also comments that a large amount of information such as species evenness is lost. Krebs (1989) also comments that rarefaction results should not be used where different types of plant community are to be compared, as is the case in the Forest of Dean, because different habitats will have different expected diversities.

A second approach is to use only data collected from a standardised area within each plot for the comparison of species diversity, as used by Simberloff (1972), whereby a computer was used to randomly select samples from within the total data-set. In this study, species data taken at the level of the quadrat or the subunit that are constant across all sites could be used.

It was therefore decided to use the data from un-modified data-sets to construct both the diversity indices and the species-abundance curves to enable all the possible information within the data-sets to be viewed and examined. The extent to which species-area does affect the samples can then be examined.

Further investigation of data taken from standardised units can be used if the species-area effect is found to adversely influence results (Section 7.3.4.3).

6.3 Floristics

This section evaluates the techniques that are available for analysing multivariate vegetation data taken at the level of the quadrat (Section 5.7). The methods chosen as being the most suitable for the type of data collected are examined further.

6.3.1 The roles of multivariate analysis in vegetation research

According to Quinn and Keough (2002), a data-set is multivariate if it includes more than one variable recorded from a number of replicate sampling units. The data collected from the Forest of Dean for example consists of over 300 samples that may contain species abundance scores from between 1 to 30+ species. Multivariate statistical techniques are therefore required to analyse this type of data for practical reasons such as to the reduction of complexity by efficiently exploring and summarising sources of variance this variance (Gauch, 1982).

However, some of the multivariate techniques that have been developed for vegetation analysis are also historically associated with particular schools of ecological thought on plant succession (Section 2.1). In choosing which techniques to use in this study therefore, the overall statistical methodology should not biased towards one school of thought more than the other (Section

2.1.1.). Techniques should instead be chosen that are complementary to each other, highlighting different aspects of the data (Kent and Ballard, 1988).

6.3.1.1 Reducing complexity

Vegetation data can be complex, as described in Table 6.6, with many different sources of variability. One role of multivariate analysis methods in this study is to reduce the complexity and bulk of the data and to distinguish between major sources of variance caused by differing environmental variables, and minor variance caused by noise, redundancy and outliers (Fowler *et al.* 1998; Gauch, 1982).

Table 6.6: Tbe main sources of complexity in vegetation data

Data attribute	**Brief description of the problem**
Noise	Even where environmental conditions identical, floristic composition likely to differ. Replicate samples may differ due to seasonality.
Redundancy	Some samples floristically similar to others. Distributions of species across samples may be similar. Main sources of variation can become obscured by such duplications. Data reduction necessary.
Size	Large data-set is needed to distinguish recurrent patterns from noise.
Outliers	Samples may occur with dissimilar composition to rest of the samples due to disturbed or heterogeneous sites.

Source: Gauch (1992); Kent and Coker (1992)

6.3.1.2 The roles of classification and ordination

According to Kent and Ballard (1988), classification and ordination are inductive techniques, used to describe data and summarise trends, and therefore the use of these techniques should be limited to generating hypotheses as to the underlying causes of variation found, not testing them. The authors further argue that it is important to use both classification and ordination methods in analysing vegetation data rather than just using one or the other. This is because each of the methods is associated with a particular viewpoint of how vegetation is distributed in space, as discussed in Section 2.1. By using both techniques, this study will produce results that are not biased towards either theory.

Classification seeks to group samples or species together on the basis of shared characteristics into abstract units or types of plant communities (Whittaker, 1962). The assumptions behind classification are firstly that plant communities are discontinuous, having discrete boundaries that can be delimited, and secondly that plant communities are repeated in space, so defining vegetation types is meaningful and useful (Kent and Coker, 1992). Ordination meanwhile assumes that vegetation is distributed along a continuum, and that changes in species populations and community characteristics may be related to changes in environment. This method of analysis arranges samples from plant communities in sequence by their positions along an environmental gradient, or in mathematical space. Critics of ordination have argued that the researchers who developed the modern methods imposed an assumption of continuity on their research, and that much of the evidence for the continuum concept arise from the results of ordination methods themselves. The apparent continuity of the communities may be an artefact resulting from the circularity of the method (Whittaker, 1978b; Greig-Smith, 1980; Austin, 1985; Callaway, 1997).

Moreover, Kent (1981) explains how the use of both methods in vegetation studies is complementary rather than contradictory. Classification

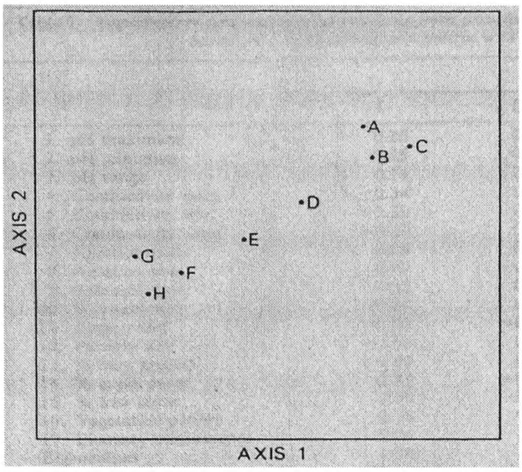


Figure 6.1: Simplified two-dimensional ordination diagram of hypothetical samples A-H taken from Kent (1981). The closer together spatially, the more similar the samples.

sorts sites or species into groups, such as ABC and D in one group and EFGH in another. Ordination meanwhile, displays the similarity between individuals so that the relationship between the samples can be seen. In Figure 6.1 for example, samples E and D lie between the two main clusters and may be more similar to each other than with either cluster. In this study classification may be useful for defining what vegetation types exist on the colliery spoil heaps, and whether these vegetation types tend to change over time. Ordination may be useful for determining the underlying gradients.

6.3.2. The choice of technique for each multivariate method

6.3.2.1. Classification techniques

The first type of classification techniques originated with Braun-Blanquet (1932), where matrices were constructed that arranged the species in a sequence to concentrate species similar in their distributions in the samples, and to arrange the samples in a sequence bringing together samples similar in species composition (Gauch, 1982). According to Gauch (*op. cit.*) this method was time-consuming, and difficult to apply to vegetation in new areas where the species associations were not well understood. However, computer programmes such as TABORD, developed in the 1970s, and TWINSPAN (Hill, 1979) have developed this table-arrangement technique. Agglomerative techniques such as association analysis (the basis of the CLUSTAN programme) meanwhile, are based on assigning each sample or species to a cluster, placing similar samples or species together.

Table 6.7: A summary of the general principles of classification techniques used in vegetation science over the past 25 years.

Hierarchical	**Non-hierarchical**
Results displayed in a dendrogram (linkage diagram).	Individuals assigned to clusters without hierarchical relationships being shown.
Divisive	**Agglomerative**
Starts with the total sample set which is progressively divided into smaller groups. Process halted when each group comprises an individual only, or at a predetermined point.	Starts with individuals that are joined to form groups, then groups joined into larger groups. Process halted when an interpretable set of groups emerges.
Polythetic	**Monothetic**
Classification process based on all the data	Allocate individuals to groups on the basis of one variable or species.
Equal emphasis of species	**Unequal emphasis of species**
All species present given equal weight	Rare species down-weighted, or importance of dominant species increased
Single analysis	**Joint analysis**
Analysis of quadrats separately from species	Classification of quadrats and species carried out simultaneously

Sources: Gauch (1982), Kent and Coker (1992), van Tongeren (1995),

Table 6.6 summarises the general principles of classification techniques. According to Kent and Coker (1992) and van Tongeren (1995), TWINSPAN is popular for use in floristic studies because it produces hierarchical diagrams which clearly show different levels of similarity or dissimilarity, is able to undertake joint analysis of quadrats and species, and because it is polythetic. This means that division is not made on the presence or absence of one species, unlike clustering techniques such as association analysis, but on the species composition of the whole quadrat.

Furthermore TWINSPAN uses differences in abundance information as a further measure of similarity/dissimilarity through the idea of pseudospecies. Here, the cover abundance % scale can be divided into levels that best represent the data. For example, as many of the sites in the Forest of Dean are only scarcely vegetated, levels should be designed to include species of lower abundances as well as those that are more frequent, such as:

1: 0.1-2%　　2: 2.1-7%　　3:7.1-20%　　4:20%+

These different levels of abundance are then used in a presence/absence form during the classification. For example, *Fragaria vesca* occurring at 1% is present at level 1. *Fragaria vesca* occurring at 60% would be described as occurring at level 4 (Kent and Coker, 1992). The relative sophistication of TWINSPAN is the reason that it will be used in this study.

6.3.2.2. Ordination techniques

According to Palmer (2000), the ideal ordination technique would possess the following qualities:

a) Practical (easy to use and understand, available, inexpensive)
b) It does not distort data

c) It should display clusters if clusters exist in the data but should not produce clustering when that is not present.

d) Ecological similarity is related in proximity to space produced on the resulting ordination diagram

e) The method is not sensitive to noise

f) The method is robust enough to work on data-sets with very different ecological qualities

Palmer (*op. cit.*) considers that the perfect ordination technique does not yet exist, but these criteria can be used to evaluate the techniques that are available.

Table 6.8: Summary of four indirect ordination techniques

Technique	**Brief description**
Polar Ordination. Bray and Curtis (1957)	User specifies end-points, all other samples defined relative to them (1)
Principal Components Analysis (PCA). Goodall (1954), Orloci (1966).	Projects multidimensional cloud of points into a space of fewer dimensions, using rigid rotation to derive orthogonal axes which maximise the variance (3).
Reciprocal Averaging (RA), or Correspondence Analysis (CA). Hill (1973, 1974)	Sample scores calculated as weighted average of species scores; species scores calculated as weighted average of sample scores. Iterations continue until no change (1)
Detrended Correspondence Analysis (DCA). Gauch and Hill (1980).	Extension of RA whereby arch effect is removed by detrending (dividing 1st axis into segments, centering the 2nd axis on 0), and rescaling (positions of samples on axes shifted to make beta diversity constant) (1)

Sources: Palmer (1); Barbour *et al.* (2); Gauch (1982) (3)

Table 6.8 briefly describes four indirect ordination techniques as discussed in Gauch (1982), listed in chronological order of when they were developed for use in ecology. Table 6.9 meanwhile assesses the advantages and disadvantages of each method. It can be seen that Detrended Correspondence Analysis as the

Table 6.9: Advantages and disadvantages of the main indirect ordination techniques that have been developed since the 1950s

Technique	Advantages	Disadvantages
Polar Ordination	Easiest technique to visualise; can undertake without a computer (1,2)	Subjectivity by user in deciding which samples used as end-points (2)
PCA	Objective (3), All floristic information used as simultaneously ordinates species and samples (1,3)	Horseshoe effect distorts data (1); Inappropriate for some data-sets (3)
RA/CA	Objective; -Simultaneously ordinates species and samples; New samples put in without affecting the rest of the ordination (1)	Horseshoe effect distorts data (1); Ends of gradients compressed (2)
DCA	As for RA. Arch effect and compression removed ensuring that similar floristic or ecological differences between samples are expressed as similar distances in ordination space (1,2)	Sensitive to parameters that determine the number of segments (1). –Vulnerable to outlying species or samples(4).

Sources: Palmer (1); Barbour *et al.* (2); Gauch (1982) (3)

culmination of many years research into ordination techniques, is able to correct the main problems found to exist with other techniques. It is for these reasons that the DCA technique will be used in this study.

However, ter Braak (1995) notes that the technique has not solved the original problems of Reciprocal Averaging as it is still based on the assumption that species distribution is unimodal. As this idealistic bell-shaped curve is not universally found in vegetation data, Austin (1987) and Austin *et al.* (1984, 1994) have therefore questioned the validity of DCA and other approaches based on this assumption. According to an evaluation by Minchin (1987), the detrending and rescaling processes involved with DCA analysis may loose some of the information contained in the data, as it flattened out some of the variation associated with one environmental gradient tested. Mazzoleni *et al.* (1991) in a test of DCA, PCA and Polar Ordination on successional data found that PCA reflected the underlying gradients better than DCA on successional data.

Peet *et al.* (1988) however, describe DCA as "one of the most powerful multivariate tools available" for representing pattern in communities. They point out that whilst it does have minor problems, it has less problems than the other techniques available. An evaluation of DCA by Rasmus (2000) concluded that DCA is a robust and useful technique, but agree with Austin *op. cit.* that the "perfect" method of ordination has yet to be developed.

6.3.2.3. Classification and ordination techniques used in current vegetation research

To give an indication of which types of techniques are used in current ecological research, articles in 4 ecological journals were reviewed. *Oikos*, the *Journal of Ecology*, the *Journal of Applied Ecology* and the *Biological Journal of the Linnean Society* were selected because they review a wide range of ecological disciplines rather than just vegetation science. An insight into techniques used in other fields of ecology may therefore be gained. Five of the most recent issues were reviewed in April 2001, and as each of the journals are issued quarterly the review took place over a similar time-period. The different types of multivariate methods found are summarised in Table 6.10.

This was not intended to be a full review of methods. The purpose was to examine whether other types of multivariate technique than those outlined in Tables 6.8 and 6.9 are used in current ecological research. It was also undertaken to assess whether the techniques selected in Sections 6.3.2.1 and 6.2.2.2 are suitable for the purposes of the study.

Table 6.10: The applications of multivariate analysis within modern ecological studies

Multivariate technique	**Application**	**Source of Reference**
Classification	Vegetation mapping. Analysis of vegetation distribution patterns. SPSS Cluster Analysis.	Denk *et al.* (2001)
	Cluster analysis (programme unknown) on bee distribution (1613 samples) along a disturbance gradient	Liow *et. al.* (2001)
	TWINSPAN analysis of floristic data taken across a wet heath habitat.	Morris *et al.* (2000)
Indirect ordination	DCA analysis of differences in floristic composition of experimental grazing plots	Humphrey & Patterson (2000
	DCA analysis of composition & abundance of bacterial communities exposed to different disturbance regimes	Fukami (2001)
	DCA analysis of floristic change over time	Collins *et al.* 2000

The results demonstrate that despite the wide-range of subjects covered, the type and applications of classification and ordination techniques were similar to the application of this study. The choice of multivariate techniques used in this study can be further justified. It can be seen from the table that DCA is widely used in ecological studies, and whilst cluster analysis is used for some classification studies, TWINSPAN is used where floristic data needs analysis.

6.3.3 Association analysis

Whilst classification gives some visual indication of how similar the samples taken from each site are in terms of how closely together they are grouped, a measurement of similarity or dissimilarity can be calculated quantitatively to complement the multivariate analysis result. Kent and Coker (1992) list several methods that can be used on vegetation samples, such as the Jaccard, Sorensen or Czekanowski coefficients.

Two coefficients were selected to use on the data to provide a comparison of the results. The Sørensen coefficient and Jaccard coefficient are both suitable for qualitative (i.e. cover-abundance data), whereas the Czekanowski coefficient can be used on qualitative or quantitative data. The Sørensen coefficient was selected because it gives weight to the species that are common to both sites rather than species that only occur in one or the other. This coefficient may therefore be less sensitive to the species-area effect. The Czekanowski coefficient was selected for use as a comparison to the Sørensen method, as it is considered by Kent and Coker (*op. cit.*) as being the most widely known and used coefficient.

In order to use the method to compare plot similarity rather than sample similarity, the coefficients have both been used on the summary data for each plot, whereby the species abundance data for each quadrat taken within the plot has been summed, and divided by the number of quadrats to give an average

a)

$$S_s = \frac{2a}{2a+b+c}$$

b)

$$S_c = \frac{2\sum_{i-1}^{m} \min(X_i, Y_i)}{\sum_{i=1}^{m} X_i + \sum_{i=1}^{m} Y_i}$$

Figure 6.3: Formulae for the Sørensen (a) and Czekanowski (b) coefficients

species abundance per plot. The formulae for each coefficient are shown in Figure 6.3. In both cases, the coefficient values range from 0 (complete dissimilarity) to 1 (total similarity), and can be multiplied by 10 to give results as % similarity.

6.4 Summary

Correlation analysis was selected to examine the relationship between the non-floristic data. Of the methods evaluated, Spearman's rank correlation co-efficient was selected as the most suitable co-efficient due to the differences in the quality and type of data collected. However, the method is conservative (less likely to pick up significant relationships), and is unreliable on data where more than half of the observations are tied.

The species diversity methods were selected to measure β diversity between and within plots. A multi-method approach was constructed to enable diversity data to be fully described and understood, and the effects of the species area effect examined. Four diversity indices were selected for testing on the data, along with the construction of species-abundance diagrams. Association analysis and floristic analysis were decided as being suitable for measuring β diversity along gradients.

Multivariate analysis was chosen as being the most type of statistical method to analyse the floristic data as it reduces the complexity of the data. It was decided to use both classification and ordination on the data because these techniques are complementary to each other. Classification groups samples together into abstract groups on the basis of shared characteristics. Ordination assumes that vegetation is distributed as a continuum and results display differences or similarities of each sample spatially.

The TWINSPAN classification was selected for use because the results are displayed clearly, because it is polythetic, and because it uses differences in species abundance to classify samples. The DCA method of ordination was chosen because it corrects the main problems associated with other methods, such as the arch effect and compression. However, it is still vulnerable to outlying species or samples. Both methods are widely used in contemporary ecological studies.

Association analysis will be used to quantitatively measure how similar the plots are floristically. The Soresen and Czeckanowski coefficients will both be used on the data.

Chapter 7.0: Results analysed using uni-variate statistical methods

This chapter helps to address objectives iv), v) and vi) (Section 1.1.), by showing that environmental and vegetation data from within the framework of the experimental design (chapter 5) has been analysed so that it can be further examined in chapter 9. The results of data analysed using uni-variate statistics are displayed and summarised in this chapter. The floristic results analysed using multivariate statistical techniques are summarised in chapter 8.

The univariate data-sets have been organised in a similar way to Chapters 2 and 5 (Table 7.1) to facilitate Objective vi). This chapter also shows the results of correlation analysis undertaken on the data to examine the levels of co-variance between the different parameters (Section 6.1), as required by Objective v).

As discussed in Section 6.1.1.1, the data-sets that are described in this chapter have different properties, and so different statistical analyses have been undertaken on each. The properties of the data and the types of statistical analysis that have been undertaken are therefore summarised at the start of each chapter.

The results of distribution data needed in Section 6.1.1.2 are also displayed in this chapter. Three non-ordinal data-sets collected at the quadrat scale were randomly selected (Soil depth, % bare ground, and number of species per quadrat). These data-sets were investigated using the methods of Fowler *et. al.* (1998), who notes that data is not usually normally distributed if 70% of the results for each data-set fall between the sample mean and the sample standard deviation. This was checked by constructing frequency graphs.

7.1 Substrate factors

This section describes the results of the analysis of substrate parameters collected according to method outlined in Section 5.2, summarised in Table 7.1.

Table 7.1: statistical analyses undertaken on the non-floristic Forest of Dean data-sets

Data-sets		Type of data		Statistical analyses					
	Parameter	**Scale**	**Density**	**Mn**	**Md**	**SD**	**CA**	**D**	**S**
Substrate	pH value	I	P			✓	✓		✓
	Pyrites (cm)	O	P				✓		
	Soil depth (cm)	R	Q	✓		✓	✓	✓	✓
	Plant vigour (index)	O	Q		✓		✓		

Key:

P = Plot; T = Transect; SP = subplot; Q = Quadrat
N = nominal; O = Ordinal; I = Interval; R = Ratio
Mn = mean; Md = Mode; SD = Standard deviation; CA = correlation analysis; D = distribution; S = significance

To enable the data to be used in correlation analysis, results per plot have been ranked from 1-8 to provide a standard numerical basis for comparison with other data-sets using the Spearman rank method (Section 6.1.1). Correlation analysis results between the substrate factors are shown in Section 7.1.5, and the relationships between all factors are summarised in Section 7.5.

7.1.1 pH

Table 7.2 displays the pH results that were gained from the analysis method described in Section 5.2.2. These were undertaken on bulked samples collected per plot, so no further statistical analyses were undertaken on the data (Table 7.1). It can be seen that the pH of the sites ranges from the highly acidic

Table 7.2: pH values of 8 spoil heaps of different ages in the Forest of Dean taken from bulked samples collected on 12th December 2001.

Site	pH	Rank
Hawkeswell	3.02	1
True Blue	3.98	2
Northern United	4.60	3
Cannop B	4.79	4
Lightmoor	5.00	5
New Fancy A	5.73	6
Cannop A	5.93	7
New Fancy B	6.38	8

Hawkeswell (pH 3.02) to the New Fancy B plot (pH 6.38) which is approaching neutral (pH 7). The results were ranked from most acidic to least acidic.

7.1.2 Pyrites

The test for pyrites is described in Section 5.2.3. All of the spoil samples from the Forest of Dean were found to have only slight tan colouration, indicating

Table 7.3: Colorimetry development on samples taken from 8 spoil heaps in the Forest of Dean ranked from darkest to lightest in colour

Site	**Colour development rank (darkest = 1,lightest =8)**
Cannop A	1
Northern United	2
Hawkeswell	3
Cannop B	4
New Fancy B	5
New Fancy A	6
Lightmoor, True Blue	7.5

a very weak pyrites content (available in Appendix 3.1). However, to enable the results from the different study plots to be compared, the filter papers were examined by eye to assess which were darkest and which lightest. These results were assigned a numerical value for the Spearman rank analysis (Section 6.1.1) so that they can be compared to other data-sets, as shown in Table 7.3.

Cannop A was observed to have the highest pyrites content of the Forest of Dean sites, and Northern United the second highest. Lightmoor and True Blue would appear to have the weakest content. As the colouration on these two sites was very similar, they were considered to be tied observations and standard methodology used to gain a mean rank (Fowler *et al.* 1998).

7.1.3 Soil depth

The soil depth measurements were recorded per quadrat according to methodology described in Section 5.2.4. As 404 measurements were taken, the raw data table was placed in Appendix 3.2, and a summary provided in Table 7.4.

Table 7.4: Soil depth results (cm) summarised from results recorded per quadrat.

Plot	Max. depth recorded	Min depth recorded	Mean depth	Standard deviation	Rank (deepest = 8; lowest = 1)
HW*	0	0	0	0	1
NU	0.2	0	0	0.02	2
CPA	0.5	0	0.06	0.17	3
NFA	3.0	0	1.35	0.74	7
NFB	2.5	0.3	0.74	0.56	6
CPB	5	0	0.18	0.73	4
LM	10	0	0.58	2.08	5
TB	2.5	0	1.63	0.77	8
Whole sample	10	0	0.41	1.05	

*No soil other than bare colliery substrate was recorded on Hawkeswell as it was being re-worked at the time of sampling

All sites apart from New Fancy A and True Blue had on average less than 1cm of soil, and both Northern United and Hawkeswell were devoid of soil.

Figure 7.1 shows that the data is skewed towards the 0 cm depth frequency category rather than being normally distributed. Of 404 samples, only 45 (11%) were found to lie between the standard mean and standard deviation (Appendix 3.2), also indicating that the data is not normally distributed (Fowler *et al.* 1998), and therefore not suitable for parametric methods of analysis (Section 6.1.1.2).

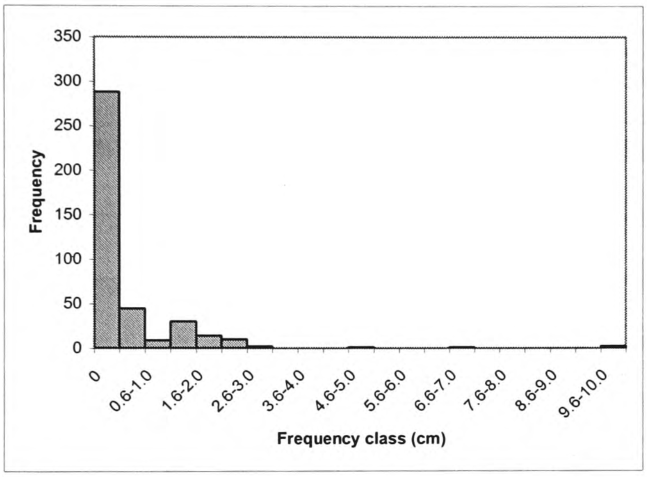


Figure 7.1: Frequency distribution of the soil depth results

7.1.4 Plant vigour

The plant vigour assessment recorded for each quadrat is available in Appendix 3.3, and summarised in Table 7.5. In order to use this nominal data-set within the Spearman Rank correlation analysis, the mode vigour category (1-5) was used to assign rank to the data rather than the mean. Several of the sites were found to have mode categoriess of 4 or 5. In order to reduce the number of tied observations within the ranking system (Section 6.1.1.1), the percentage of samples falling within the mode score category was used to assign rank. For example, New Fancy A and True Blue both have a mode vigour score of 2, but a higher percentage of the True Blue quadrats fall within this category than New Fancy A plots. True Blue has therefore been assigned a higher rank that New Fancy A. Hawkeswell quadrats were all assigned a score of 5 as there was no vegetation present at all.

Table 7.5: Plant vigour index results summarised from results recorded per quadrat.

Plot	Max. vigour score	Min vigour score	Mode vigour score/plot	% samples within the mode score category	Rank (unhealthiest = 8; healthiest = 1)
HW*	5	5	5	100	8
NU	3	5	4	74	6
CPA	4	5	5	72	7
NFA	2	4	2	54	2
NFB	2	3	3	88	3
CPB	2	5	4	65	4
LM	2	5	4	70	5
TB	2	3	2	79	1

*No vegetation was found on Hawkeswell in preliminary investigations prior to re-working. It was awarded a score of '5' for this reason.

7.1.5 Correlations between the substrate factors

The results of Spearman's Rank correlation analyses on ranked substrate results (summarised in Sections 7.2.1-7.2.4) are shown in Table 7.6. Correlations significant at the P<0.05 level or above are highlighted. The correlations between substrate factors and other data-sets are summarised in Section 7.5.

Table 7.6: half-matrix to show results of Pearson product-moment correlation undertaken on ranked substrate data.

Pyrites	*-0.04*		
Soil depth	0.31	*0.80*	
Vigour	*-0.19*	*-0.85*	*-0.92*
	pH	**Pyrites**	**Soil depth**

Key:

0.643	**indicates result significant at the P<0.05 level**
0.738	**indicates result significant at the P<0.025 level or above**
0.065	**indicates ordinal data difficult to assign significance to**

The table shows that the relationship between pH and soil depth is not significant at the 95% confidence level set in Section 6.1.1.3.

7.2 Microclimate

This section outlines the results of the microclimate data-sets and uni-variate analyses summarised in Table 7.7. To enable the data to be used in

Table 7.7: statistical analyses undertaken on the non-floristic Forest of Dean data-sets

Data-sets		**Type of data**		**Statistical analyses**					
	Parameter	**Scale**	**Density**	**Mn**	**Md**	**SD**	**CA**	**D**	**S**
Micro-climate	Slope factor (°)	R	SP	✓		✓	✓		✓
	Aspect (°)	I	T	✓			✓		
	Canopy cover (%)	R	Q	✓		✓	✓		✓

Key:
P = Plot; T = Transect; SP = subplot; Q = Quadrat
N = nominal; O = Ordinal; I = Interval; R = Ratio
Mn = mean; Md = Mode; SD = Standard deviation; CA = correlation analysis; D = distribution; S = significance

Spearman rank analysis (Section 6.1.1), results per plot have been ranked from 1-8. The correlation results between the microclimate factors are shown in Section 7.2.4, and the relationships between all factors are summarised in Section 7.5

7.2.1 Slope factor

Slope factor data was collected according to the methodology described in Section 5.3.1. Appendix 3.4 contains the raw data table, summarised in Table 7.8.

Table 7.8: summary of slope information (°) recorded per subplot

Plot	Max.° per subplot	Min ° per subplot	Mean ° per plot	Standard deviation	Rank (steepest = 8; flattest = 1)
HW*	0	0	12	0	1
NU	21	10	15.4	4.25	2
CPA	40	15	30.1	10.50	6
NFA	31	19	26.6	4.55	5
NFB	32	26	30.3	2.10	7
CPB	40	18	32.3	6.92	8
LM	40	13	25.9	7.98	4
TB	29	12	19.2	6.33	3

* One mean recording is supplied for the Hawkeswell plot to avoid having to walk over re-worked spoil areas for health and safety reasons, and also to avoid gaining anomalous results from the temporary piles of spoil created during re-working.

The mean slope factor result per subplot has been used to rank the sites. Cannop B was found to be the steepest site using this ranking system, although it can be seen that Cannop A, and Lightmoor also have slope factors of 40°. The mean slope factor for the Hawkeswell transects was 12°, so this figure has been used to rank the site.

7.2.2 Aspect

Table 7.9 shows the aspect data recorded per transect (Section 5.3.2). This shows that transects on plots such as New Fancy A are very similar in aspect, but transects on Lightmoor and Cannop B can vary by up to 20°. For the purposes of correlation analysis, the data has been ranked according to the mean aspect of the plots, from 1 = 180 ° (most southerly –facing) to 8 = 270° (most westerly facing).

Table 7.9: Aspect (°) of each plot in the Forest of Dean

	T1	T2	T3	Mean	Rank
HW*	180			180	1
NU	179	183	187	183	2
CPA	260			260	6
NFA	264	261		263	7
NFB	270			270	8
CPB	235	245	240	240	4
LM	240	220	200	220	3
TB	255	260		258	5

*One recording only was made on Hawkeswell.

7.2.3. Canopy cover

Canopy cover results were recorded according to the methodology described in Section 5.3.3. The raw data table has been placed in Appendix 3.5 due to size, but this has been summarised in Table 7.10. It can be seen that New Fancy B has the highest mean canopy cover (54%), with Cannop B (42.6%) and New Fancy A (41.77%) next in rank. There were no trees of canopy-height (2m and above) present on Lightmoor, Hawkeswell or True Blue at all.

Table 7.10: summary of % canopy cover information recorded per quadrat

Plot	Max.% cover /quadrat	Min. % cover / quadrat	Mean % cover/ plot	Standard deviation	Rank (least shaded = 8; most shaded = 1)
HW	0	0	0	0	7
NU	23	0	1.74	4.77	5
CPA	35	0	5.63	15.57	4
NFA	100	0	41.77	38.50	3
NFB	80	0	54.25	30.42	1
CPB	95	0	42.60	31.47	2
LM	0	0	0	0	7
TB	0	0	0	0	7

7.2.4. Correlations between microclimatic factors

Table 7.11 shows the results of correlation analyses undertaken on the ranked microclimate data presented in Sections 7.2.1-7.2.3. Significant correlations at the 95% level or above (Section 6.1.1.3) have been highlighted. The results of correlations between all data-sets are summarised in Section 7.6.

Table 7.11: half-matrix to show results of Pearson product-moment correlation undertaken on ranked microclimate data

Aspect	**0.69**	
Canopy cover	**-0.83**	**-0.68**
	Slope factor	**Aspect**

Key:

0.643	**indicates result significant at the P<0.05 level**
0.738	**indicates result significant at the P<0.025 level or above**
n	**indicates ordinal data difficult to assign significance to**

It can be seen from this table that there are correlations between all of the microclimate factors at the 95% significance level (P<0.05) or above.

7.3 Vegetation factors

This section outlines the results of the vegetation height, cover and biomass index, measured according to methods described in Section 5.4. Diversity indices and rank abundance diagrams have been constructed and analysed in Section 7.3.4 to allow comparision of data using the Spearman rank method. The data-sets and statistical analyses undertaken are summarised in Table 7.12.

Table 7.12: statistical analyses undertaken on the non-floristic Forest of Dean data-sets

Data-sets		Type of data		Statistical analyses					
	Parameter	**Scale**	**Density**	**Mn**	**Md**	**SD**	**CA**	**D**	**S**
Vegetation factors	Moss height (cm)	R	Q	✓		✓	✓		✓
	Herb height (cm)	R	Q	✓		✓	✓		✓
	Shrub height (cm)	R	Q	✓		✓	✓		✓
	Moss cover (%)	R	Q	✓		✓	✓		✓
	Herb cover (%)	R	Q	✓		✓	✓		✓
	Shrub cover (%)	R	Q	✓		✓	✓		✓
	Bare ground cover (%)	R	Q	✓		✓	✓	✓	✓
	Biomass (index)	O	Q	✓			✓		
Diversity indices	(S)	R	P				✓		
	Shannon H'	R	P				✓		
	Shannon E	R	P				✓		
	Simpson 1/D	R	P				✓		
	(S)/Quadrat	R	Q	✓		✓	✓	✓	✓
	(S)/Subunit	R	Q	✓		✓	✓		✓

Key:

P = Plot; T = Transect; SP = subplot; Q = Quadrat
N = nominal; O = Ordinal; I = Interval; R = Ratio
Mn = mean; Md = Mode; SD = Standard deviation; CA = correlation analysis; D = distribution; S = significance

The results per plot have been ranked from 1-8 for correlation analyses. Correlation results between the vegetation factors are shown in Section 7.3.5, and the relationships between all factors are summarised in Section 7.5.

7.3.1 Vegetation height

Vegetation height calculations were undertaken as described in Section 5.4.1. The raw data tables for ground, herb and shrub layers are provided in Appendix 3.6, and summarised in Table 7.13.

The mean height of the shrub layer vegetation ranges from 53.8cm on Northern United to 8.2cm on Lightmoor, and 0 on Hawkeswell. The standard deviations are high for all plots relative to the mean except True Blue, indicating that shrub height is patchy across all plots. The mean height of the herb layer is less varied, ranging from 26cm on New Fancy A to 0cm on Hawkeswell, but standard deviations still high for all plots. The mean height per plot of the moss layer ranges from 2.35cm on New Fancy A to 0.04cm on Northern United.

7.3.2 Vegetation cover

The mean percentage cover was calculated for the ground, herb and shrub vegetation layers by summarising floristic data collected according to methods outlined in Section 5.7. The species occurring within each quadrat were separated into the three categories (Section 5.4.1) and % cover summed per quadrat. The results are available in Appendix 3.7, and summarised in Table 7.14.

Table 7.13: summary of vegetation height data (cm), recorded per quadrat, where rank 8 = lowest mean height, and 1 = highest mean height

	Shrub layer height (cm)					Herb layer height (cm)					Ground layer height (cm)				
Plot	Max height per quadrat	Min. height per quadrat	Mean height per plot	ST. DV.	Rank	Max height per quadrat	Min. height per quadrat	Mean Height per plot	ST. DV.	Rank	Max height per quadrat	Min. height per quadrat	Mean height per plot	ST. DV.	Rank
HW*	0	0	0	0	8	0	0	0	0	8	0	0	0	0	8
NU	180	0	53.18	51.11	1	36	0	16.58	7.94	3	1.0	0	0.37	0.26	6
CPA	261	0	11.88	46.28	6	46	0	9.59	15.50	5	0.5	0	0.35	0.21	7
NFA	175	0	42.43	30.30	7	60	8.8	26.02	11.94	1	10.0	0.2	2.35	2.14	1
NFB	110	0	25.31	32.83	4	40	18	25.61	4.91	2	3.0	0	0.99	0.58	3
CPB	350	0	22.79	74.86	5	10	0	4.17	2.65	7	5.0	0	0.72	0.79	5
LM	83	0	8.21	16.80	7	35	2.4	8.81	7.27	6	5.0	0	0.68	1.22	4
TB	42	8.6	26.38	8.78	3	25	5	13.74	5.21	4	5.4	0.5	2.25	1.93	2

Table 7.14: summary of vegetation cover-abundance data (% cover), recorded per quadrat where rank 8 = lowest mean height, and 1 = highest mean height

	Shrub-layer species cover-abundance (%)					Herb-layer species cover-abundance (%)					Ground-layer species cover-abundance (%)				
Plot	Max % per quadrat	Min. % per quadrat	Mean % per plot	ST. DV.	Rank	Max % per quadrat	Min. % per quadrat	Mean % per plot	ST. DV.	Rank	Max % per quadrat	Min. % per quadrat	Mean % per plot	ST. DV.	Rank
HW*	0	0	0	0	8	0	0	0	0	8	0	0	0	0	8
NU	23	0	4.09	4.64	4	78	0	14.16	15.38	6	16	0	0.93	3.20	6
CPA	17	0	1.71	3.71	6	68	0	15.41	23.42	5	1.2	0	0.04	0.21	7
NFA	64	0	13.79	17.77	3	90	9	54.42	20.59	3	79	2.3	38.02	20.47	1
NFB	90	0	15.05	24.91	2	91	4.3	56.54	20.54	1	55	0	33.05	17.38	2
CPB	16	0	1.92	3.67	5	63	0	15.77	16.54	4	48	0	7.14	13.64	4
LM	21	0	1.26	3.45	7	124	0	54.87	26.21	2	29	0	3.70	6.24	5
TB	98	14	70.34	23.41	1	52	1.6	13.02	13.33	7	51	0.2	18.20	12.13	3

*Hawkeswell is given a score of 100% bare. This is partly a consequence of being re-worked at the time of survey but the site was also found to be bare in preliminary surveys conducted prior to re-working.

It can be seen from Table 7.14 that True Blue has the highest mean shrub cover of the plots, and a low standard deviation relative to the mean. All other plots have a mean shrub cover of less than 16% and high standard deviations relative to the mean indicating that shrub cover is not evenly distributed across the plots. For example, shrub cover on New Fancy B ranges from 0-90%.

New Fancy A, New Fancy B and Lightmoor have a high mean herb cover of more than 54% relative to the rest of the plots which have a lower percentage herb cover below 16%. The standard deviations on these 3 plots are also lower relative to the mean, indicating that herb cover-abundance is more evenly distributed than on other plots.

The mean ground layer cover ranged from 33-38% on the New Fancy sites to 18% on True Blue and just 0.04% on Cannop A. Plots such as Cannop A and Northern United that had a low mean ground layer cover also had high standard deviations compared to the mean, indicating an uneven distribution.

The percentage bare ground cover was recorded per quadrat at the same time as floristic data. This data has been placed in Appendix 3.8, and summarised

Table 7.15: summary of the % bare ground information, recorded per quadrat

Plot	Max.% cover /quadrat	Min. % cover / quadrat	Mean % cover/ plot	Standard deviation	Rank (least bare = 8; most bare = 1)
HW*	100	100	100	0	1
NU	100	28	86.3	15.90	3
CPA	100	34	88.83	18.84	2
NFA	63	0	9.8	18.21	7
NFB	57	0	9.64	11.94	8
CPB	100	21	82.26	20.61	4
LM	93	0	52.05	23.61	5
TB	72	0	14.18	18.35	6
Whole sample			65.86	37.85	

*As explained in Tables 7.13 and 7.14, Hawkeswell is given a score of 100% due to re-working and conditions prior to re-working.

in Table 7.15. A frequency distribution graph was also constructed for this parameter, as explained in Section 6.1.1.2.

Table 7.15 shows that apart from Hawkeswell, more than 80% bare ground cover was recorded on Cannop A, Cannop B and Northern United, confirming the poor overall level of vegetation development on these plots compared to the New Fancy plots, where less than 10% bare ground was recorded.

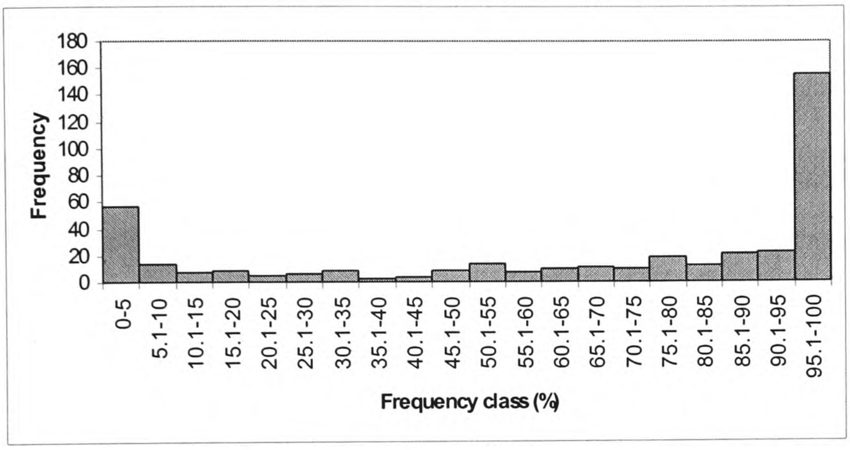


Figure 7.2: Frequency distribution of % bare ground results

Figure 7.2 reflects these results, as the data is bi-modally skewed towards the 0-5% and 95-100% bare ground classes, rather than normally distributed around the sample mean of 66%. Of the 404 observations taken, only 48 (11%) lie within the sample mean and the standard deviation, also indicating that the data is not normally distributed (Fowler *et al.*, 1998), and therefore confirming that parametric methods of analysis should not be used (Section 6.1.1.2).

7.3.3. Biomass index

The tables available in Appendix 3.9 (a-c) were used to calculate biomass indices for each layer of vegetation per quadrat according to the methodology described in Section 5.4.2 (Appendix 3.9d). A frequency-distribution table was compiled (Appendix 3.9e) to find the mode result (Section 6.1.1.1). The results are summarised in Table 7.16. Where plots share the same mode category (Such as NU, CPA and CPB), the percentage of samples falling within the category are used to assign rank. This was done to avoid tied observations (Section 6.1.1.3). For example, the CPB plot is assigned a lower biomass rank than NU because 94% of the samples fall within the 0-499 category – higher than the 62% of samples from NU that fall within the category.

Table 7.16: summary of the biomass index calculated for each plot

Plot	Max.biomass score /quadrat	Min. biomass score / quadrat	Mode biomass category	% of samples within mode category	Assigned rank (1 = highest)
HW*	0	0	0-499	100	8
NU	4984	0	0-499	62	6
CPA	4908	0	0-499	88	5
NFA	5686	514	500-999	19	3
NFB	10,580	722	1000-1499	33	2
CPB	5600	0	0-499	94	7
LM	4735	26	500-999	25	4
TB	3840	231	2000-2499	25	1

*Hawkeswell is given a score of 0 due to the lack of vegetation caused by re-working, but also because there was no vegetation recorded on the site during preliminary surveys prior to re-working. It is therefore assigned the lowest rank.

True Blue has the highest biomass mode category (2000-2499), followed by New Fancy B (1000-1499). However, there is a high range between the highest and lowest scores for all plots (except Hawkeswell), for example between 26-4735 on Lightmoor, reflecting the findings from Sections 7.3.1 and 7.3.2 that the distribution of vegetation cover and its height vary considerably across each plot.

7.3.4 Species diversity

This section describes species diversity results calculated using information collected alongside floristic data, as described in Section 5.5. The choice of diversity index calculations is explained in Section 6.2.2 and species-abundance diagrams in Section 6.2.3. Correlation analysis was undertaken on diversity indices and area data (number of quadrats sampled) to analyse the effect of the species-area relationship (Section 2.3.4.2), rather than using the rarefaction technique as described in Section 6.2.5. Hawkeswell is not included in the index calculations (Section 7.3.4.1) or rank-abundance diagrams (Section 7.3.4.2) due to the lack of data. The plot has however, been included in Spearman rank calculations in Sections 7.3.4.3 and 7.3.5 so that diversity data-sets can be compared to vegetation data-sets and those from Sections 7.1 and 7.2.

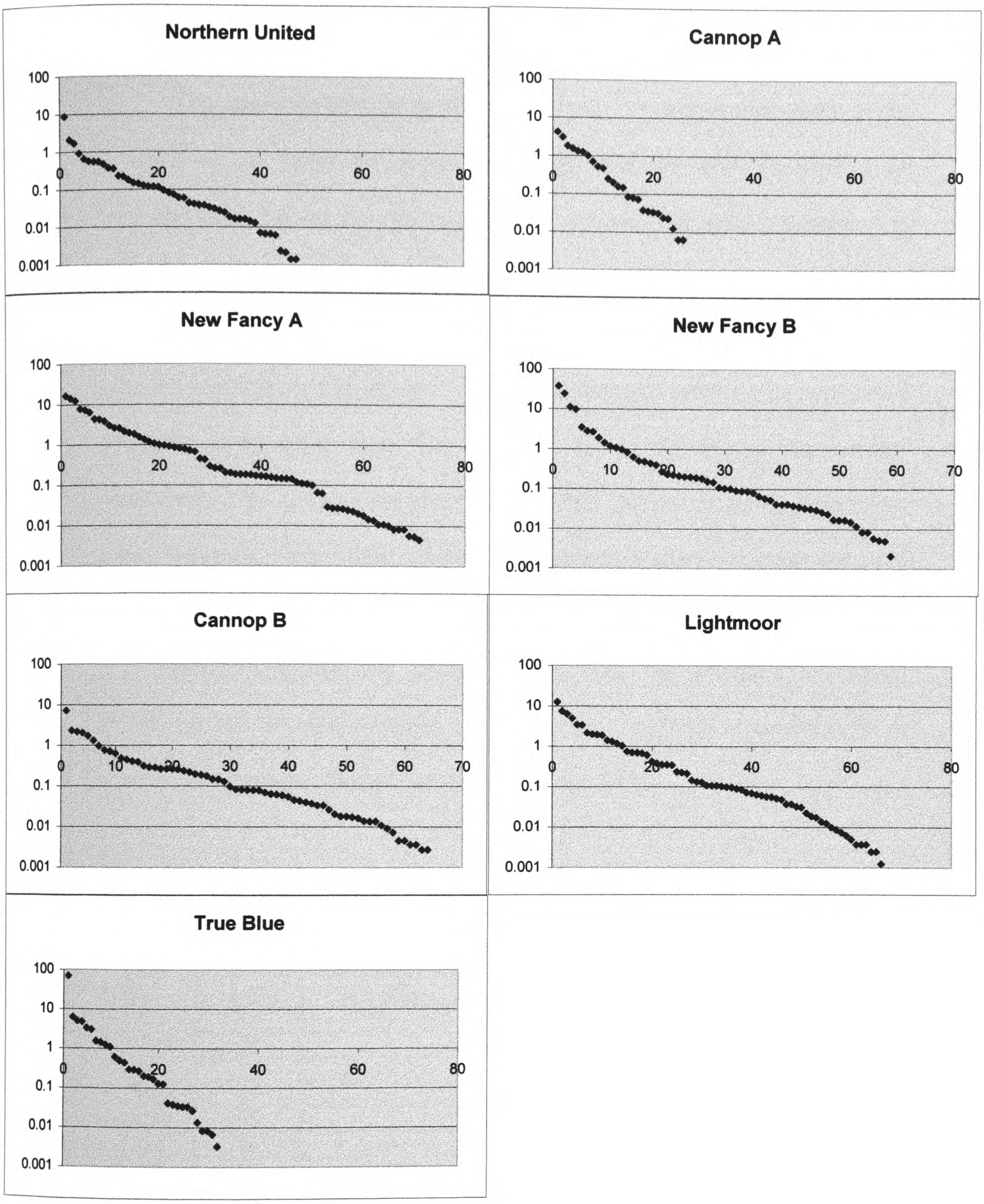
7.3.4.1 Diversity indices

The calculations undertaken on species richness (S) and Shannon H' and Shannon 'E' are available in Appendix 3.10 and the Simpson 1/D calculations in Appendix 3.11. These are summarised in Table 7.17. Lightmoor has the highest species richness and Cannop A the lowest. However, as Lightmoor is the second largest site surveyed, with 60 samples taken, the result is likely to be influenced by the area sampled (Section 7.3.4.3). New Fancy A is most diverse according to the Shannon H' index and Simpson 1/D, but Cannop A has the highest species-evenness distribution according to Shannon 'E'. True Blue is least diverse and the least species-even according to Simpson 1/D, Shannon H' and Shannon 'E'.

Table 7.17: showing summarised species diversity measurement data, ranked for correlation analysis, alongside environmental information on each plot.

Site	Sample size	Rank	(S)	Rank	Shannon H'	Rank	Shannon E	Rank	Simpson 1/D	Rank	(S)/ quadrat	Rank	(S)/ subunit	Rank
Northern United	84	1	54	3	2.2272	3	-0.5583	3	05.16	3	6.62	2	1.65	2
Cannop A	32	5	26	1	2.3522	4	-0.7219	7	13.06	6	4.03	1	0.94	1
New Fancy A	48	3.5	72	6	3.0313	7	-0.7088	6	14.95	7	19.50	6	5.81	7
New Fancy B	24	6.5	59	4	2.1221	2	-0.5204	2	05.09	2	17.28	5	4.16	5
Cannop B	48	3.5	65	5	2.8916	6	-0.6927	5	13.04	5	12.31	4	2.55	3
Lightmoor	60	2	76	7	2.7521	5	-0.6355	4	10.49	4	19.75	7	5.25	6
True Blue	24	6.5	32	2	1.1100	1	-0.3203	1	02.06	1	9.88	1	2.59	4

Figure 7.3: Rank-abundance diagrams to show species richness of seven sites in the Forest of Dean



7.3.4.2 Rank-abundance diagrams

The rank-abundance plots shown in Figure 7.3 give similar results to the diversity indices. Here, the species are arranged from the most abundant to the least abundant. Information on both species richness and species-abundance is used in these graphs, and so diversity and evenness patterns can be seen visually.

It can be seen from the diagrams that New Fancy A is the most diverse plot. It has a high species-richness, and each of the species has a high abundance, compared to the other plots. Some 30% of the species have a mean cover-abundance of 1% or more per plot (Table 7.18). Lightmoor, Cannop B and New Fancy B also have long "tails" which reflects their high species richness, but more than 50% of the species have a mean cover-abundance per plot of less than 1%.

Northern United has neither a long tail, nor evenness of species abundance. It is not as species rich as the other sites, and 94% of species occur at a cover-abundance per plot of less than 1% (Table 7.18).

Table 7.18: the amount of species which occur at total abundances of more than (>) 1% and less than (<) 1% on Forest of Dean plots.

Site	Total no. species	No. species > 1% abundance	% of total species	No. species <1% abundance	% of total species
NU	54	3	6	21	94
CPA	26	7	27	19	73
NFA	72	20	28	52	72
NFB	59	11	19	48	81
CPB	65	6	9	59	91
LM	76	14	18	62	91
TB	32	10	31	22	68

Cannop A is more difficult to interpret. It has the least species, reflecting the small size of the plot (Section 7.3.4.3), and the rank-abundance plot does not 'tail off' gradually, which would show that the species are evenly distributed. However, it is likely to have scored highly in the diversity indices (Section 7.3.4.1) because 30% of the species present occur at more than 1%, indicating that fewer species occur only rarely.

True Blue is also species poor in terms of numbers of species (section 7.3.4.3), and although this plot also has some 30% of species occurring at more than 1%, the species are not evenly distributed as one species, *Calluna vulgaris*, has a high overall abundance of 70%. The rest of the species occur at less than 10%, and 68% of the species occur at abundances of less than 1%.

7.3.4.3 Species-area effect

The potential effect of the different plot sizes described in Section 5.1.4 on the diversity index results (Section 7.3.4.1) was investigated using Spearman's rank (Section 6.1.1.2). Ranks of the indices (Table 7.17) were correlated with ranked sample-size information (also shown in Table 7.17). Sample-size information was used because it is directly proportional to the area of the plots (Figure 5.2). The results of the correlation analysis are shown in Table 7.19, and graphs have been produced as shown in Figure 7.4.

Table 7.19: showing the results of Pearson-product moment correlation analysis on ranked data.

Correlations on ranked data	**Sample size**
Species Richness	0.45
Shannon H	0.51
Shannon Evenness	0.29
Simpson 1/D	0.35
Number of species/quadrat	0.15
Number of species/subunit	-0.02

Figure 7.4: Scattergrams to show the correlation between sample size and 4 species diversity indices, where P<0.10 = 0.60

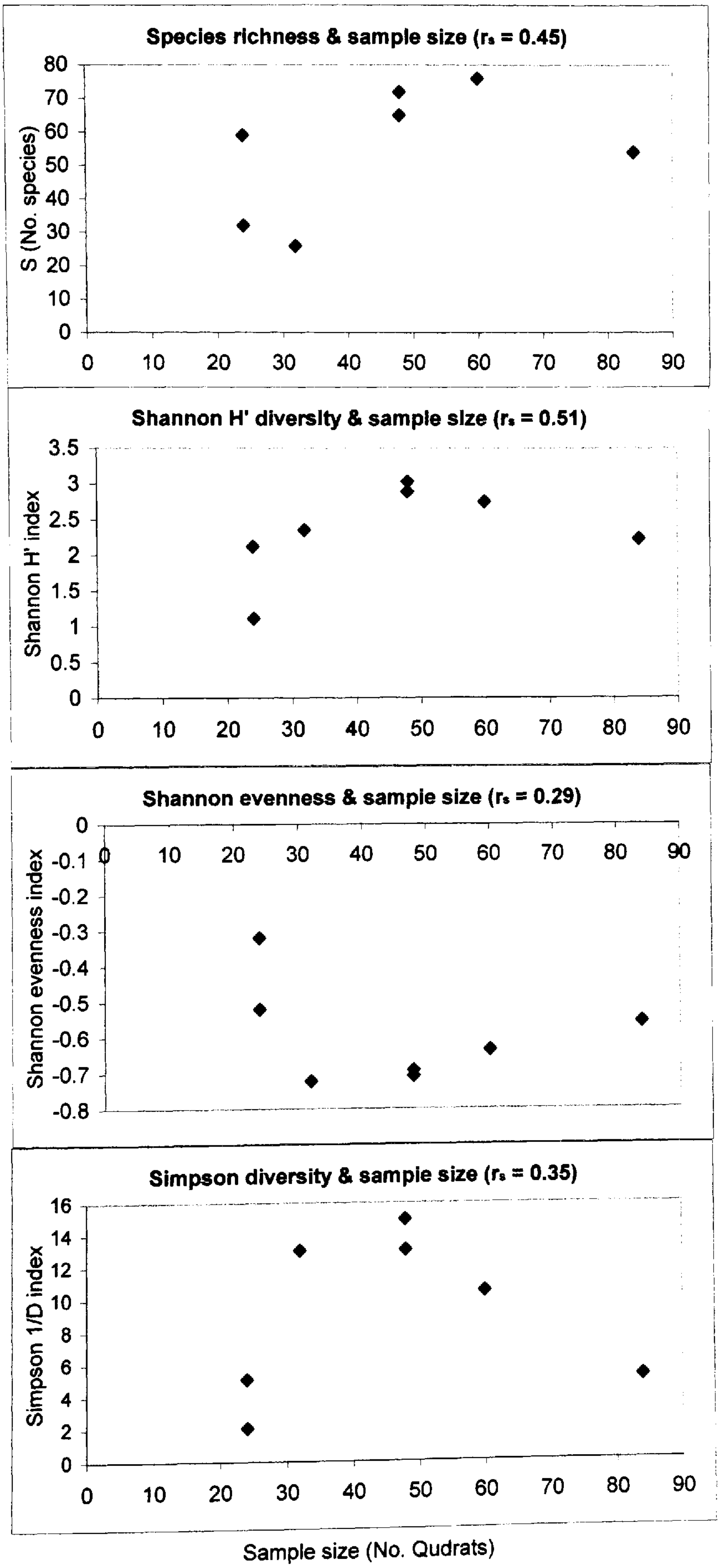


Figure 7.4 shows that site size and diversity tend to be positively correlated, but none of these relationships are significant at the 95% level or above (Section 6.1.1.3). The correlation between increasing sample size and Shannon H diversity is the highest correlation result, where $r_s = 0.51$.

However, because the results show that sample size may have a moderate positive effect on species diversity, two further indices were used in the correlation analyses undertaken between all factors (Section 7.6). These indices are the mean number of species per quadrat (1m x 1.5m), and the mean number of species per subunit of the quadrat (20 x 30cm), information on which was collected during sampling (Section 5.5). Both of these units areas are constant across all plots, and should therefore be less affected by sample size. Table 7.20 summarises the species-richness data of these units, taken from Appendix 3.12.

Table 7.20 shows that Lightmoor and New Fancy A have the highest (S) scores, with a mean of over 19 species per quadrat, and a mean of over 5 species per subunit. Cannop A has the lowest (S) scores, with a mean number of species per quadrat of 4.03, and a mean of less than 1 species per subunit.

Table 7.20: summary of species richness (S) per quadrat (Q) and per subunit (SU), on all plots

Plot	Max. (S)/ Q	Min. (S)/ Q	Mean (S)/ Q	St. Dv.	Max. (S)/ SU	Min. (S)/ SU	Mean (S)/ SU	St. Dv.
NU	28	1	6.62	5.30	7.2	0.2	1.65	1.60
CPA	15	0	4.03	4.69	4.8	0	0.94	1.53
NFA	28	8	19.50	5.01	9.2	2.3	5.81	1.52
NFB	29	3.6	17.28	6.24	6.9	1.7	4.16	1.50
CPB	32	0	12.31	8.09	9.1	0	2.55	2.35
LM	33	11	19.75	5.70	9	3.1	5.25	1.43
TB	15	4	9.88	2.69	3.7	1.6	2.59	0.59
Whole sample			13	8			3.27	2.39

These patterns also reflect results found in Sections 7.3.4.1, but correlations between sample size and diversity were found to be much lower at 0.15 and -0.02 respectively (Table 7.17), meaning that the indices of (S)/Q and (S)/SU are likely to be less affected by sample size than (S), Shannon E, Shannon H' or Simpson 1/D.

Figure 7.5 shows the calculations undertaken for Section 6.1 to investigate the properties of the data. It shows that the number of species per quadrat data-set is skewed towards the lower frequency classes, with slight peaks at the 0-4 and 15-19 (S)/quadrat classes.

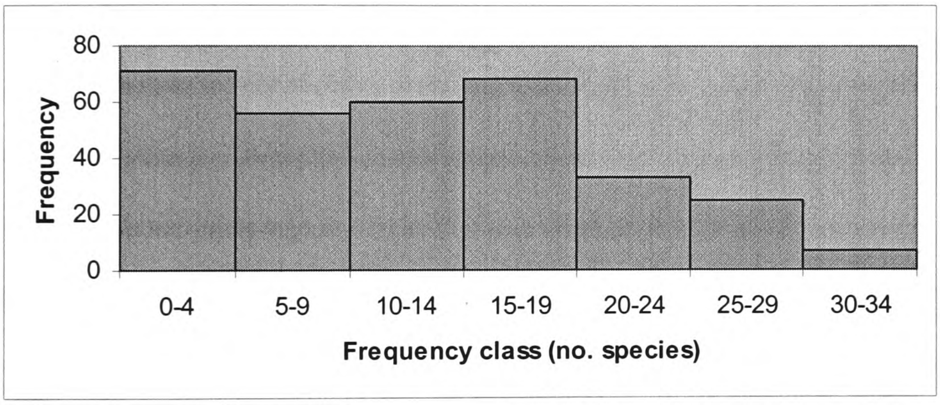


Figure 7.5: frequency distribution of (S)/quadrat

The data is not normally distributed around the sample mean (12 species/quadrat), and confirms that parametric methods of analysis should not be used on the diversity data (Section 6.1.1.2).

Table 7.21: summary of the ranks given to each of the vegetation parameters

	Vegetation height			Vegetation cover				Biomass	Number of species	
	Shrub	Herb	Moss	Shrub	Herb	Moss	Bare ground	All	Spp/quadrat	Spp/subunit
1 8	Highest Lowest	Highest Lowest	Highest Lowest	Highest Lowest	Highest Lowest	Highest Lowest	Highest Lowest	Highest Lowest	Lowest Highest	Lowest Highest
HW	8	8	8	8	8	8	1	8	1	1
NU	1	3	6	4	6	6	3	6	3	3
CPA	6	5	7	6	5	7	2	5	2	2
NFA	7	1	1	3	3	1	7	3	7	8
NFB	4	2	3	2	1	2	8	2	6	6
CPB	5	7	5	5	4	4	4	7	4	4
LM	7	6	4	7	2	5	5	4	8	7
TB	3	4	2	1	7	3	6	1	5	5

Table 7.22: Half matrix to show the results of Pearson-Product Moment correlation analysis on ranked non-floristic vegetation data

Height	**Herb**	0.41								
	Moss	0.14	**0.69**							
	Shrub	0.63	**0.76**	**0.76**						
Cover	**Herb**	-0.11	0.43	0.50	0.19					
	Moss	0.16	**0.71**	**0.95**	**0.79**	0.60				
	Bare ground	-0.19	**-0.71**	**-0.93**	**-0.76**	**-0.69**	**-0.95**			
Biomass index		*0.26*	*0.69*	*0.83*	*0.79*	*0.41*	*0.74*	*-0.83*		
Spp/quadrat		0.06	-0.48	**-0.83**	-0.38	**-0.76**	**-0.76**	**0.83**	*-0.67*	
Spp/subunit		0.06	-0.60	**-0.90**	-0.48	**-0.74**	**-0.86**	**0.88**	*-0.69*	**0.98**
		Shrub	**Herb**	**Moss**	**Shrub**	**Herb**	**Moss**	**Bare ground**	**Biomass**	**Spp/quadrat**
			Vegetation height			**Vegetation cover**				

Key:

0.643	**indicates result significant at the P<0.05 level**
0.738	**indicates result significant at the P<0.025 level or above**
n	**indicates ordinal data difficult to assign significance to**

7.3.5 Correlations between height, cover, biomass index and diversity

Table 7.21 is a summary of the ranks assigned to vegetation height, cover, biomass index, and diversity data (S)/quadrat and (S)/subunit. Table 7.22 was produced from this summary to show the correlation coefficients produced between the vegetation factors. Correlations significant at the 95% level or above ($P<0.05$) are highlighted.

Increasing biomass index results show 'strong' positive correlations with herb height, moss height and cover, shrub cover, and a 'very strong' negative correlation with % bare ground. The significance of these results could not be tested here (Section 6.1.1), but improvements for further research are suggested in Section 10.4.2.

Both species diversity indices show 'strong' negative correlations with biomass, and significant correlations ($P<0.05\%$) with moss height, herb and moss cover, and a positive relationship with bare ground ($P<0.05\%$, $r^s =$ 0.83 and 0.88). Taking ranking directions assigned to each data-set into account, this means that diversity increases as bare ground decreases, and diversity increases alongside moss height and moss and herb cover.

7.4 **Species strategies**

Information on vascular species strategies was compiled according the outlined methodology (Table 5.10, Sections 5.6 and 6.1.2). The full data-matrix produced is available in Appendix 3.13. This has been summarised in Appendix 3.14. Appendix 3.14 has been used to construct the tables and diagrams in Sections 7.4.1-7.4.7. Table 7.23 summarises the statistical calculations undertaken on each data-set.

Table 7.23: statistical analyses undertaken on the non-floristic Forest of Dean data-sets

Data-sets		Type of data		Statistical analyses					
	Parameter	Scale	Density	Mn	Md	SD	CA	D	S
Species strategies	Life form	N/R	P	✓		✓			
	Competitive strategy	N/R	P	✓		✓			
	Raunkaier life-form	N/R	P	✓		✓			
	Reproductive strategies	N/R	P	✓		✓			
	Special attributes	N/R	P	✓		✓			
	Capacity for lateral spread	N/R	P	✓		✓			
	Optimum pH range	N/R	P	✓		✓			

Key:

P = Plot; T = Transect; SP = subplot; Q = Quadrat
N = nominal; O = Ordinal; I = Interval; R = Ratio
Mn = mean; Md = Mode; SD = Standard deviation; CA = correlation analysis; D = distribution; S = significance

Strategy data has been plotted against age in these diagrams to examine whether trends appear to change over time, as predicted in Table 2.2. Trends have also been examined in relation to pH to examine the expectation in Table 2.2 that species adapted to stressful environments will be replaced by more competitive species as the environment becomes less stressful. PH was chosen as an indicator of environmental stress instead of soil depth, pyrites, plant vigour, aspect, or bare ground. pH is quantitative, and of the parameters considered, it has the least strong correlation with age (Section 7.5) meaning that the potential effects of time and stress on species strategies may be isolated.

The results have been displayed using scattergrams where possible. Proportional bar-chart diagrams are used when there are a large number of categories (e.g. Figure 7.7). The results are discussed further in Section 9.5.

7.4.1 Life form

Life form data are summarised in Table 7.24, and graphs have been produced (Figure 7.6) to assess whether the life-form of the different species changes with increasing plot age or plot pH. It can be seen that the percentage of perennials is more than 80% on every plot, despite changes in age or pH. The low standard deviations of the categories compared to the mean indicate that this trend is consistent across all of the

Table 7.24: The types of life strategy that the vascular species occurring in Forest of Dean possess, listed by % of species occurring on each plot. Information taken from Grime *et al.* (1988), and Stace (1997)

Variable			% vascular species		
	Age	**pH**	**Annual**	**Biennial**	**Perennial**
NU	6	4.60	8.50	4.25	89.36
CPA	16	6.38	4.00	0	96.00
NFA	36	5.73	8.89	5.17	86.21
NFB	36	5.93	10.35	4.44	86.67
CPB	41	4.79	7.90	2.63	92.11
LM	60	5.00	12.90	3.22	83.87
TB	100	3.02	11.11	5.55	88.89
Mean			9.09	3.61	89.01
STDEV			2.83	1.89	4.05
% plots within 1 STDEV of mean			71.43	71.43	71.43

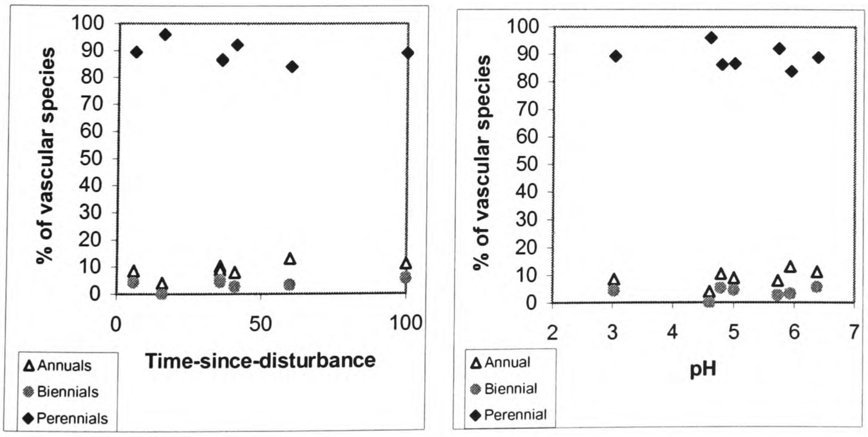


Figure 7.6: scattergrams to show the relationships between the % of vascular species that are annuals, biennials or perennials per plot and a) time and b) pH

plots. Lightmoor has the lowest proportion of perennials (83%), and the highest proportion of annuals (12.9%). Cannop A has the highest proportion of perennials (96%) and the lowest proportion of annuals (4%). The % of biennial species remains under 5.5% for all plots.

7.4.2 Competitive strategy

Data on competitive strategies are summarised in Table 7.25, and the graphs produced are shown in Figure 7.7. It can be seen that species with an intermediate or "generalist" CSR strategy are the most numerous on all sites, between 29-39%. There appears to be a decline of species possessing competitive-ruderal or ruderal-competitive (RC/CR) species over time, from 10.6% at 6 years to 5.5% at 100 years. Species possessing these strategies appear to increase on plots with more neutral pH.

Table 7.25: The types of Grime's competitive strategies that the vascular species occurring in Forest of Dean possess, listed by % of species occurring on each plot. Information taken from Grime *et al.* (1988)

	Variables		Grime's strategy						
	Age	pH	CSR	C	CS/SC	S	SR/RS	R	RC/CR
NU	6	4.60	34.04	12.77	14.89	8.51	4.26	8.51	10.64
CPA	16	6.38	32.00	16.00	24.00	8.00	0.00	8.00	12.00
NFA	36	5.73	31.03	5.17	18.97	15.52	3.45	12.07	10.34
NFB	36	5.93	33.33	2.22	24.44	6.67	8.89	13.33	8.89
CPB	41	4.79	28.95	7.89	18.42	23.68	2.63	10.53	7.89
LM	60	5.00	30.65	8.06	14.52	17.74	6.45	14.52	6.45
TB	100	3.02	38.89	0.00	22.22	22.22	5.56	5.56	5.56
Mean			32.70	7.45	19.64	14.62	4.46	10.36	8.82
STDEV			3.22	5.63	4.07	7.01	2.86	3.19	2.34
% within 1 STDEV of mean			71.00	71.00	46.00	57.00	71.00	71.00	57.00

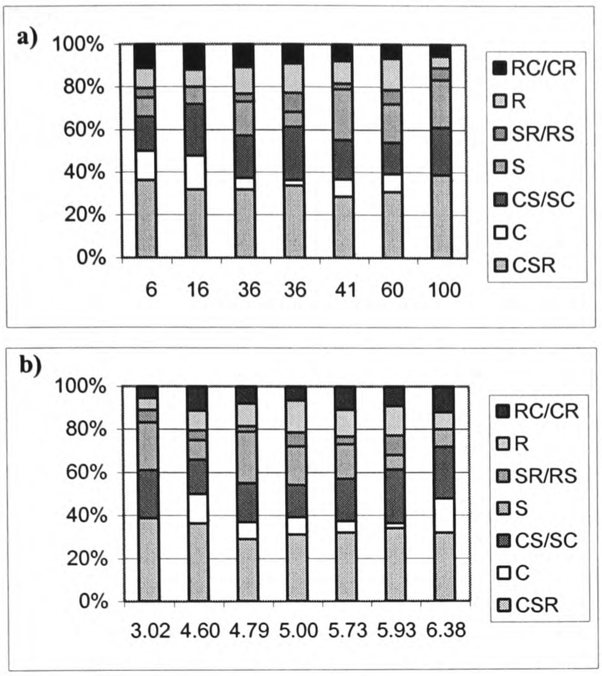


Figure 7.7: The % of vascular species on each plot that possess various Grime's competitive strategies, with plots arranged by increasing time (a) and pH (b)

There is a decline of competitive (C) species over time, from 13% at 6 years to 0% on TB, but an increase in the number of stress-tolerant (S) species over time, from 8.5% at 6 years to 22% at 100 years. The percentage of species that have stress tolerant (S) strategies appears to increase with increasing pH, with 22% occurring on the plot with the most acidic pH of 3.02, and 8% occurring on the site with the most neutral pH (6.38). The percentage of species with generalist species decreases with as pH becomes more neutral, from 39% at pH 3.02 to 32% at pH 6.38.

7.4.3 Raunkaier life-form

Table 7.26 shows the summarised data on the life-form of the species using the Raunkaier life-form categories, and the graphs produced are shown in Figure 7.8. It can be seen from Figure 7.8 that the semi-rosette hemicryptophyte (Hs) life-form is

Table 7.26: The percentage of vascular species occurring on each site that belong to one of the 8 Raunkaier life-form categories. Information taken from Stace (1997), and Grime *et al.* (1988).

	Variables		Raunkaier life-form categories							
Plot	**Age**	**Ph**	**P**	**Ch**	**H**	**Hp**	**Hs**	**Hr**	**G**	**Th**
NU	6	4.60	23.91	4.35	08.70	19.57	21.74	06.52	06.52	08.70
CPA	16	6.38	12.00	04.00	04.00	20.00	32.00	04.00	16.00	08.00
NFA	36	5.73	19.64	03.57	07.14	14.29	28.57	12.50	03.57	10.71
NFB	36	5.93	20.45	02.27	06.82	15.91	34.09	09.09	02.27	09.09
CPB	41	4.79	10.53	02.63	05.26	23.68	34.21	07.89	05.26	10.53
LM	60	5.00	11.48	04.92	08.20	21.31	24.59	13.11	03.28	13.11
TB	100	3.02	11.76	11.76	00.00	17.65	41.18	05.88	00.00	11.76
Mean			15.60	04.79	05.73	18.91	30.91	08.43	05.27	10.72
ST DEV			05.74	03.21	03.00	03.22	06.55	03.39	05.17	01.81

KEY:

P	Phanerophyte	Hs	Semi-rosette hemicryptophyte
Ch	Chamaephyte	Hr	Rosette hemicryptophyte
H	Hemicryptophyte	G	Geophyte
Hp	Protohemicryptophyte	Th	Therophyte

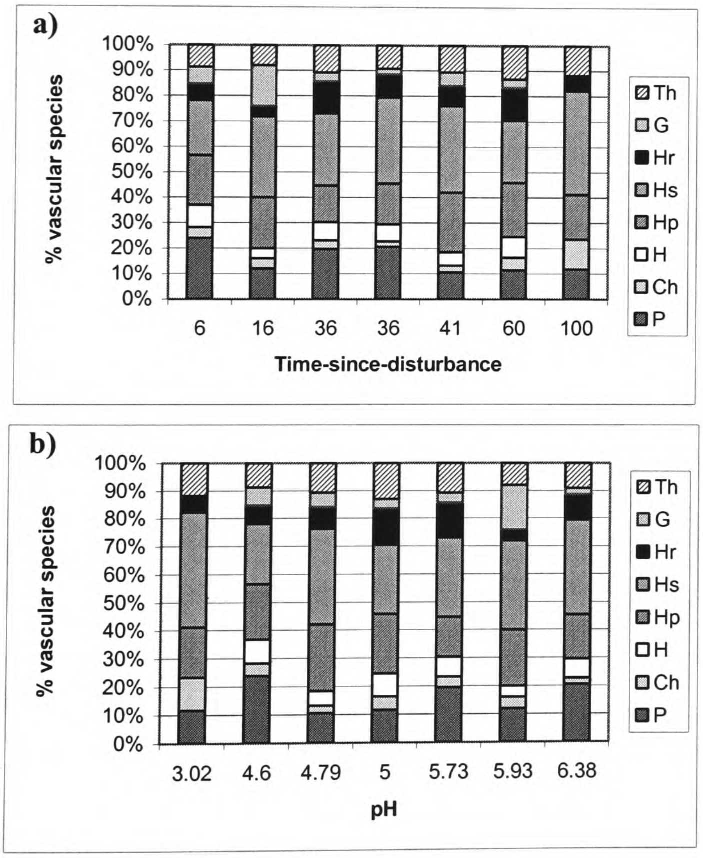


Figure 7.8: Graph to show the proportion (%) of vascular plant species per plot that belong to one of 8 life-form categories of Raunkier (1937), displayed by age of plot (a), and pH (b)

the most frequent category, with 22-41% of species on each plot belonging to this category. Proto-hemicryptophytes (Hp) are also frequent on all plots (14-23% of species), as are Phanerophytes (P) (10.5-24%). Chamaephyte species are one of the least frequent categories (2-5%), except on True Blue (rising to 12%). Geophytes are also infrequent (2-6%) except on Cannop A where 16% of species are geophytic, which gives this plot a high standard deviation of 5.17. None of the categories appear to progressively increase or decrease with the age or pH of the site.

7.4.4 Reproductive strategies

Table 7.27 shows the summarised data on the various reproductive strategies of the species, using classifications provided in Grime *et al.* (1988), and the graphs produced are shown in Figure 7.9.

It can be seen from Table 7.26 and Figure 7.6 that vegetative (V) reproduction is the most frequent strategy on all sites (between 51-68% of species on all plots). The ability to create a persistent seed bank (Bs) is also a frequent and consistent

Table 7.27: The % of vascular species growing on each plot in the Forest of Dean that fall within one of five reproductive strategies listed within Grime *et. al.* (1988).

	Variables		Reproductive strategy				
	Age	**pH**	**V**	**S**	**W**	**Bs**	**Bj**
NU	6	4.60	36.92	12.31	20.00	30.77	0
CPA	16	6.38	38.46	15.38	17.95	28.21	0
NFA	36	5.73	37.21	18.60	15.18	29.07	0
NFB	36	5.93	38.57	18.57	12.86	30.00	0
CPB	41	4.79	39.39	16.67	13.64	30.30	0
LM	60	5.00	34.78	19.57	13.04	32.61	0
TB	100	3.02	38.71	25.81	6.45	29.03	0
Mean			37.72	18.13	14.15	30.00	0
St. Dv.			1.56	4.18	4.32	1.44	0

NB: Where Grime *et al.* (1988) list a species as having more than one main reproductive strategy, all strategies have been included

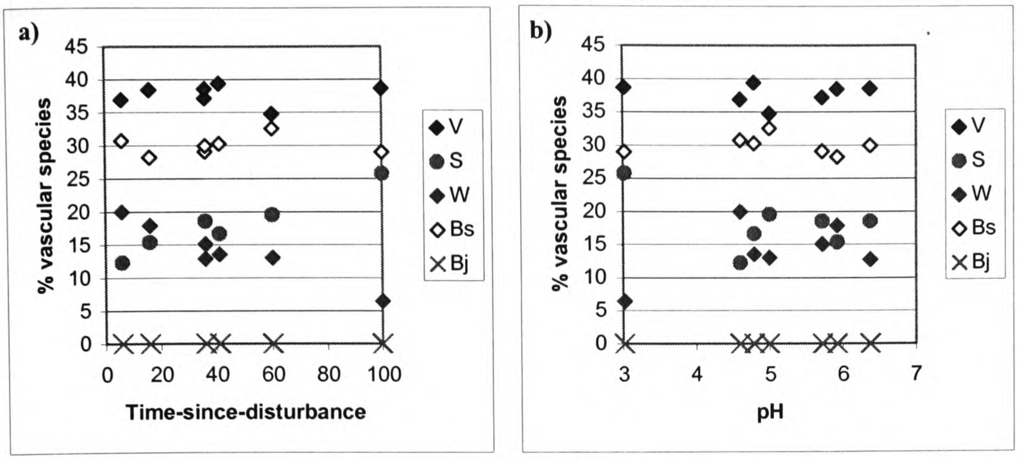


Figure 7.9: % of vascular species growing on each plot that belong to one of the 5 reproductive strategies recognised by Grime et al. (1988), with plots displayed by age (a) and by pH (b).

reproductive strategy (43-53% of species on all plots). These strategies do not appear to change with increasing time or pH.

The number of species with the capacity to produce large quantities of seed (W) appears to decline over time, from 20% of species possessing this strategy at year 6 to 13% at year 60, and 6% at year 100. The number of species with the capacity to reproduce using seasonal regeneration (S) appears to increase over time, with 12% at 6 years, to 26% at 100 years. Species strategies did not appear to consistently change with changing pH. No species possessed the strategy of reproduction through persistent juveniles (Bj).

7.4.5 Special attributes

Table 7.28 shows summarised data on special attributes of the species found on colliery spoil that may confer a competitive advantage, and the graphs produced are shown in Figure 7.10. The % of species that possess a clonal growth strategy is

Table 7.28: the % of species within each plot that possess one of three attributes that may confer an advantage for colonising colliery spoil heaps

	Variable		Attribute		
	Age	PH	Tap-root	Clonal	Legume
NU	6	4.60	21.28	38.30	10.64
CPA	16	6.38	24.00	44.00	0
NFA	36	5.73	20.69	34.48	12.07
NFB	36	5.93	17.78	33.33	06.67
CPB	41	4.79	26.32	39.47	0
LM	60	5.00	22.58	29.03	11.09
TB	100	3.02	22.22	44.44	0
Mean			22.12	37.58	5.81
STDEV			2.68	5.67	5.96

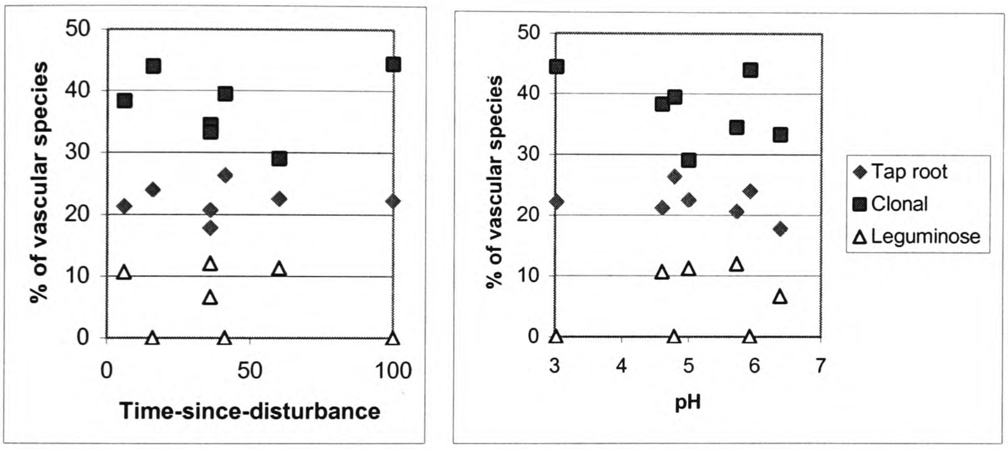


Figure 7.10: scattergrams to show the % of species within each plot that possess one of three special attributes – tap root, clonal or legume

consistently higher than other strategies studied here across all plots, ranging from 29-44% of all species. The % of species that possess a tap-root is much less, ranging from 18% to 26%, and the % of legume species is less again, ranging from 0 –12%. The standard deviations of both the tap-root and clonal categories are low relative to the mean, showing that the frequency of these results are relatively constant across all plots. However, the standard deviation for the legume category is higher than the mean showing reflecting the variation within the category. The strategies do not appear to change with changing pH or age.

7.4.6 Capacity for lateral spread

Table 7.29 and Figure 7.11 show that the frequency of species with a low capacity for lateral spread (Category 1) is lower than for the other categories, but

Table 7.29 to show the % of species from each plot assigned to one of 5 categories of lateral spread by Grime *et al.* (1988)

	Variable		Category to denote capacity for lateral spread				
	Age	pH	1	2	3	4	5
NU	6	4.60	14.89	23.40	08.51	23.40	40.43
CPA	16	6.38	08.00	28.00	16.00	28.00	40.00
NFA	36	5.73	13.79	24.14	18.97	17.24	32.76
NFB	36	5.93	15.56	24.44	22.22	20.00	28.89
CPB	41	4.79	13.16	26.32	21.05	26.32	26.32
LM	60	5.00	16.13	27.42	17.74	20.97	24.19
TB	100	3.02	22.22	16.67	22.22	44.44	22.22
Mean			14.82	24.34	18.10	25.77	30.96
STDEV			4.23	3.8	4.83	9.02	7.33

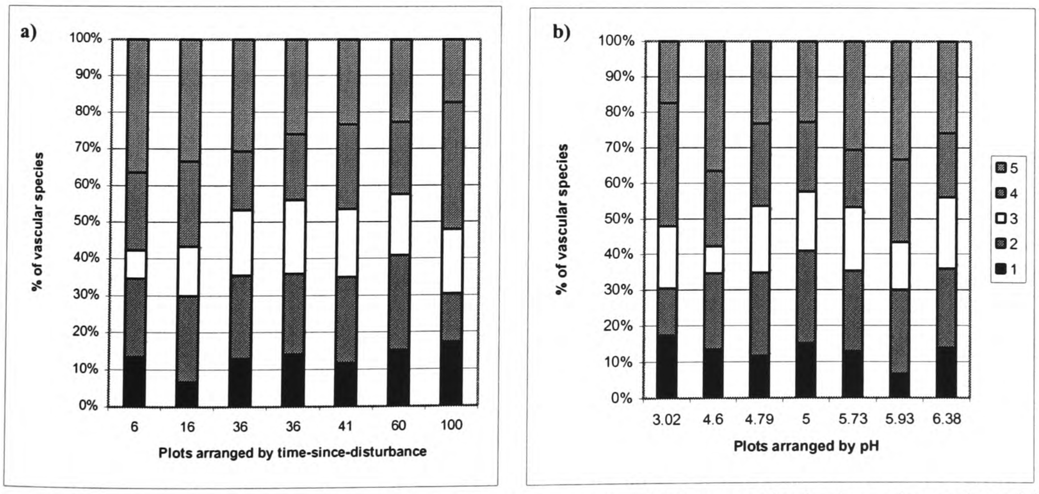


Figure 7.11: a) graph to show the relationship between the % (proportion) of species assigned to categories 1-5 of capacity for lateral spread (where 1 = low and 5 = high) from 1-5 and a) time-since-disturbance and b) pH. Information from Grime *et al* (1988).

increases consistently over time from 15% at year to 22% at year 100. The frequencies of species in Categories 2 and 3 remain relatively constant throughout all plots at a mean of 24% and 18% respectively, with low standard deviations relative to the mean. Category 4 species increase from 23 % at year 6 to 44% at year 100. The % of species with a high capacity for lateral spread (Category 5) shows a marked decrease over time, from 40% at year 6, to 22% at year 100. The categories do not appear to increase or decrease with changes in the pH of the plots.

7.4.7 Optimum pH range

Table 7.30 and Figure 7.12 show that species with an optimum pH range of 7 (neutral) are the most frequent on all plots, and do not appear to increase or decrease with the measured acidity of the plot. There are only 4 species occurring on the plots that Grime *et al.* (1988) found to grow optimally at a pH of 3 - *Pteridium aquilinum, Betula pubescens, Ilex aquifolium* and *Galium saxatile.* These species make up a higher percentage of the flora on True Blue (which does have the lowest pH), but also on Cannop A, which has a higher pH. There are only 2 species that grow optimally on

Table 7.30: % of species from each plot that have been assigned to each of 6 pH categories to denote their "optimum" pH range by Grime *et. al.* (1988)

		Optimum pH range					
Site	pH	W	3	4	5	6	7
NU	4.60	0.00	6.38	12.77	31.91	14.89	38.30
CPA	6.38	4.00	20.00	20.00	28.00	20.00	28.00
NFA	5.73	1.72	6.90	13.79	25.86	17.24	39.66
NFB	5.93	4.44	11.11	11.11	26.67	13.33	42.22
CPB	4.79	5.26	13.16	18.42	31.58	10.53	34.21
LM	5.00	3.23	6.45	11.29	30.65	12.90	40.32
TB	3.02	5.56	22.22	27.78	16.67	5.56	50.00
Mean		3.46	12.32	16.45	27.33	13.49	38.96
STDEV		2.00	6.56	6.06	5.27	4.66	6.81

NB: W = widespread distribution

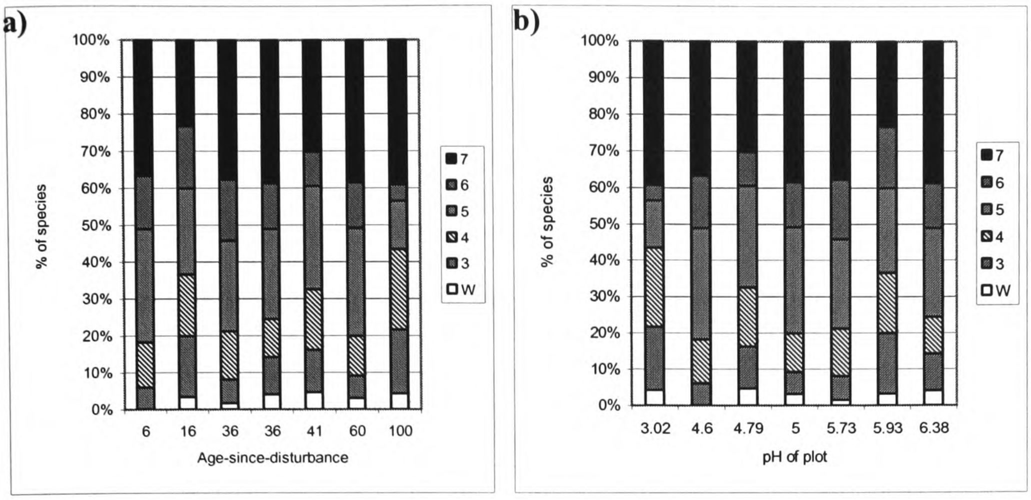


Figure 7.12: graph to show the relationship between the optimum pH range categories assigned by Grime *et al* 1988 and a) age-since-disturbance, or b) the meansured pH of the plots

a wide range of pH values – *Festuca ovina,* and *Teucrium scorodonia.* This category therefore remains at a low frequency throughout all plots. The categories do not appear to change with age.

7.5 Correlations between all data-sets

Table 7.31 is a half-matrix showing the correlation coefficients between all of the substrate, microclimate and vegetation data-sets alongside age to help see whether trends outlined in Table 2.2 have occurred. Coefficients with different levels of significance are highlighted, and summarised in Tables 7.32-7.35. Table 7.36 contains the data that could not be tested for significance, such as biomass index results. The direction of the ranking systems used in the correlation analyses (Sections 7.1.5, 7.2.5 and 7.3.5) is also shown in Tables 7.32-7.36.

As shown in Table 7.31, and summarised in Table 7.32 there are significant correlations at the highest level (99.5% unlikely to be the result of sampling error)

Table 7.31: Half-table to show the correlations between substrate, microclimate and non-florisic vegetation factors.

Age																
pH	0.096															
Pyrites	0.740	-0.036														
Soil depth	0.802	0.310	0.862													
Plant vigour	-0.679	-0.190	-0.850	-0.921												
Slope	0.359	0.738	0.012	0.333	-0.333											
Aspect	0.323	0.810	0.216	0.690	-0.619	0.690										
Canopy cover	0.049	-0.708	0.221	-0.171	0.268	-0.830	-0.683									
Shrub height	-0.100	0.087	0.112	-0.111	0.285	0.037	-0.037	0.139								
Herb height	-0.084	-0.524	-0.192	-0.571	0.595	-0.167	-0.690	0.439	0.408							
Moss height	-0.695	-0.310	-0.790	-0.952	0.952	-0.286	-0.643	0.244	0.136	0.690						
Shrub cover	-0.443	-0.214	-0.383	-0.762	0.857	-0.238	-0.643	0.366	0.631	0.762	0.762					
Herb cover	-0.359	-0.833	-0.347	-0.429	0.357	-0.690	-0.619	0.610	-0.111	0.429	0.500	0.190				
Moss cover	-0.587	-0.429	-0.647	-0.881	0.929	-0.476	-0.738	0.512	0.161	0.714	0.952	0.786	0.595			
Bare cover	0.611	0.500	0.707	0.881	-0.881	0.429	0.738	-0.439	-0.186	-0.714	-0.929	-0.762	-0.690	-0.952		
Biomass	-0.635	-0.405	-0.659	-0.905	0.810	-0.190	-0.643	0.366	0.260	0.690	0.833	0.786	0.405	0.738	-0.833	
Spp/Quad	0.707	0.429	0.826	0.762	-0.690	0.310	0.452	-0.146	0.062	-0.476	-0.833	-0.381	-0.762	-0.762	0.833	-0.667	
Spp/subunit	0.647	0.452	0.790	0.810	-0.762	0.333	0.548	-0.244	0.062	-0.595	-0.905	-0.476	-0.738	-0.857	0.881	-0.690	0.976
	Age	Substrate factors				Microclimate			Vegetation height			Vegetation cover				Biomass	Spp/quad
		pH	Pyrites	Soil depth	Plant vigour	Slope	Aspect	Canopy cover	Shrub	Herb	Moss	Shrub	Herb	Moss	Bare		

KEY

Text	Significant at the 0.025 level (one tailed)
Text	Significant at the 0.05 level (one tailed)
Text	Ordinal data - significance difficult to predict

between factors such as soil depth, moss height and cover and % bare ground. Moss height and the % of bare ground are both correlated with species evenness (S)/Subunit ($r_s = -0.91$, with the direction of the ranking meaning that where moss height tends to be low and % of bare ground high, species diversity tends to be low.

Table 7.32: A summary of correlations between the vegetation and environmental factors at the $P<0.005$ (99.5%) significance level

1st Factor	Rank (from 1-8)	Correlating factor	Correlating rank		Significance
Soil depth	Shallow-deep	Moss height	Low-high	-0.95	**$P < 0.005$**
	Shallow-deep	% Moss cover	Low-high	-0.881	**$P < 0.005$**
	Shallow-deep	% Bare cover	High-low	0.881	**$P < 0.005$**
Moss height	High-low	% Moss cover	High-low	0.95	**$P < 0.005$**
	High-low	% Bare ground	Low-high	-0.93	**$P < 0.005$**
	High-low	Spp/subunit	Low-high	-0.91	**$P < 0.005$**
% Moss Cover	High-low	% Bare ground	High-low	-0.95	**$P < 0.005$**
% Bare ground	High-low	Spp. subunit	Low-high	0.881	**$P <0.005$**
Spp/quadrat	Low-high	Spp/unit	Low-high	0.98	**$P < 0.005$**

Tables 7.33 and 7.34 show that at the 95-97.5% significance levels, there is a positive correlation between age and soil depth, indicating that soil depth rank tends to increase as age rank increases. This trend is discussed further in Section 9.1.3. At the 95% significance level (Table 7.35) there are also correlations between age and moss height (9.3.1), and age and species richness (Section 9.4.1), indicating that where age rank increases, moss height and species richness ranks tend to increase.

Table 7.33: A summary of correlations between the vegetation and environmental factors at the $P<0.01$ (99%) significance level

1st Factor	Rank (from 1-8)	Correlating factor	Correlating rank		Significance
PH	Acid-neutral	% Herb cover	Low-high	-0.83	**$P < 0.01$**
Moss height	High-low	Spp/quad	High-low	-0.83	**$P < 0.01$**
Soil depth	Shallow-deep	% Moss cover	High-low	-0.952	**$P < 0.01$**
% Moss Cover	High-low	Spp./subunit	High-low	-0.86	**$P < 0.01$**
% Bare ground	High-low	Spp./quadrat	High-low	0.83	**$P < 0.01$**

Table 7.34: A summary of correlations between the vegetation and environmental factors at the $P<0.01$ (97.5%) significance level

1st Factor	Rank (from 1-8)	Correlating factor	Correlating rank		Significance
Age	Young-old	Soil depth	Shallow-deep	0.80	$P < 0.025$
pH	Acid-neutral	Slope	Flat-steep	0.74	$P < 0.025$
	Acid-neutral	Aspect	South-west	0.81	$P < 0.025$
	Acid-neutral	%Canopy cover	Low-high	-0.71	$P < 0.025$
Soil depth	Shallow-deep	% Shrub cover	Low-high	-0.762	$P < 0.025$
	Shallow-deep	Spp richness (both)	Low-high	0.76/ 0.81	$P < 0.025$
Slope	Flat-steep	% Canopy cover	Low-high	-0.83	$P < 0.025$
Aspect	South-west	% Moss cover	Low-high	-0.74	$P < 0.025$
	South-west	% Bare ground	High-low	0.74	$P < 0.025$
Herb height	High-Low	% Shrub cover	High-Low	0.76	$P < 0.025$
Moss height	High-low	% Shrub cover	High-low	0.76	$P < 0.025$
% Shrub cover	High-low	% Moss cover	High-low	0.79	$P < 0.025$
	High-low	Bare ground cover	Low-high	-0.76	$P < 0.025$
% Herb Cover	High-low	Spp richness(both)	High-low	-0.76/ -0.74	$P < 0.025$
% Moss Cover	High-low	Spp/quadrat	High-low	-0.76	$P < 0.025$

There are correlations between pH and some microclimate factors such as slope and aspect at the 97.5% significance level (Table 7.34). These show that plots where pH is more neutral tend to have steeper slopes and face in a more westerly direction than other plots, as discussed in Section 9.2. Tables 7.33 and 7.34 also show that as pH becomes more neutral, the % canopy cover and % herb cover tend to increase (Section 9.3).

As soil depth increases, moss cover increases at the 99.9% level (Table 7.33), and shrub cover and species richness increase at the 97.5% level (Table 7.34). The se correlations are discussed further in Section 9.1.3. Table 7.35 also shows that where soil depth is high, the aspect of the plots tends to be westerly ($P<0.05$) (Section 9.1.3).

There are correlations between Slope and % canopy cover (Table 7.34), and % herb cover (Table 7.35), showing that as slope becomes steeper, the two vegetation parameters increase. Aspect is also correlated with several vegetation factors such as

% moss cover and moss height and the % bare ground (Table 7.34). These factors are discussed further in Section 9.2.2.

Table 7.35: A summary of correlations between the vegetation and environmental factors at the $P<0.05$ (95%) significance level

1st Factor	Rank (from 1-8)	Correlating factor	Correlating rank		Significance
Age	Young-old	Moss height	High-low	-0.70	**P < 0.05**
	Young-old	Spp richness (both)	Low-high	0.71/ 0.65	**P < 0.05**
Soil depth	Shallow-deep	Aspect	South-west	0.69	**P < 0.05**
Slope	Flat-steep	Aspect	South-west	0.69	**P < 0.05**
	Flat-steep	% Herb cover	High-Low	-0.69	**P < 0.05**
Aspect	South-west	% Canopy cover	Low-high	-0.68	**P < 0.05**
		Herb height	Low-high	-0.69	**P < 0.05**
		Moss height	High-low	-0.64	**P < 0.05**
		% Shrub cover	Low-high	-0.64	**P < 0.05**
Herb height	High-low	Moss height	High-low	0.69	**P < 0.05**
	High-Low	% Moss cover	High-Low	0.71	**P < 0.05**
	High-Low	% Bare ground	High-Low	-0.71	**P < 0.05**
% Herb Cover	High-low	% Bare ground	High-low	-0.69	**P < 0.05**

Table 7.36 shows the correlations that involve ordinal data-sets, where significance tests could not be undertaken. Correlations that are 'strong' or 'very strong' (Section 6.1.1.3) are therefore included in the table. There are strong positive correlations between increasing age and decreasing pyrites strength, and decreasing pyrites strength and increasing plant vigour, moss height and species richness as discussed in Section 9.1.2. Increasing soil depth is also strongly positively correlated with increasing plant health (vigour) and higher biomass (Section 9.1.3).

The correlations between vegetation factors are described in Section 7.3.5.

Table 7.36: A summary of the correlations that could not be tested for significance, but were classified as 'moderate' to 'very strong' (Fowler *et al.*, 1998)

1st Factor	Rank (from 1-8)	Correlating factor	Correlating rank		Strength of correlation
Age	Young-old	Pyrites	Dark-light	0.74	Strong
Pyrites	Dark-light	Soil depth	Shallow-deep	0.86	Strong
	Dark-light	Plant vigour	Unhealthy-healthy	-0.85	Strong
	Dark-light	Moss height	Low-high	-0.79	Strong
	Dark-light	% Bare ground	High-low	0.71	Strong
	Dark-light	Spp richness (both)	Low-high	0.83/0.79	Strong
Soil depth	Shallow-deep	Plant vigour	Unhealthy-healthy	-0.92	Very strong
	Shallow-deep	Biomass	Low-high	-0.81	Strong
Plant vigour	Healthy-unhealthy	Herb height	High-low	0.70	Strong
	Healthy-unhealthy	Moss height	High-low	0.93	Very strong
	Healthy-unhealthy	% Shrub cover	High-low	0.92	Very strong
	Healthy-unhealthy	% Moss cover	High-low	0.90	Very strong
	Healthy-unhealthy	% Bare ground	Low-high	-0.90	Very strong
	Healthy-unhealthy	Biomass	High-low	0.85	Strong
	Healthy-unhealthy	Spp./subunit	High-low	-0.74	Strong
Herb height	High-Low	Biomass	High-Low	0.86	Strong
Moss height	High-low	Biomass	High-low	0.86	Strong
% Shrub cover	High-low	Biomass	High-low	0.76	Strong
% Moss Cover	High-low	Biomass	High-low	0.83	Strong
% Bare ground	High-low	Biomass	High-low	-0.93	Very strong
Biomass index	High-low	Spp. richness (both)	High-low	-0.76/-0.81	Strong

7.6 Summary of results

Table 7.37 summarises the data-sets analysed and described in this chapter. Substrate analyses (Section 7.1) show that the pH of the sites ranges from acidic (3.02) on Hawkeswell to approaching neutral (6.38) on New Fancy B. At the 95% significance level or above, % canopy cover and % herb cover tend to increase as pH becomes more neutral.

Cannop A had the highest pyrites rank, and Lightmoor and True Blue the lowest. There are strong positive correlations between increasing age and decreasing pyrites strength, and decreasing pyrites strength and increasing plant vigour, moss height and species richness.

Table 7.37: statistical analyses undertaken on the non-floristic Forest of Dean data-sets

Data-sets		Type of data		Statistical analyses					
	Parameter	**Scale**	**Density**	**Mn**	**Md**	**SD**	**CA**	**D**	**S**
Substrate	pH value	I	P			✓	✓		✓
	Pyrites (cm)	O	P				✓		
	Soil depth (cm)	R	Q	✓		✓	✓	✓	✓
	Plant vigour (index)	O	Q		✓		✓		
Micro-climate	Slope factor (°)	R	SP	✓		✓	✓		✓
	Aspect (°)	I	T	✓			✓		
	Canopy cover (%)	R	Q	✓		✓	✓		✓
Vegetation factors	Moss height (cm)	R	Q	✓		✓	✓		✓
	Herb height (cm)	R	Q	✓		✓	✓		✓
	Shrub height (cm)	R	Q	✓		✓	✓		✓
	Moss cover (%)	R	Q	✓		✓	✓		✓
	Herb cover (%)	R	Q	✓		✓	✓		✓
	Shrub cover (%)	R	Q	✓		✓	✓		✓
	Bare ground cover (%)	R	Q	✓		✓	✓	✓	✓
	Biomass (index)	O	Q	✓			✓		
Diversity indices	(S)	R	P				✓		
	Shannon H'	R	P				✓		
	Shannon E	R	P				✓		
	Simpson 1/D	R	P				✓		
	(S)/Quadrat	R	Q	✓		✓	✓	✓	✓
	(S)/Subunit	R	Q	✓		✓	✓		✓
Species strategies	Life form	N/R	P	✓		✓			
	Competitive strategy	N/R	P	✓		✓			
	Raunkaier life-form	N/R	P	✓		✓			
	Reproductive strategies	N/R	P	✓		✓			
	Special attributes	N/R	P	✓		✓			
	Capacity for lateral spread	N/R	P	✓		✓			
	Optimum pH range	N/R	P	✓		✓			

Key:
P = Plot; T = Transect; SP = subplot; Q = Quadrat
N = nominal; O = Ordinal; I = Interval; R = Ratio
Mn = mean; Md = Mode; SD = Standard deviation; CA = correlation analysis; D = distribution; S = significance

Mean soil depth on the plots ranged from 0 on Hawkeswell and Northern United to 1.63 on True Blue. At the 97.5% significance level, there is a positive correlation between age and soil depth. There are significant correlations at the 99.5% level between soil depth, moss height and cover and % bare ground. As soil depth increases, moss cover increases (P<0.01), and shrub cover and species richness increase ($P<0.025$). Where soil depth is high, the aspect of the plots tends to be westerly ($P<0.05$). Plant vigour scores are poor on Hawkeswell, Northern United, Cannop A, Cannop B and Lightmoor, indicating environmental conditions are least favourable on these sites. There are strong correlations between increasing plant health and decreasing % bare ground, and very strong correlations between increasing plant health and increasing moss height and cover.

The microclimatic data described in Section 7.2 shows that Cannop B was the most steeply sloping site with a mean of 32.3°, although 40° slopes were also recorded on Lightmoor and Cannop A. There are significant correlations between decreasing slope and increasing % canopy cover and % herb cover. There is also a significant correlation between decreasing slope and southerly facing plots.

Hawkeswell and Northern United were the most southerly facing slopes at 180-183°, whereas Cannop B, New Fancy A, and New Fancy B were more westerly facing, between 260-170°. Significant correlations were recorded between a southerly direction and lower % moss cover and height, a lower herb height, and a higher % bare ground cover. New Fancy B had the highest mean % canopy cover at 54%, whereas Hawkeswell, Lightmoor, and True Blue had no canopy layer vegetation

Shrub height was highest on Northern United with a mean of 54cm, due to the presence of conifers, but shrub cover was highest on True Blue at 70%. Herb height was highest on New Fancy A (26cm), and most abundant on New Fancy B (56.4%). Moss height and cover was highest on New Fancy A. Hawkeswell had the highest % bare ground (100%). Cannop A, Northern United, and Cannop B all had a mean % bare ground cover of over 80%. True Blue had the highest mode score (25% of the samples fell within the 2000-2499 frequency class, whereas 88% or more of samples from Hawkeswell, Cannop A and Cannop B fell within the lowest 0-499 frequency class. There are many significant correlations between the vegetation factors, such as increasing moss cover and height with decreasing % bare ground, and increasing species diversity.

The different diversity indices tested on the results give differing scores. Lightmoor has the highest overall species richness (S=76), and Cannop A the lowest (S=26), after Hawkeswell (S=0). New Fancy A has the highest diversity score according to the Shannon 'H' and Simpson 1/D indices (3.03 and 14.95 respectively), and True Blue the least diverse (1.11 and 2.06). Cannop A has the highest Shannon Evenness score (-0.72), and True Blue the lowest (-0.03). The rank abundance diagrams show that New Fancy A has the high richness and evenness. Site size and diversity tend to be positively correlated, with species richness showing the highest correlation with sample size (0.45) and the Simpson 1/D index the least (0.35). Mean species richness per quadrat and per subunit were less affected by size (0.15 and –0.02 respectively).

For the species strategies, perennials dominate all plots, forming between 83-96% of species. Life form categories do not change with increasing time or pH. Semi-hemicryptophytes are the most frequent life form for species occurring on all sites. There do not appear to be any progressive changes with increasing time or pH. Vegetative reproduction is the most frequent strategy on all sites. The amount of species with the ability to produce large quantities of seed decreases over time. Having a clonal growth form was more frequent a strategy that having a long tap-roots or being able to fix nitrogen. Species with an intermediate or "generalist" CSR strategy are the most frequent on all sites, as are species that grow optimally in conditions of neutral pH (7). Species that grow optimally at low pH conditions are not consistently more prevalent on sites with low pH.

Chapter 8: Floristic Results

This chapter displays and describes floristic results following the application of TWINSPAN and DCA multivariate techniques (Section 6.3). This addresses objective v). The samples from all plots were analysed to look at the level of floristic similarity or dissimilarity within the data-set as a whole. Separate analyses of each plot were also undertaken to look at the floristic groupings within plots. The TWINSPAN analyses were used to map the distribution of each floristic group within the plot. The DCA samples were identified by symbols according to environmental data such as location on the slope, age, pH, or canopy cover category. These procedures enabled the relationships between floristic results and environmental results to be indirectly examined.

8.1 Classification

The results from TWINSPAN analyses undertaken on the data-sets are described in Sections 8.1.2-8.1.11. Section 8.1.1 summarises the analyses that were undertaken on each data-set, and describes any changes made to the standard TWINSPAN descriptors for each data-run.

8.1.1 TWINSPAN Methodology

8.1.1.1 Overview of the data-sets and TWINSPAN run descriptors

Table 8.1 summarises the data-sets on which TWINSPAN analyses were undertaken. Each of the plots is included except for Hawkeswell, where no

Table 8.1: TWINSPAN analyses undertaken on the Forest of Dean data

	Standard	Species/samples removed	Rare species down-weighted
All plots	✓	✓	✓
Northern United	✓	✗	✗
Cannop A&B	✓	✗	✗
Cannop A	✓	✗	✗
Cannop B	✓	✗	✗
New Fancy A&B	✓	✗	✗
New Fancy A	✓	✗	✗
New Fancy B	✓	✗	✗
Lightmoor	✓	✗	✗
True Blue	✓	✗	✗

vegetation was recorded at the time of survey (Section 4.1.2). Where plots from the same site were sampled, such as New Fancy A and B, a data-set containing samples from both plots was analysed so that patterns of floristic similarity or dissimilarity across the site could be examined.

Table 8.2: Run descriptors for the three TWINSPAN analyses undertaken on the Forest of Dean data

Run descriptors	Standard	Species/samples removed	Rare species down-weighted
Cut levels	0.1 5.1 7.1 20.1	0.1 5.1 7.1 20.1	0.1 5.1 7.1 20.1
Pseudospecies weight	1,1,1,1	1,1,1,1	0,1,2,3
Indicator potentials	1,1,1,1	1,1,1,1	0,0,1,1
Minimum group size	5	5	5
No. indicator species	7	7	7
Max no. species	100	100	100
Max division level	5	9	9
Samples removed	0	As required	As required
Species removed	0	As required	As required

Table 8.2 provides an overview of the TWINSPAN analyses undertaken, and the descriptors of each TWINSPAN run. For 1 data-run, descriptors were set to the default values provided in VESPAN III, to provide a standardised and therefore comparable output of all data-sets for analysis. Sections 8.1.1.2- 8.1.1.5 describe any variations made to the standard run.

8.1.1.2 Cut levels

The standard cut levels on TWINSPAN (0.1-5.1%, 5.2-7.1%, 7.2-20%, 20%+) were felt to be more appropriate for use in this study than levels used for the Braun-Blanquet method (such as 0-5%, 5-20%, 20.1-50%, 50.1+). The standard cut-levels focus on a lower percentage range. Given the lack of vegetation that has colonised many of the plots (Section 7.3.2), the standard cut-levels were felt to better describe the data collected in this study (Section 6.3.2.1) because they focus on the low cover-abundance distributions that many species occur at. As shown in Section 7.3.4.2 (Figure 7.3), more than 50% of species on Lightmoor, Cannop B and New Fancy B occur at a cover-abundance per plot of less than 1%. Only New Fancy B and True Blue contained species that occur with cover-abundance values per plot of more than 10%.

8.1.1.3 Pseudospecies weight and indicator potentials

An analysis of the 'all plots' data-set was undertaken whereby run descriptors were set to down-weight rare species. Pseudospecies weight and indicator potentials were manipulated so that only psuedospecies with the highest levels of abundance in each sample (3: 7.1% -20%, and 4: 20.1+) could be used to separate the samples. Moreover, pseudospecies level 4 was given twice the weight of level 3. This was done to emphasise the floristic similarities between the plots by increasing the focus on dominant species within the samples and minimising the effects of species that occur at lower cover-abundance values.

8.1.1.4 Indicator species

Given the species paucity of the plots, a maximum of 7 species was felt to be sufficient to characterise the data. As shown in sections 8.1.2-8.1.11, in many of the single plot analyses only 1-2 species have been identified by TWINSPAN as characterising particular samples. Codes used to display the indicator species within the TWINSPAN dendrograms are provided in Appendix 4.

8.1.1.5 Maximum division level

Because TWINSPAN classifies data using divisive methods, i.e. starting with all samples and dividing them until the programme tells it to stop, the groups at either end of the diagram tend to contain less samples than the groups in the middle unless the number of division levels are increased. The standard run has a maximum division level of 5. As shown in Figures 8.1 and 8.2, this was found to be a suitable level for most of the smaller data-sets. For large data-sets such as the 'all-plots' run however, it can be difficult to assess whether the samples in the middle of the dendrogram are really closer together floristically, or whether this is a product of the programme. Where samples were highly clustered therefore, a TWINSPAN run with up to 9 divisions was used.

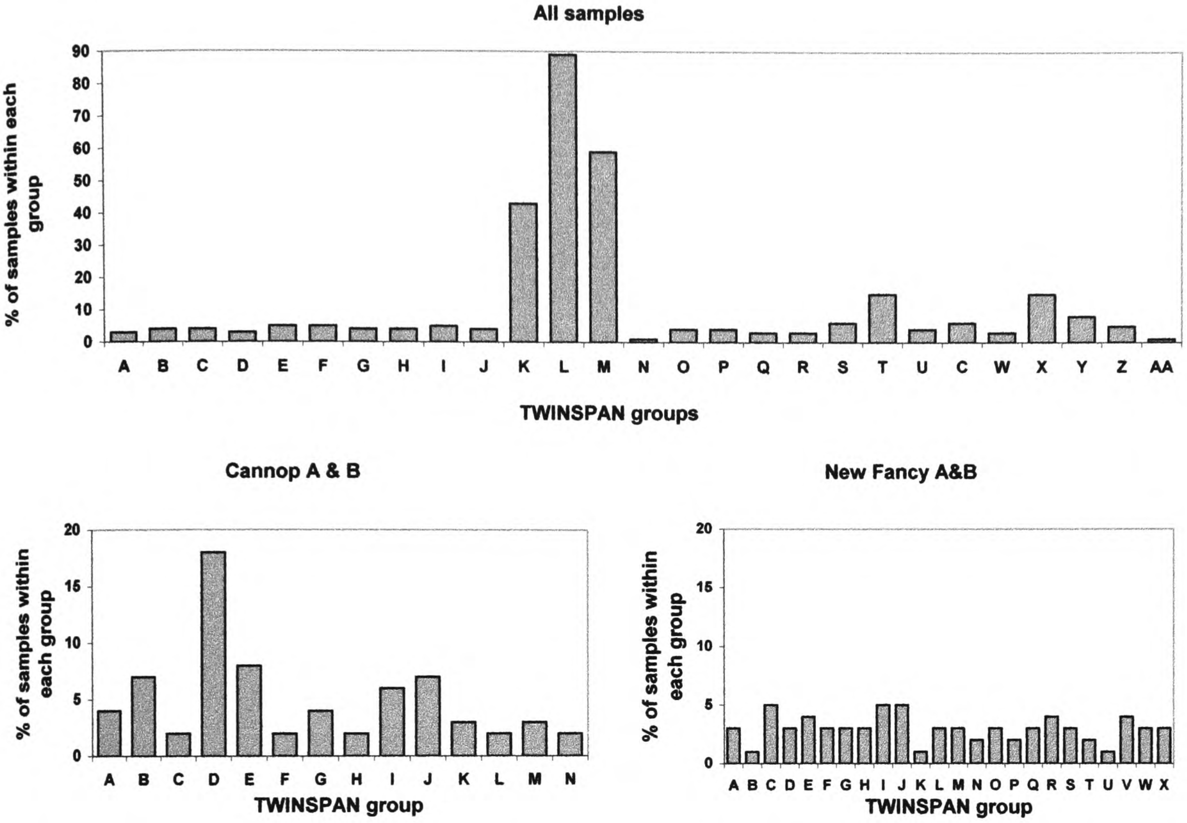


Figure 8.1:Graph to show the distribution of samples within each floristic group formed by standard TWINSPAN analyses on all sites and joint-plot data

Table 8.3: The number of samples within each TWINSPAN group created by the standard run

Group	Allsites	NU	CPA&B	CPA	NFA&B	NFA	NFB	CPB	LM	TB
A	3	4	4	2	3	2	2	4	2	3
B	4	10	7	2	1	3	2	4	4	2
C	4	18	2	3	5	4	3	15	4	3
D	3	3	18	2	3	3	3	2	2	4
E	5	6	8	4	4	4	2	2	1	1
F	5	9	2	2	3	2	1	1	3	4
G	4	4	4	2	3	2	4	4	6	4
H	4	2	2	3	3	3	3	2	11	3
I	5	11	6	4	5	3	2	3	13	
J	4	6	7		5	4	2	3	4	
K	43	1	3		1	1		3	1	
L	89	3	2		3	4		3	4	
M	59	5	3		3	1			3	
N	1	1	2		2	1			2	
O	4	1			3	3				
P	4				2	3				
Q	3				3	2				
R	3				4	3				
S	6				3					
T	15				2					
U	4				1					
V	6				4					
W	3				3					
X	15				3					
Y	8									
Z	5									
AA	1									
Total Number Groups	27	15	14	9	24	18	10	12	14	8
Total samples	310.00	84.00	70.00	24.00	72.00	48.00	24.00	46.00	60.00	24.00
Mean	11.48	5.60	5.00	2.67	3.00	2.67	2.40	3.83	4.29	3.00
Standard Deviation	20.15	4.70	4.31	0.87	1.14	1.03	0.84	3.64	3.56	1.07

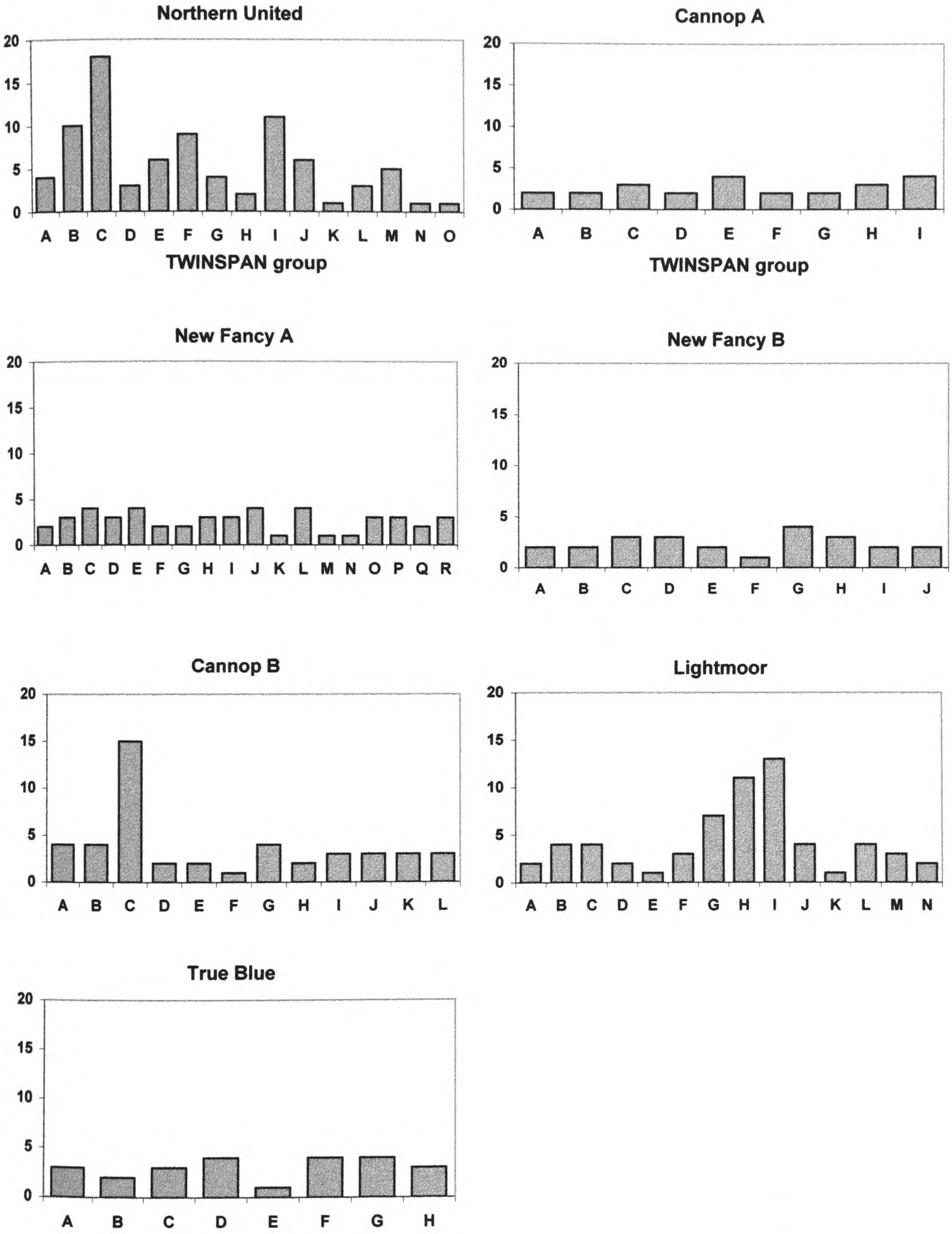


Figure 8.2: Graph to show the distribution of samples within each floristic group formed by standard TWINSPAN analyses on single-plot data sets

8.1.1.6 Samples/species removed

Samples or species were only removed from analyses where they were found to affect the analysis of the results. Sample 65 taken on Northern United for example, was classified into its own floristic group even in the rare species down-weighted data run which skewed the other floristic groupings (Section 8.1.1.2). Other species or samples removed are described in the relevant sections below (8.1.2-8.1.11). Of the 320 samples, ten were found to be completely devoid of vegetation (Table 8.4). The absence of information contained in these samples means that they were not processed in TWINSPAN.

Table 8.4: Bare samples listed by number and plot

Plot	**Sample numbers**
Cannop A	86, 89, 90, 93, 97, 98, 110, 116
Cannop B	217, 236
Hawkeswell	Whole plot

8.1.1.7 Displaying the data

Dendrograms showing the linkages between samples were constructed from each TWINSPAN analysis undertaken. The samples that have been placed by classification into each floristic grouping are listed underneath the dendrogram. Diagrams showing the spatial distribution of floristic groups across each plotwere then constructed from the dendrograms.

Because bare sites are not processed within TWINSPAN, the sample numbers generated by the programme and the real sample numbers become unsynchronised. Real sample numbers have been used wherever possible. Tables are provided to show where they were taken within the plotin the relevant sections below. As the lack of vegetation may be as important as the vegetated sites in this study, potentially indicating extreme environmental conditions, the bare samples have been added to the dendrograms as a separate category, denoted on the spatial diagrams by a symbol (•).

8.1.2 All Plots

8.1.2.1. Standard Run

Figure 8.3 shows the divisions and groupings produced by the standard TWINSPAN analysis of all 320 samples. Figure 8.4 is a summary of the dendrogram, showing simplified groupings of the plots by age and habitat. Both figures show that the first division separates samples from Northern United characterised by *Pinus sylvestris* and *Hypochoeris radicata* from all other samples, which contain herbs and grasses such as *Brachypodium* ***sylvaticum***, *Fragaria vesca*, *Prunella vulgaris*, and *Festuca ovina.* All True Blue samples are separated at the second division due to the presence of *Calluna vulgaris* (not recorded on any other plot).

Division 01 contains samples from all of the other plots. Groups K-N are separated from Groups G-J due to the increased presence of *Brachypodium* ***sylvaticum*** at pseudospecies level (2), *Fragaria vesca* (1) and *Prunella vulgaris* (1). Groups G-J comprise 13 samples from Cannop A and 4 from Cannop B, Group K contains the majority of the Cannop B samples and Group L contains all

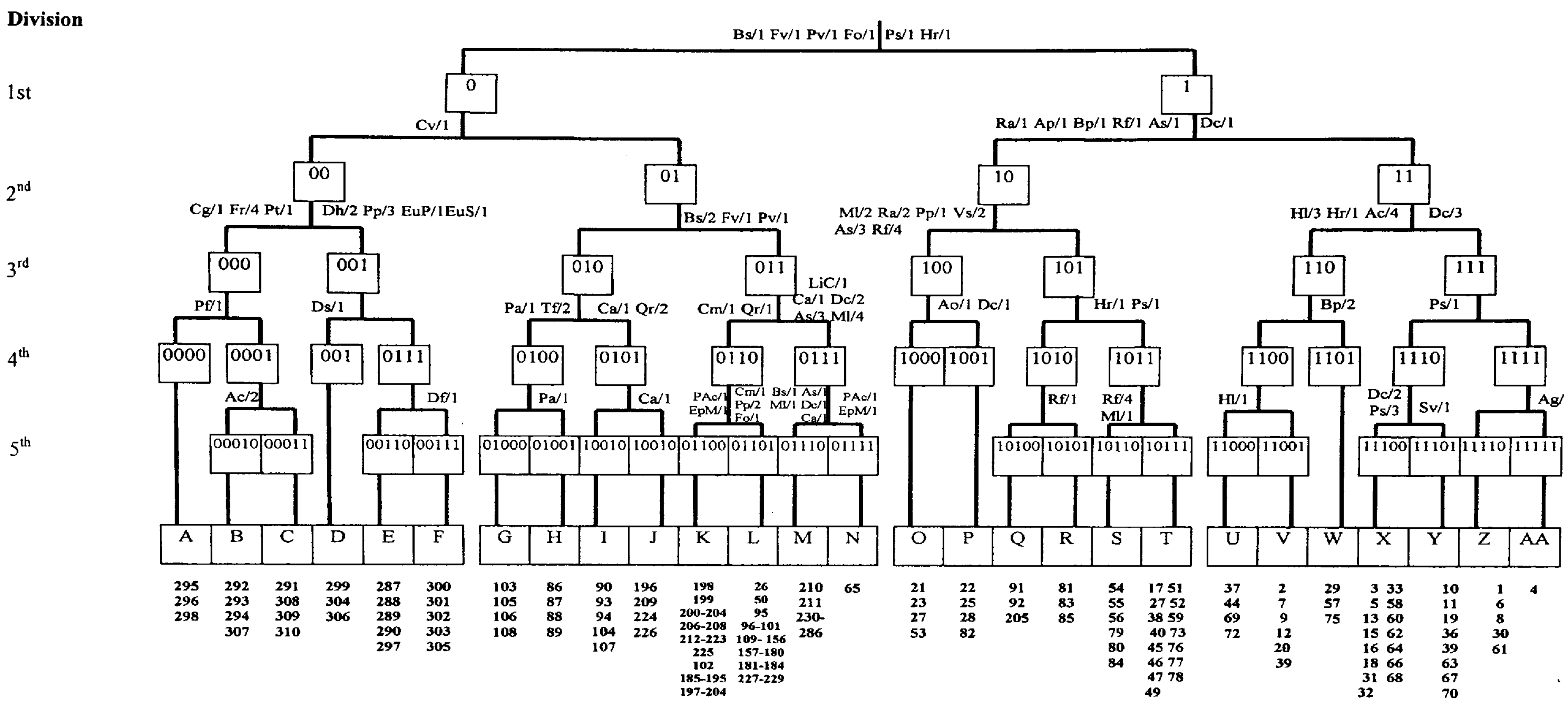


Figure 8.3: Dendrogram constructed from a standard TWINSPAN analysis of 320 quadrats from Forest of Dean coal spoil heaps, showing the final floristic groups represented by letters with relative quadrat numbers listed underneath

Age	100	15	40	36	60	6
Habitat	HT	PB	GB	GB	G	P
Site	**TB**	**CPA**	**CPB**	**NFA** **NFB**	**LM**	**NU**
Division	2nd	3rd	5th	4th	1st	

Key to habitats: HT= Heath; PB= Pioneer & birch; GB= Grass & birch; G= Grassland; P= Pioneer.

Figure 8.4: simplified diagram to show the main floristic groupings of the standard TWINSPAN run by plot, showing the level of the division between each grouping.

of the samples from New Fancy A and B. These groups are characterised by the presence of woody species *Crataegus monogya* (1) and *Quercus robur* (2). Group M contains the majority of the Lightmoor samples, and is characterised by *Medicago lupulina* (4), *Agrostis stolonifera* (3) and *Deschampsia caespitosa* (2) with *Cirium arvense* and *Linium catharticum* (1). Group N comprises a single outlying sample from Northern United.

As shown in Figure 8.1 the distribution of samples within each floristic group is highly clustered, with 62% of samples being classified in just three groups, K,L and M, with insufficient divisions to determine the major floristic differences within and between these sites. A TWINSPAN run with more divisions was felt to be necessary to further divide these middle sites.

8.1.2.2 Rare species down-weighted

Figure 8.5 shows the results of the rare-species down-weighted TWINSPAN run (Table 8.2). *Pinus sylvestris* was omitted from the run because

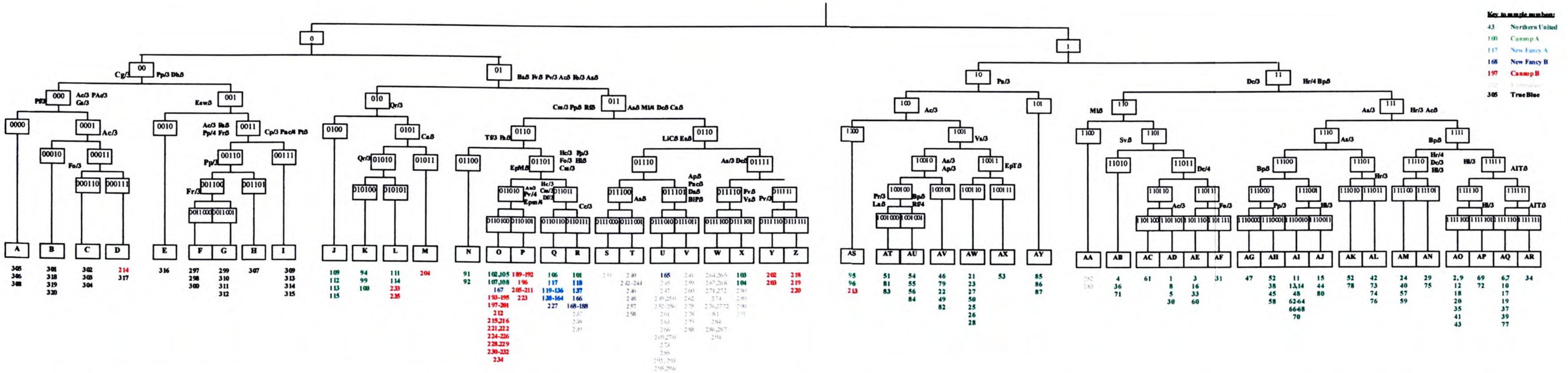


Figure 8.5: Dendrogram constructed from a 'rare species downweighted' TWINSPAN analysis of 320 quadrats from Forest of Dean coal spoil heaps. The final floristic groups derived from the analysis are represented by letters. Sample numbers are listed underneath and colour coded by plot.

Northern United is managed as a plantation. Omitting the species will therefore prevent the effects of planted species from obscuring natural floristic patterns as found in Figure 8.3. Sample 65 was also omitted as this outlying sample was still classified into a separate floristic group on all runs. This sample is examined further in Section 8.1.3.

There are many similarities between Figures 8.3 and 8.4. For example, most samples from Northern United are still separated at the first division from samples from other sites despite *Pinus sylvestris* being omitted. The division 1 samples are now characterised by *Agrostis capillaris* (4), whereas the division 0 samples are characterised by *Brachypodium sylvestris* (3), *Fragaria vesca* (3), *Festuca ovina* (3), and *Prunella vulgaris* (3). All samples from True Blue are still separated at the second division, indicating that these samples are very different to the rest. The distribution of samples from other sites are also similar in the two dendrograms, as summarised in Figures 8.4 and 8.6. New Fancy A samples are clustered together in group Q, those of New Fancy B in Group R, those from Cannop B in Groups O-P and Lightmoor in groups S-W. However, these are more outlying samples from these main clusters in Figure 8.5. Samples from sites such as Cannop A and Cannop B form particularly mixed clusters.

Age	100	15	40	36	36	60	6
Habitat	HT	PB	GB	G	GB	G	P
Site	**TB**	**CPA**	**CPB**	**NFA**	**NFB**	**LM**	**NU**
Division	2nd	3rd	5th		4th	1st	

Key to habitats: HT= Heath; PB= Pioneer & birch; GB= Grass & birch; G= Grassland;P= Pioneer.

Figure 8.6: simplified diagram to show the main floristic groupings of the standard TWINSPAN run by plot, showing the level of the division between each grouping

8.1.3 Northern United

Figure 8.7 is constructed from standard TWINSPAN analysis of Northern United data. The first division separates the outlier found in Sections 8.1.1.1 and 8.1.1.2 from all other samples. Sample 65 was found to be different from all other plots because it contains an individual *Leontodon autumnalis* plant. This species is not found anywhere else within the plot, and the lack of other species within the sample makes it very difficult for TWINSPAN to classify. Groups H-N within division 01 contain 6 of 7 potential indicator species *Betula pubescens, Agrostis stolonifera, Rubus fruticosus, Potentilla reptans, Aira praecox,* and *Rumex acetosella.* On further investigation these plots were found to be more species-rich than samples within Groups A-G, which are associated with *Deschampsia caespitosa.*

The dendrogram displays a continuum of samples from species-rich on the positive side to species poor on the negative side. Groups L-N were found to be particularly species-rich. These samples are characterized by *Pseudoscleropodium purum* and *Vicia sativa* and contained between 10-20 species per quadrat - which is very high for this plot (Section 7.3.4). Groups H-K were found to contain 5-10 species per quadrat. Groups H-I were characterized by the presence of *Aira praecox*, and Groups J-K by high abundances of woody species *Rubus fruticosus* (4), and *Betula pendula* (4).

Groups D-G were separated from Groups A-C on the basis of *Agrostis capilaris* (4), *Hypochoeris radicata* (3), and *B. pendula* (1), whereas Groups A-C all contained a higher abundance of *Deschampsia caespitosa* (3). The quadrats in both Groups A-G were found to contain only 3-4 species per quadrat.

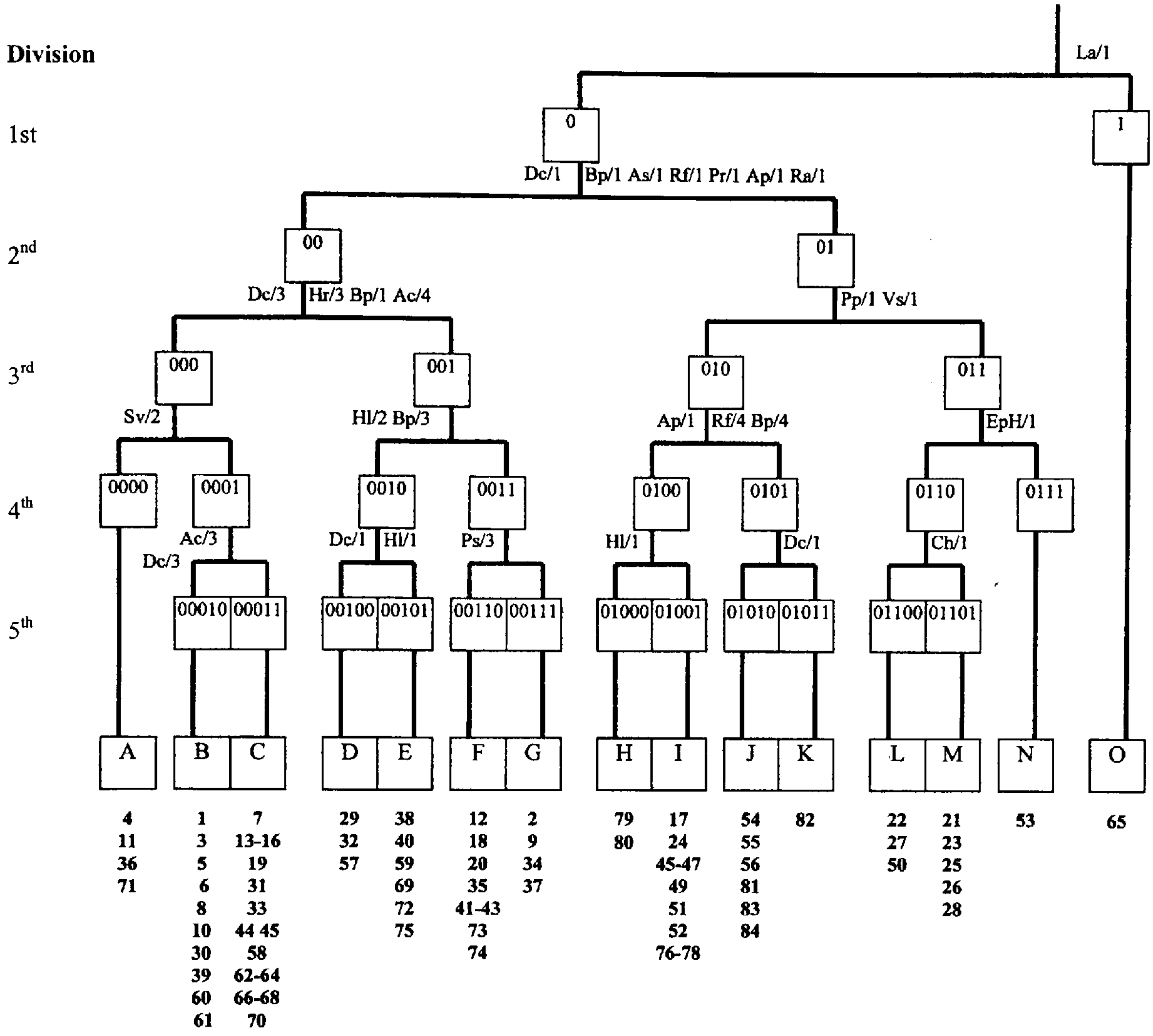


Figure 8.7: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on Northern United

Table 8.5: Location of (real) quadrat numbers on Northern United by transect and subplot.

Subplot	Transect 1	Transect 2	Transect 3
7 (upper slope)	25-28	53-56	81-84
6	21-24	49-52	77-80
5	17-20	45-48	73-76
4	13-16	41-44	69-72
3	9-12	37-40	65-68
2	5-8	33-36	61-64
1 (lower slope)	1-4	29-32	57-60

Figure 8.7 and Table 8.5 were used to construct Figure 8.8, which shows how the final floristic groupings are spatially distributed on Northern United. It can be seen from this diagram that the species poor Groups A-G tend to occur lower down on the plot whereas species rich Groups M and L occur at the top of Transect 1. Groups H,I,J and K are also more prevalent on the upper slopes.

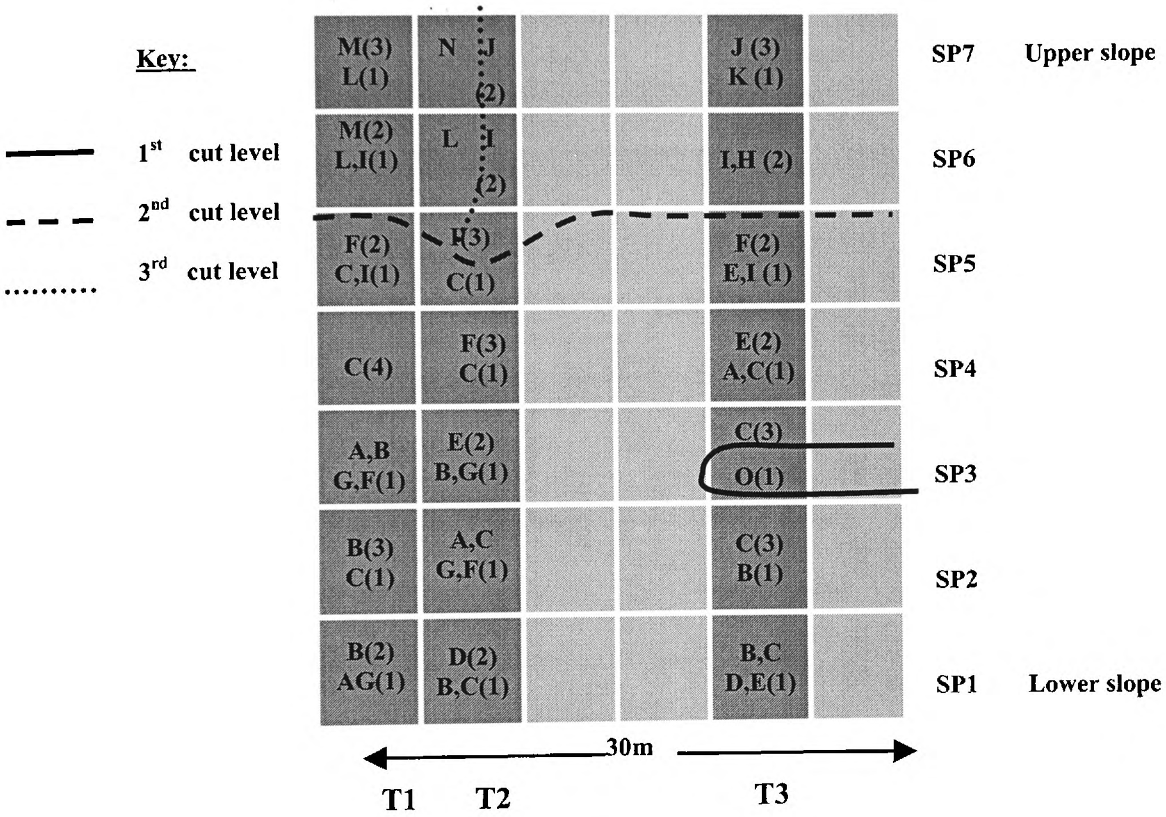


Figure 8.8: The distribution of floristic groups on Northern United as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot.

8.1.4 Cannop A & B

Figure 8.9 shows the results of the standard TWINSPAN analysis of samples taken from Cannop plots A and B. Table 8.6 and Figure 8.10 show how

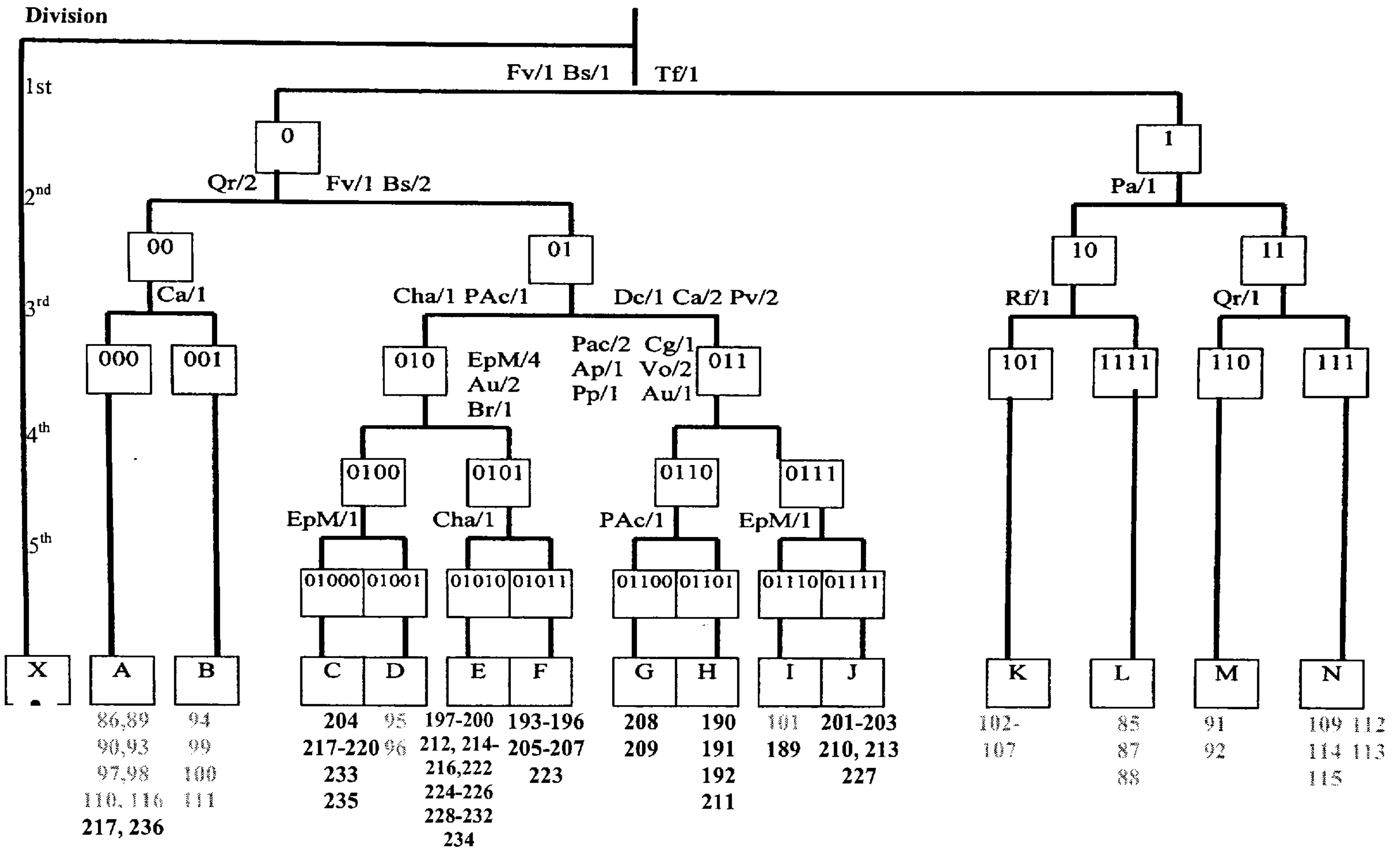


Figure 8.9: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on Cannop A and Cannop B. Bare samples have been included denoted by •.

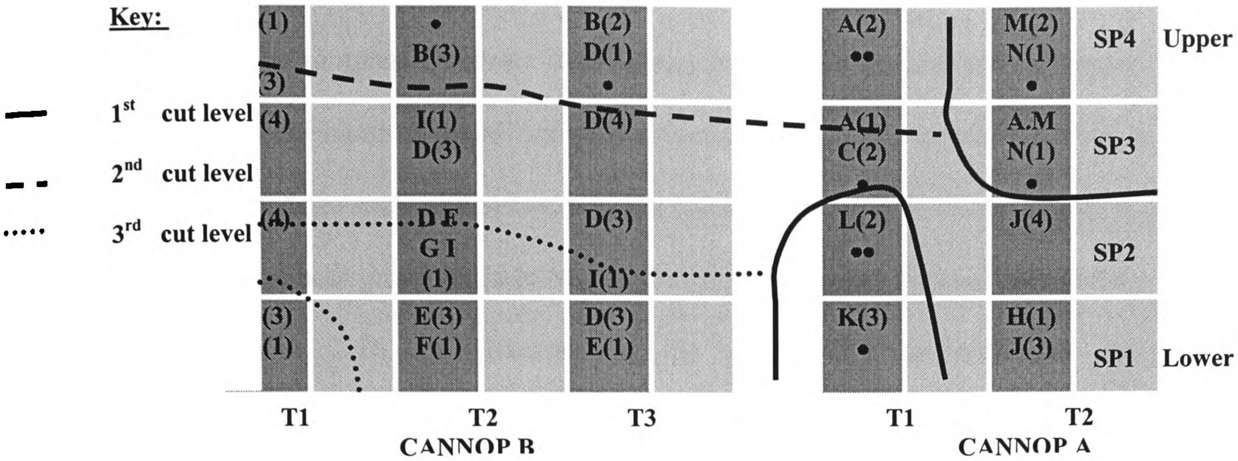


Figure 8.10: The distribution of floristic groups on Cannop A & B as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot. Bare sites denoted by symbol •.

these samples are distributed across the plot. The samples from the different plots are not clearly divided into separate floristic groups, indicating that there are similarities between the two sites. At the first division, 10 Cannop A samples are divided into Groups K-N, characterised by *Tussilago farfara* (1), a species not present on Cannop B. The 4 groups were found to be species-poor, containing a mean of 2.5 species per quadrat. Groups K and L are characterised by *Pteridium aquilinum* (1), and tend to be distributed on the lower slopes of Transect 1. This species is absent from Groups M and N samples, which are more prevalent on the upper slopes of Transect 2.

Table 8.6: Location of quadrat numbers on Cannop A and B by transect and subplot.

	Cannop B			**Cannop A**	
	Transect 1	**Transect 2**	**Transect 3**	**Transect 1**	**Transect 2**
Subplot 1	189-192	205-208	221-224	85-88	101-104
Subplot 2	193-196	209-212	225-228	89-92	105-108
Subplot 3	197-200	213-216	229-232	93-96	109-112
Subplot 4	201-204	217-220	233-236	97-100	113-116

Within the negative division 0, Groups A and B are clearly separated from the rest of the samples. Quadrats from Group A contain 1 species only, *Quercus robur* (2). These samples are all located on Cannop A. Group B quadrats contain a mean of 5 species such as *Cirsium arvense* (1), and are all located on Cannop B. Samples from both groups tend to be distributed in the upper slopes of both plots.

Groups C-D are characterised by *Chamaerion angustifolium* and *Pleuridium acuminatum*, whereas samples G-J are characterised by *Deschampsia caespitosa*, *C. arvense*, and *Prunella vulgaris*. Samples E-H are much more species rich than the rest of the samples (for example there is a mean of 19 species/quadrat in Group E). The distribution of these groups on the plot is less spatially distinct than groups A and B. However, Groups C and D appear to be more prevalent in the mid-slope subplots 2 and 3, Group E and F in the lower two subplots of Cannop B, and Groups G and H in subplot 1 of transect 1 of Cannop B, with groups I and J having a more widespread distribution.

8.1.5 Cannop A

Figure 8.11 shows the results of standard run TWINSPAN analysis for Cannop A. Bare samples were added to the dendrogram, as explained in Section 8.1.1. Figure 8.12 and Table 8.6 show how the floristic groups are distributed across the site. Groups H and I form the positive division 1, characterised by *Quercus robur* (2). The samples from H and I are all located on the upper slope in subplots 3 and 4. Group I samples are mainly distributed within Transect 1, and Group H samples within Transect 2 (characterised by *Tussilago farfara*).

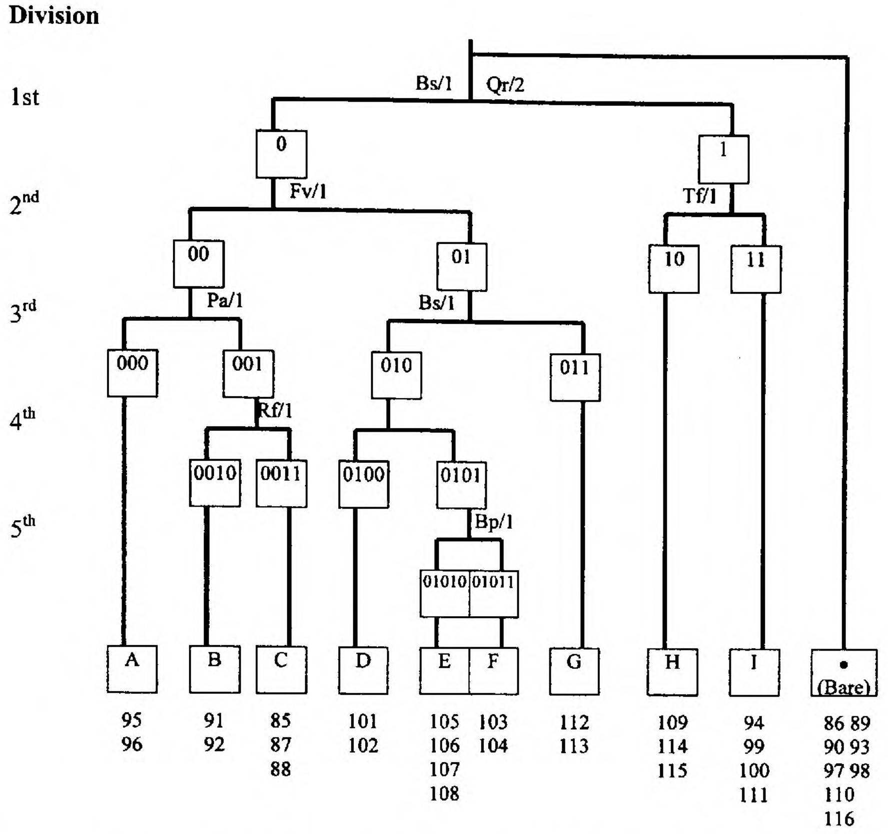


Figure 8.11: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on Cannop A. Bare samples have been included, denoted by •.

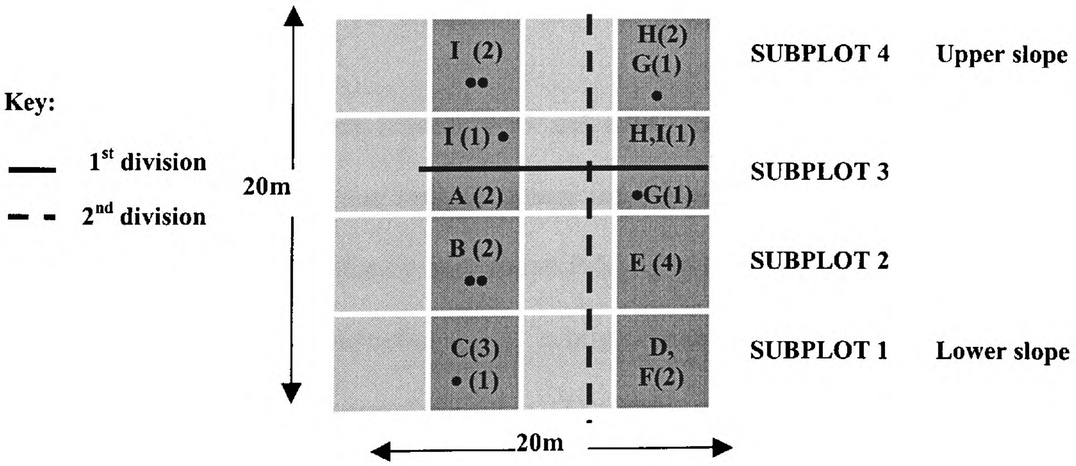


Figure 8.12: The distribution of floristic groups on Cannop A as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot. Bare sites denoted by symbol •.

On the negative side (0), groups A-G are characterised by the *Brachypodium sylvaticum* (1). Floristic groups A-C all occur on subplots 1-3 on transect 1. Groups D-G, which all occur on transect 2 and contain *Fragaria vesca* (1). Groups D-F all occur on the lower slopes of subplots 1-2. Group G occurs on the upper slopes of subplots 3 and 4, and does not contain *B. sylvaticum*1.

Groups H and I are extremely species poor, as described in section 8.1.3. Groups A and G are also species poor (mean 1.5 species). Both G samples contain *T. farfara*, whereas A samples contain *Betula pubescens*. No obvious pattern exists between slope position and bare samples, although more bare samples are recorded on transect 1 than transect 2.

Groups B and C contain a mean of 4.4 species per quadrat. All samples contain *Pteridium aquilinum* (1) and are found exclusively on the lower slopes of Transect 1. Groups D-F contain a mean of 10 species per quadrat, and are found on the lower slopes of Transect 2.

8.1.6 New Fancy A & B

It can be seen from Figures 8.13 and 8.14, and Table 8.7 that the first division clearly separates the samples taken from New Fancy A (Groups A-O) from those taken on New Fancy B (Groups P-X). The New Fancy B samples are characterised by *Ulex europaeus* (1), whilst those of New Fancy A are characterised by *Deschampsia flexuosa* (1), *Hypnum cupressiforme* (1) and *Crataegus monogya* (3).

Within Groups A-O, the second division further separates the samples taken on Transect 1 (Division 00, Groups A-G) from those taken on Transect 2

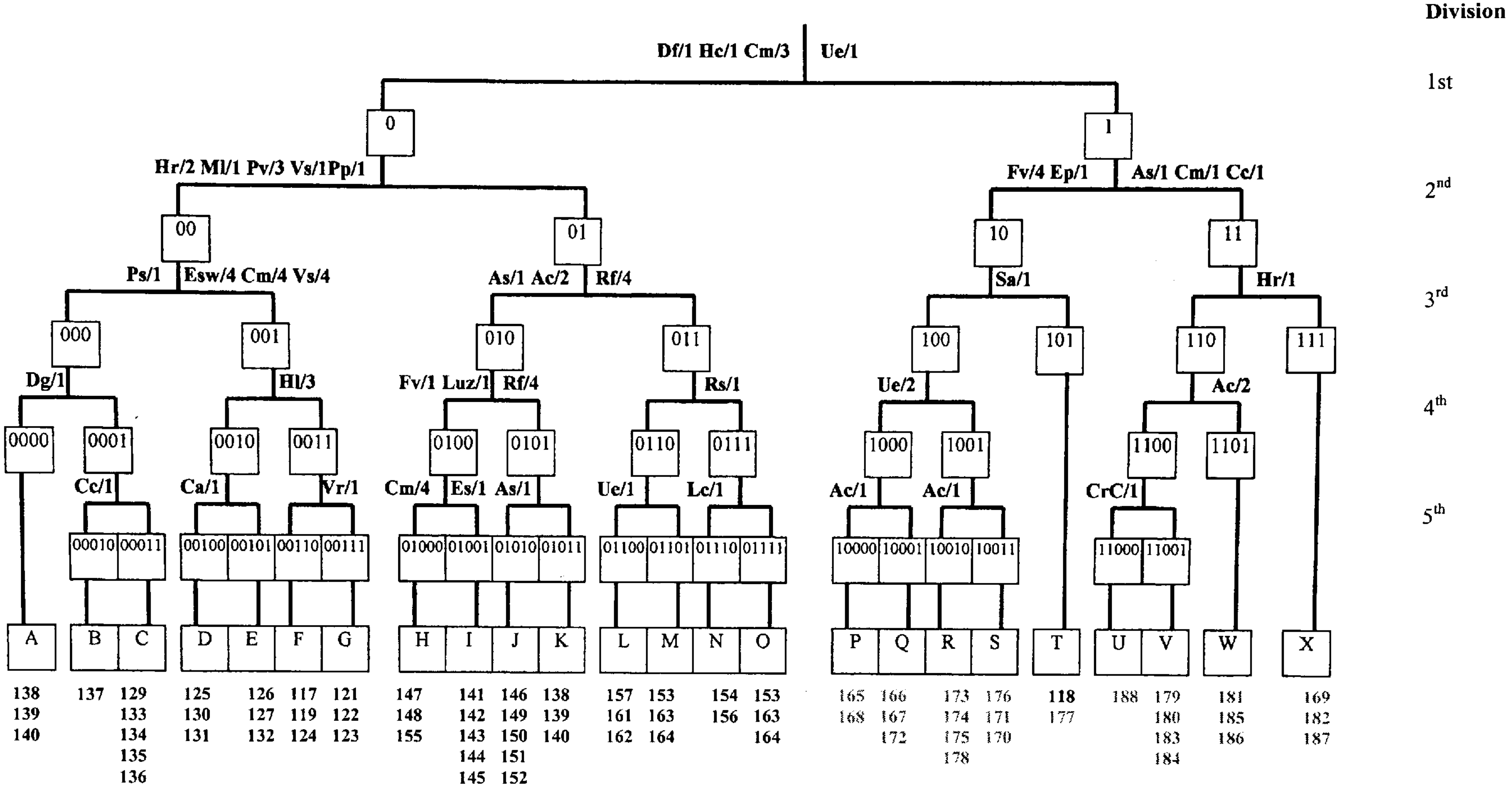


Figure 8.13: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on New Fancy A and New Fancy B.

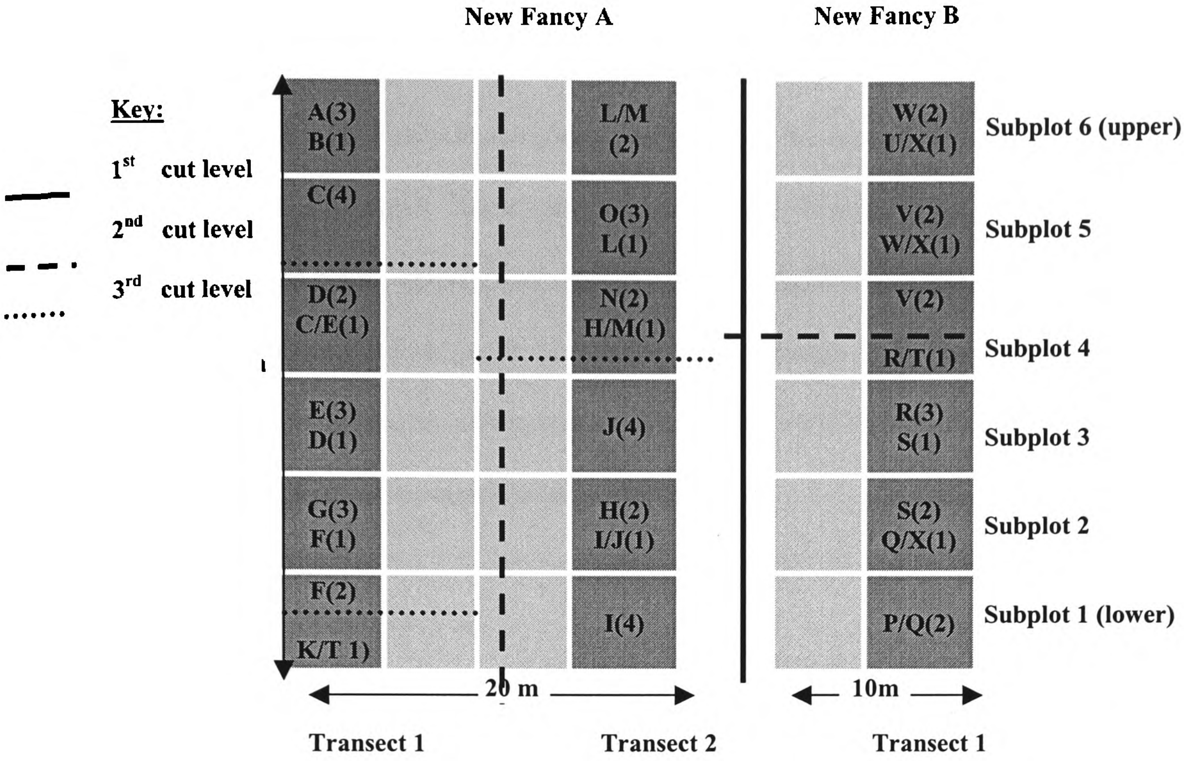


Figure 8.14: The distribution of floristic groups on New Fancy A & B as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot.

Table 8.7: Location of (real) quadrat numbers on New Fancy A and B by transect and subplot.

	New Fancy A		New Fancy B
	Transect 1	Transect 1	Transect 1
Subplot 6	137-140	161-164	185-188
Subplot 5	133-136	157-160	181-184
Subplot 4	129-132	153-156	177-180
Subplot 3	125-128	149-152	173-176
Subplot 2	121-124	145-148	169-172
Subplot 1	117-120	141-144	165-168

(Division 01, Groups H-O). Within each transect, the floristic groups separated at the third division tend to be distributed on different parts of the slope. For example, samples from the upper slopes of Transect 1 (subplots 5 and 6) mainly contain samples in groups A-C (000), whilst subplots 1-4 tend to contain samples from groups D-G (001).

Within New Fancy B samples (Groups P-X), the second division separates samples from the upper slopes from those on the lower slopes. Groups P-T (division 10) is characterised by *Fragaria vesca* (4) and *Eurhynchium praelongum* (1), and samples tend to occur in subplots 1-4. Groups U-X (division 11) are characterised by *Agrostis stolonifera* (1) *C. monogya* (1) and *Cynosurus cristata* (1), and tend to occur on upper slope subplots 4-6.

8.1.7 New Fancy A

Figures 8.15, 8.16 and Table 7.8 are consistent with Figure 8.13, showing that distinct floristic groupings occur on different parts of the plot. Samples from different transects are separated at the first division whilst the second and third divisions separate samples that occur on different parts of the slope.

Samples taken on Transect 1 (Groups A-H) are separated from those on Transect 2 (Groups I-R). Transect 2 groups appear to be characterised by the absence of species which characterise Transect 1 - *Hypochoeris radicata* (2), *Festuca ovina* (3), *Medicago lupulina* (1), *Prunella vulgaris* (3), *Vicia sativa*,(2), *Epilobium montanum* (1), and *Pleuroscleropodium purum* (1). Calculation of the average number of species per quadrat in each transect (Appendix 3.12) also supports the TWINSPAN analysis, as Transect 1 has a mean of 23 species per quadrat, and Transect 2 only 16 species per quadrat.

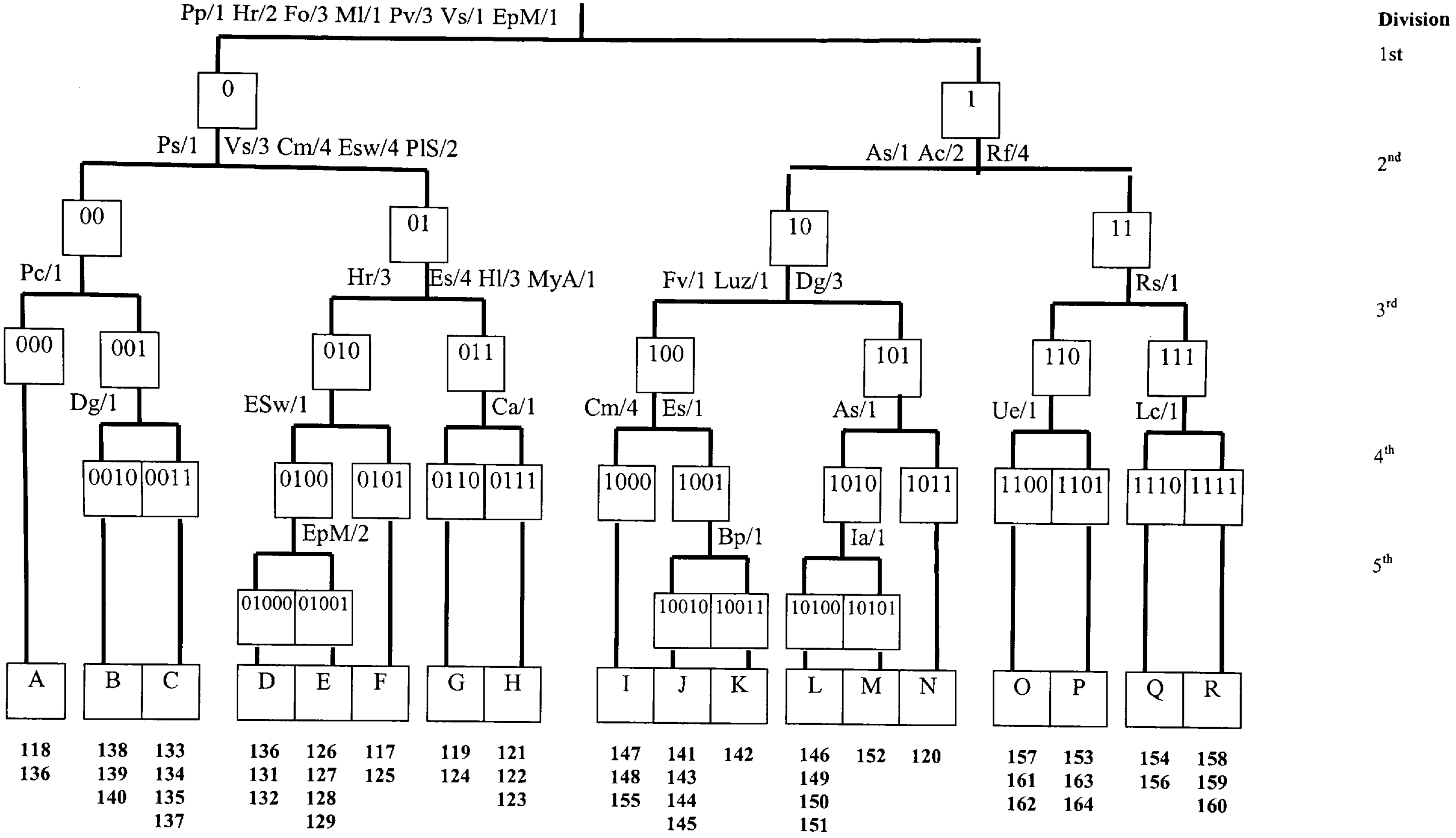


Figure 8.15: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on New Fancy A

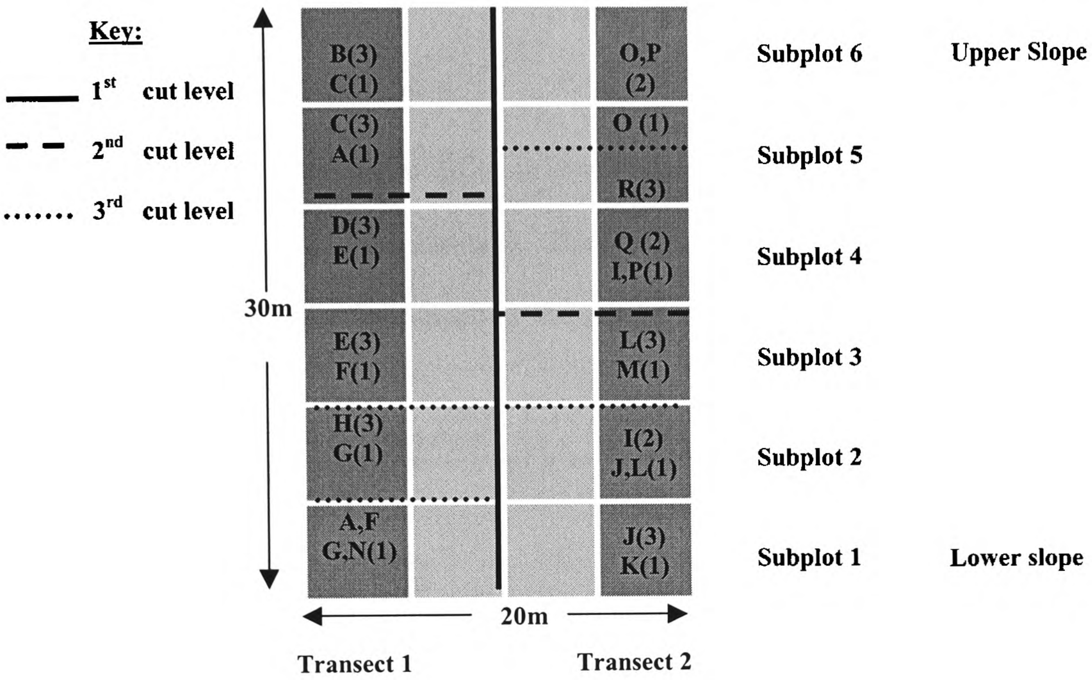


Figure 8.16: The distribution of floristic groups on New Fancy A as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot.

Within Transect 1, floristic groups that tend to occur on the upper 10m of the slope (A-C) are separated from Groups D-H, which tend to occur lower on the slope and are characterised by *Eurhynchium swartzii* (4), *Pleurozium schreberi* (2), *Crataegus monogya* (4) and *Vicia sativa* (4).

Within Transect 2, (groups I-R), samples from Groups I-N are characterised by *Agrostis stolonifera* (1) and *A. capillaris* (2) and tend to occur on the lower three subplots of the slope. Groups O-R are characterised by *Rubus frutiosus* (4) and tend to occur on the upper three slopes.

8.1.8 New Fancy B

Figures 8.17, 8.18 show that different floristic groups are also distributed on different parts of the slope on New Fancy B. The groups on the negative side (A- E) tend to be located in the upper three quadrats and groups on the positive side (F-J) in the lower three quadrats. Moreover, groups A-C tend to be distributed in subplots 5 and 6 and groups D and E in subplots 4 and 5 (although Group C quadrats are also present in Subplot 4). Groups A-C are characterised by high abundances of *Agrostis stolonifera* and *Ulex europaeus,* whereas groups D and E are characterised by *Eurhynchium striatum* and *Fragaria vesca.*

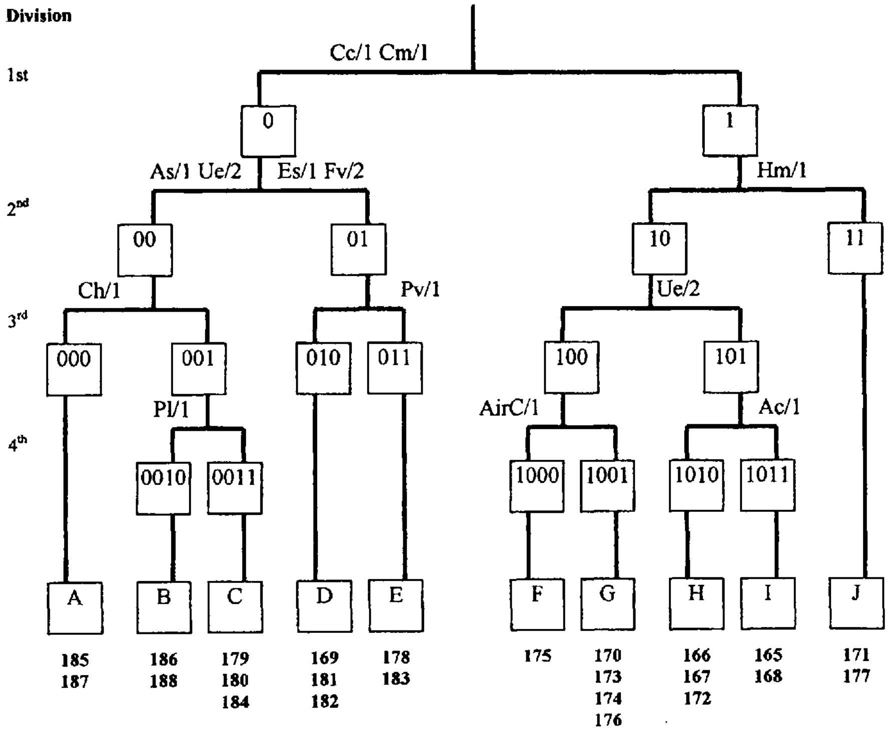


Figure 8.17: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on New Fancy B

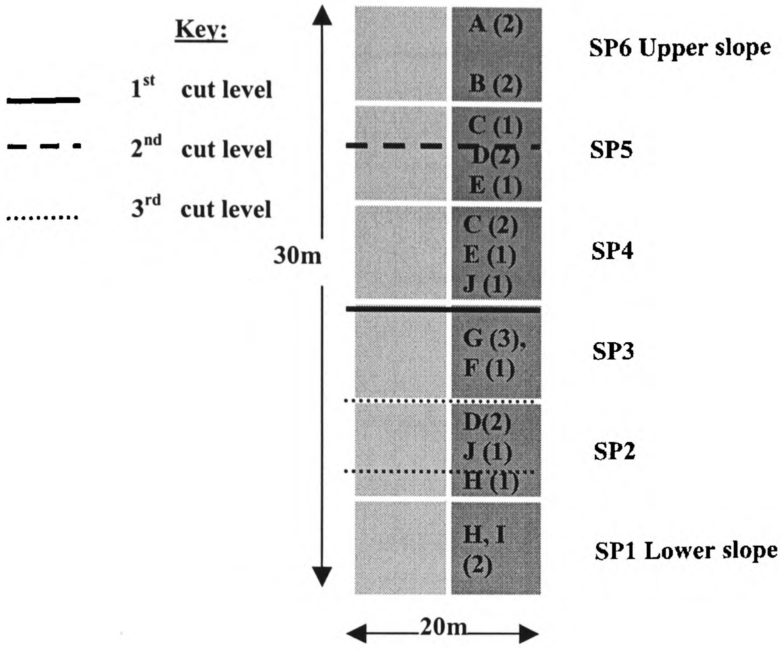


Figure 8.18: The distribution of floristic groups on New Fancy B as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot.

Groups F and G tend to be distributed in Subplot 3, and groups H and I in subplot 1. Group J is separated at the 2nd division due to the presence of *Hypnum mammilatum*, a moss which was found in two quadrats on birch tree trunks. TWINSPAN has grouped these two quadrats together, but they occur on different parts of the slope.

8.1.9 Cannop B

Figures 8.19, 8.20, and Table 8.7 show the results of the Cannop B TWINSPAN analyses. The first division of the dendrogram separates Groups A-I from Groups J-L. The quadrats from Groups J-L were all taken from the upper slope

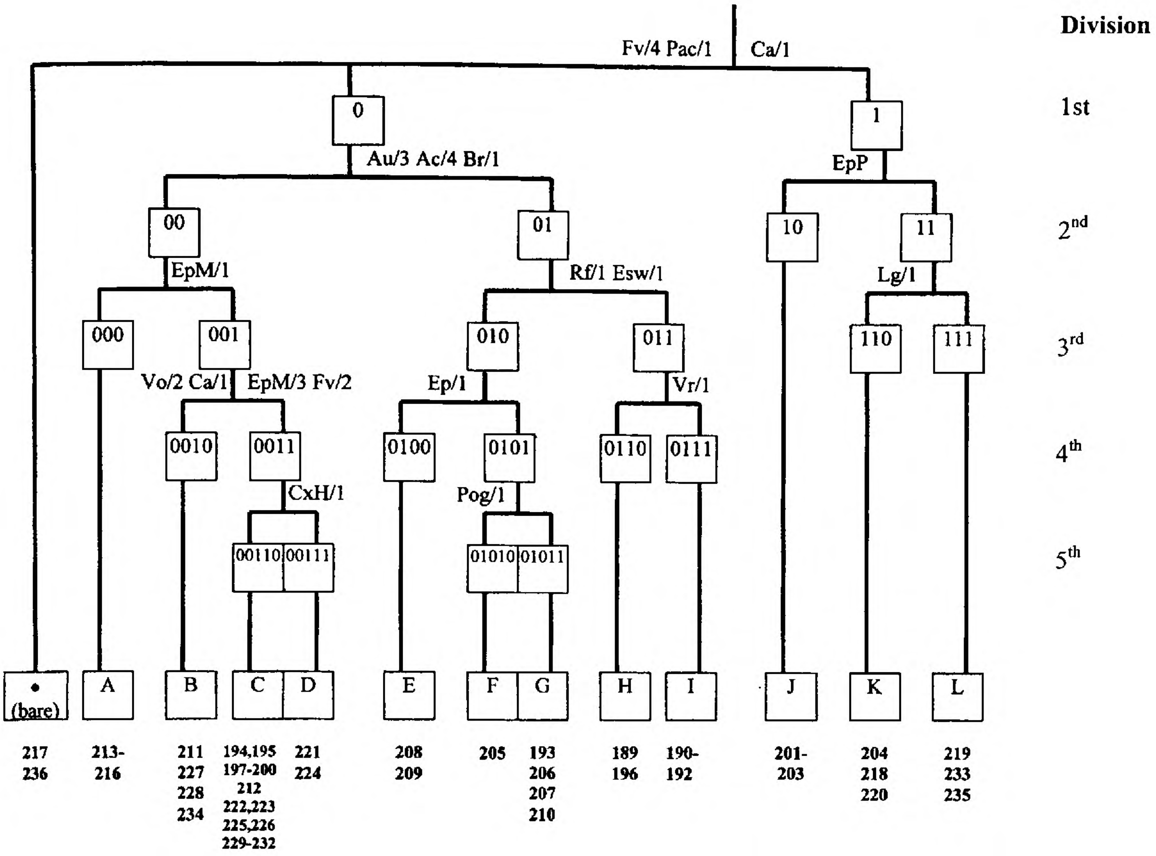


Figure 8.19: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on Cannop B

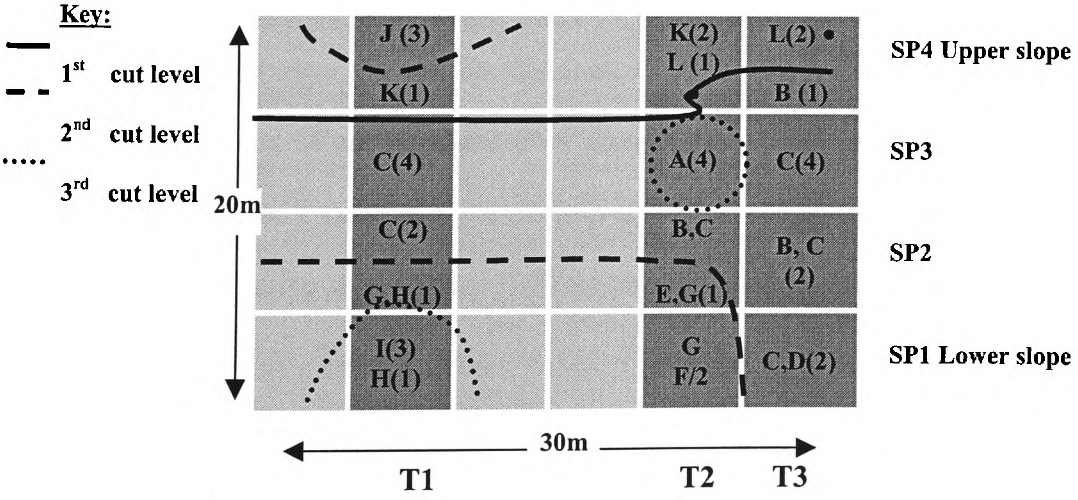


Figure 8.20: The distribution of floristic groups on Cannop B as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot.

slope (subplot 4), along with the two bare samples. The groups are characterised by the presence of *Cirsium arvense* (1), and were found on further investigation to be relatively species poor, containing a mean of 5.8 species.

Within the positive side (0), groups A-D tend to be distributed in a band across the middle of the plot. Group B samples contain a mean of 9 species. Groups E-I are more prevalent on the lower subplots of Transect 1 and 2, and are characterised by high abundances of mosses *Atrichum undulatum, Brachythecium rutabulum* and grass species *Agrostis capillaris*. These groups are more species rich, with samples from Group G containing a mean of 18.75 species.

8.1.10 Lightmoor

Figures 8.21, 8.22 and Table 8.8 show that the first division separates Groups L-N from Groups A-K. Groups L-N contain high abundances of mosses *Pseudoscleropodium purum* (3), *Rhytidiadelphus squarrosus* (1) and grass *Anthoxanthum odoratum* (1), and are distributed in Subplots 1 and 2 of Transects 1 and 2. Group N and M are separated from group L due to the presence of *Dactylis glomerata* (1). Group L samples occur exclusively in the second subplot of transect 2.

On the negative side, Groups H-K are characterised by the presence of herbs *Fragaria vesca* (1), *Prunella vulgaris* (3), *Potentilla reptans* (1), and mosses *Eurhynchium striatum* (1) and *Atrichum undulatum* (2), whereas groups A-G all contain *Dicranium scoparium* (1). Groups A-K are not straightforwardly distributed by location on the slope, with Groups A-G distributed in two bands – subplots 3-5 of Transect 2, and subplots 1-3 of Transect 3, and Groups H-K in the middle band.

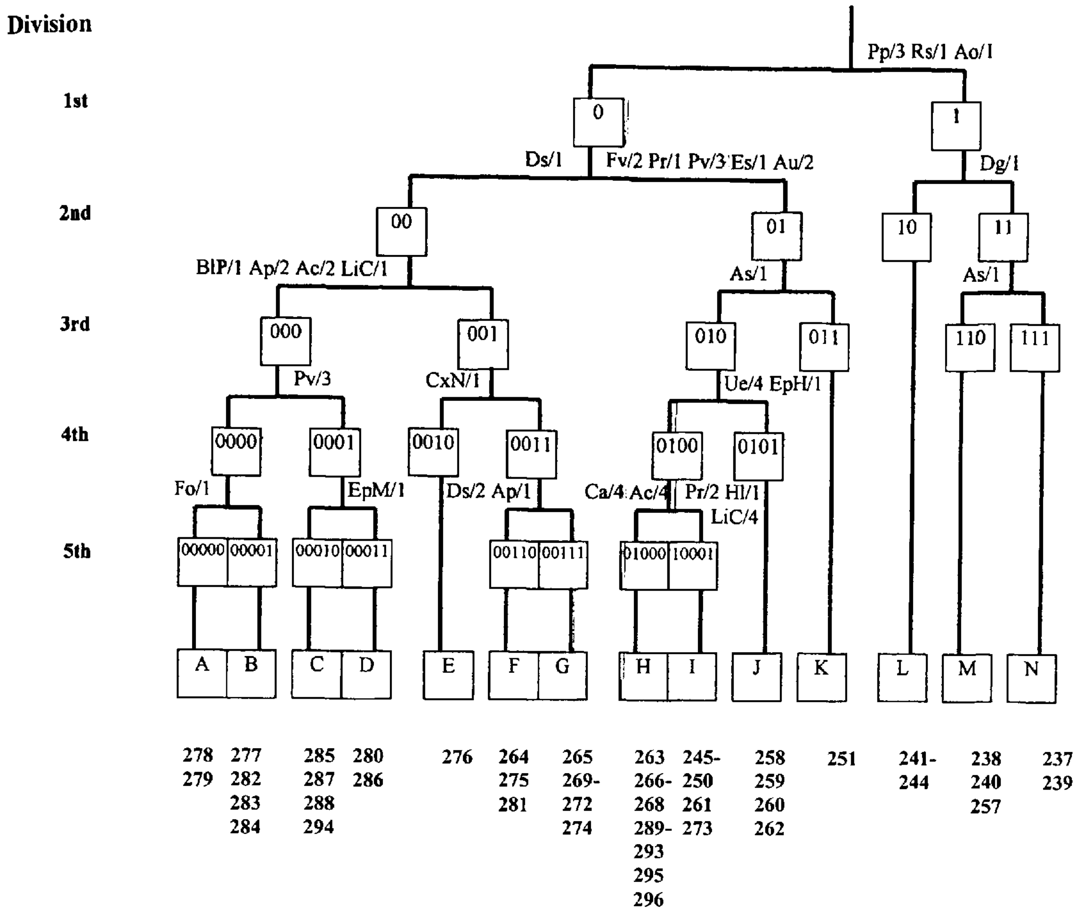


Figure 8.21: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on Lightmoor

At the third division, it can be seen that groups A-D, which all contain *Bellis perennis*, *Aira praecox*, *Agrostis capilaris* and *Linium catharticum* tend to occur on the lower slopes of Transect 3, whereas groups E-G tend to occur on the upper slopes of Transect 2. Groups H and I are only separated at the 5th cut level, with samples from H characterised by *Cirsium arvense* and *Agrostis capillaris*, and samples from I all containing *Potentilla reptans*, *Holcus lanatus*, and *Linium catharticum*. Samples from Group I are all located on subplots 3-5 of Transect 1.

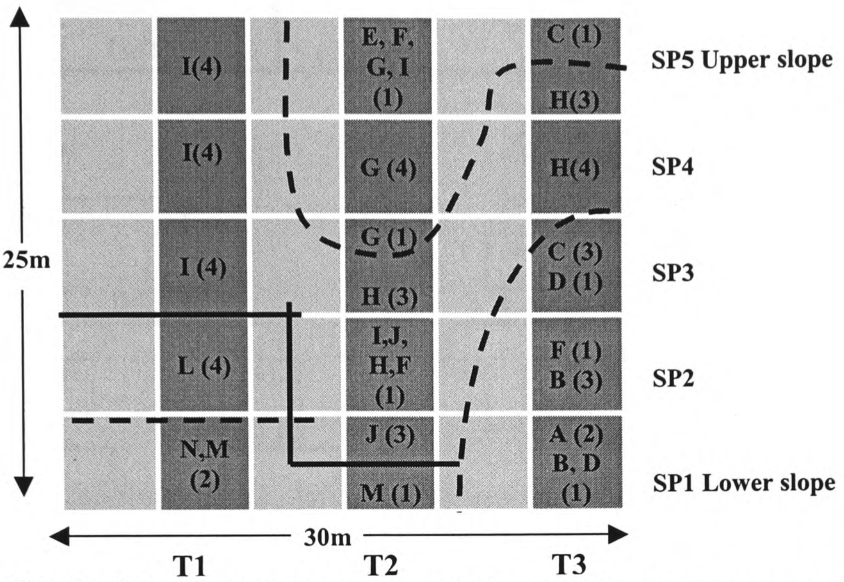


Figure 8.22: The distribution of floristic groups on Lightmoor as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot.

Table 8.8: Location of (real) quadrat numbers on Lightmoor by subplot and transect

	Transect 1	**Transect 2**	**Transect 3**
Subplot 5	253-256	273-276	293-296
Subplot 4	249-252	269-272	289-292
Subplot 3	245-248	265-268	285-288
Subplot 2	241-244	261-264	281-284
Subplot 1	237-240	257-260	277-280

8.1.11 True Blue

Figures 8.23, 8.24 and Table 8.9 show that the first division separates groups A-E from groups F-H. Whilst all quadrats contain high abundances of *Calluna vulgaris* (4), Groups A-E are characterised by high abundances of mosses *Dicranella heteromalla* (2), *Eurhynchium praelongum* (1) and *Eurhynchium striatum* (1), whilst groups F-H contain the lichen *Cladonia* (1), and grasses *Festuca rubra* (4), and *Poa*

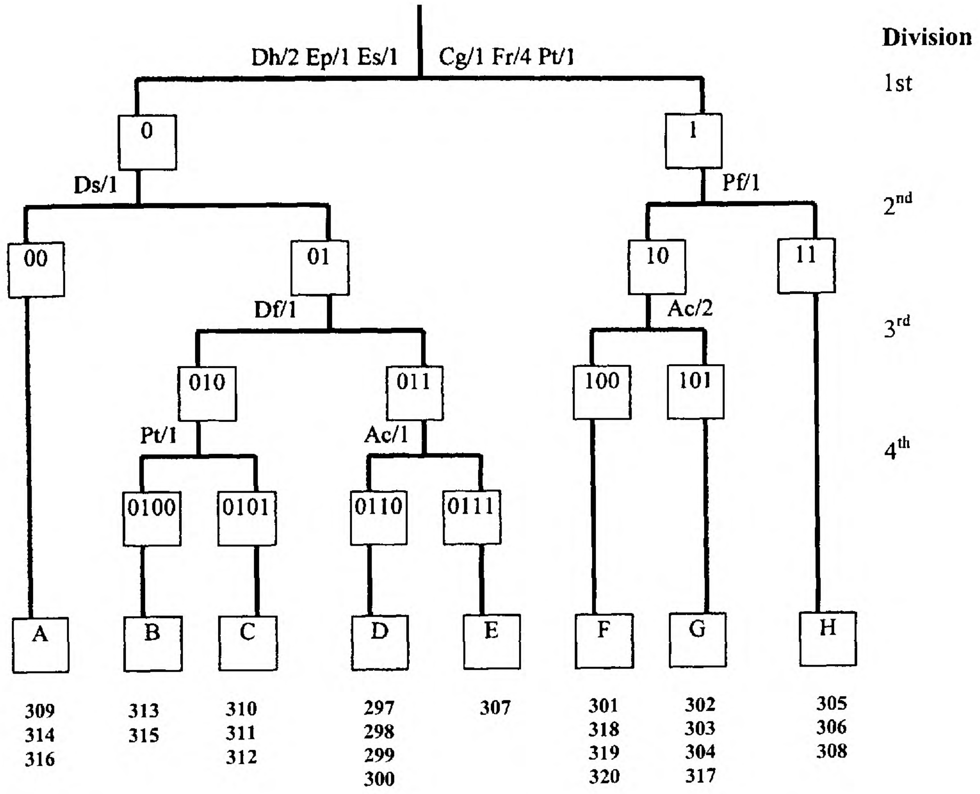


Figure 8.23: Dendrogram showing results of standard TWINSPAN analysis of data samples taken on True Blue

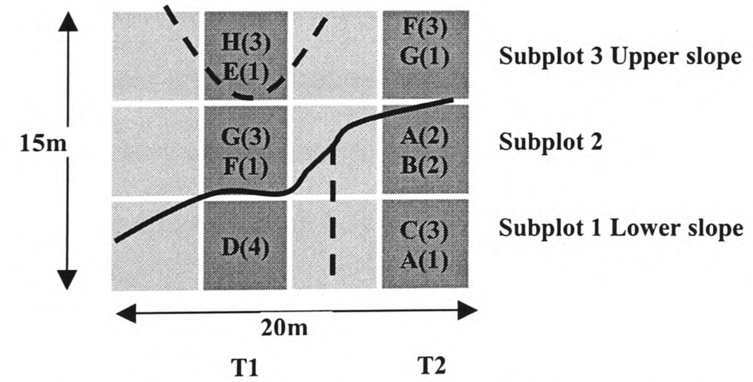


Figure 8.24: The distribution of floristic groups on True Blue as identified by a standard run of TWINSPAN. Brackets ( ) indicate the number of quadrats of each floristic group present within the subplot.

Table 8.9: Location of (real) quadrat numbers on True Blue by subplot and transect

	Transect 1	Transect 2
Subplot 3	305-308	317-320
Subplot 2	301-304	313-316
Subplot 1	297-300	309-312

trivialis (1). Groups A-D are all found in the lower subplots of both transects, with group E being the exception to the distribution of groups in the negative division, located in transect 1 subplot 3. Groups F-H are found in the upper two subplots.

At the second division on the positive side, groups F and G are separated from group H due to the presence of the monocarpous moss *Polytrichum formosum* (1) which occurs on this plot exclusively Group H. Groups H and the one outlying sample in group E all occur in the upper slope subplot 3 of transect 2.

8.2 Measurement of similarity

The data in Table 8.10 was used to calculate the Sørensen coefficient results shown in Table 8.11, and Table 8.12 to calculate the Czekanowski coefficient shown in Table 8.13. Both methods were used to analyse data because of the potential bias of results due to the species-area effect (Section 6.3.3).

Table 8.10: Half-matrix to show the number of species that each plot have in common, alongside total species per site

CPA	14						
NFA	36	17					
NFB	28	12	43				
CPB	35	22	37	34			
LM	38	20	53	45	48		
TB	14	06	23	17	23	21	
	NU	**CPA**	**NFA**	**NFB**	**CPB**	**LM**	**TB**
Total species	**52**	**26**	**71**	**59**	**66**	**75**	**32**

Table 8.11: Half-matrix to show the Sorenson coefficient of similarity between each pair of plots, expressed as (%). Figrues above 40% have been highlighted.

CPA	26					
NFA	37	17				
NFB	34	12	**43**			
CPB	37	22	37	34		
LM	37	20	**53**	**45**	**48**	
TB	25	6	23	17	23	21
	NU	CPA	NFA	NFB	CPB	LM

The Sorensen and Czekanowski methods have produced very different figures to express the floristic similarity between each pair of plots. The Sorenson figures are higher in all cases. For example, the mean percentage similarity between pairs is 15% for the Czekanowski results and 30% for the Sorensen. The ranking of plots based on % similarity of plots is the same for plots with high scores such as Lightmoor, New Fancy A, New Fancy B, and Cannop B, but plots with the lowest scores are slightly different. The Czekanowski method has identified True Blue and Northern United, and True Blue and Cannop A as the pairs with the lowest similarity, whereas the Sorensen method has identified True Blue and Cannop A, and Cannop A and New Fancy B.

Table 8.12: Half-matrix to show the sum of the lesser scores of species that each pair of plots have in common, alongside the sum of all species abundances for each plot.

CPA	2.23						
NFA	8.66	7.48					
NFB	4.82	8.00	37.07				
CPB	2.41	10.03	7.09	4.72			
LM	7.12	9.86	38.72	27.52	16.82		
TB	1.44	1.28	16.42	12.63	4.94	8.55	
	NU	**CPA**	**NFA**	**NFB**	**CPB**	**LM**	**TB**
Total Cover	**19.18**	**17.16**	**107.33**	**104.62**	**54.52**	**89.8**	**101.56**

Table 8.13: Half-matrix to show the Czekanowski coefficient of similarity between each pair of plots, expressed as (%). Figures above 20% have been highlighted.

CPA	12					
NFA	14	12				
NFB	08	13	**35**			
CPB	07	**29**	09	06		
LM	13	18	**39**	**28**	**24**	
TB	02	02	16	12	08	09
	NU	CPA	NFA	NFB	CPB	LM

8.3 Ordination

This section shows the results of ordination on the data-sets using Detreded Correspondence Analysis. Sections 8.3.2-8.3.11 describe the results of the data-sets, whereas section 8.3.1 explains the data-sets and data-runs that were undertaken using DCA, and decisions made during DCA analysis

8.3.1 Methodology and data-display

Ordination of the data was undertaken via DCA analysis using the CANOCO 3.12 programme developed by Ter Braak, 1991. Graphs were constructed using Canodraw 3.0.

8.3.1.1 Overview of the data-runs

As the DCA analysis was undertaken as a complementary technique to TWINSPAN, the same data-sets were used as described in Table 8.1. Table 8.14

summarises the data-runs that were undertaken on each data-set. As with TWINSPAN, a data run was undertaken on all data-sets using standard DCA settings to provide data comparable across all plots.

Table 8.14: Summary of DCA analyses undertaken on Forest of Dean data-sets

RUN	Standard	Outliers removed		Dominant	Dominant/ Outliers removed
		Species	Samples		
All sites	✓	Errors, 132, 7	34	✓	✗
Northern United	✓	131	65	✓	✓
Cannop A&B	✓	✗	✗	✗	✗
Cannop A	✓	✗	✗	✗	✗
Cannop B	✓	✗	✗	✗	✗
New Fancy A&B	✓	✗	✗	✗	✗
New Fancy A	✓	✗	✗	✗	✗
New FancyB	✓	✗	✗	✗	✗
Lightmoor	✓	65	251	✓	✗
True Blue	✓	✗	✗	✗	✗

A further data run had to be undertaken on some data-sets with species or samples removed. Table 8.15 provides a list of the species that were removed, corresponding to the numbers in Table 8.14.

Table 8.15: Species numbers removed during DCA analysis and corresponding name

Number	Species
132	*Alnus cordata*
7	*Alnus glutinosa*
131	*Leontodon autumnalis*
65	*Bracythecium rutabulum*

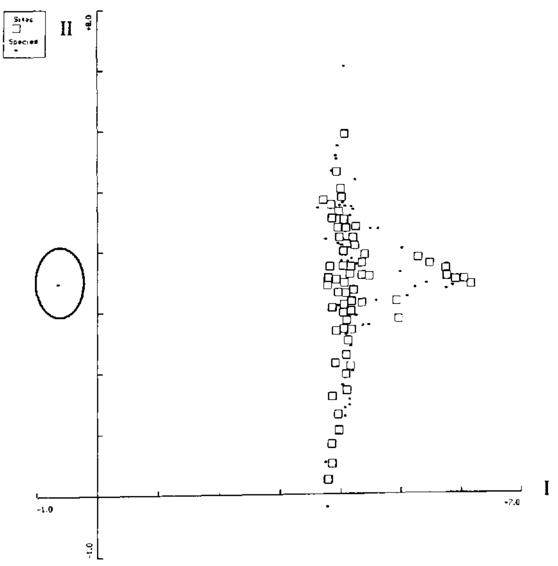
A run where all rarely occurring species were down-weighted was undertaken on the all-species data-set to emphasise the similarities between the sites, and examine the effects of this action on samples distribution. On Northern United axes were still constrained (Section 8.3.1.2) even when outlying species and samples were removed.

A run was therefore undertaken on this data-set where rare species were down-weighted and species that were still causing the axes to be constrained were removed.

Within the bi-plot diagrams, sample number and species name labels were only put in where it did not detract from the visual representation. Symbols are used to identify the samples by group to help identify any pattern within the data.

8.3.1.2 Outlying species

Outlying species or samples tend to have ordination scores that are very different to the scores of the other data, which constrain the scale of the resulting graphs, as illustrated by Figure 8.25. This shows a joint species and samples plot of



Data-entry errors constrain the rest of the data

Figure 8.25: DCA ordination of all sites, showing axes I vs II, with scale constrained on the x axis by outlying species

standard DCA analysis undertaken on the 'all-sites' data-set. It can be seen that axis I is constrained by a group of species that have much lower scores than the main cluster of the species. If there are not removed, it is difficult to see clusters that may be occurring within the rest of the data. Where axes were found to be constrained the outlying species or samples were therefore recorded and removed from the analysis.

8.3.1.3 Eigenvalues

Within ordination techniques such as DCA, the geometric calculations that are undertaken on species and samples data are 'collapsed', or plotted, on four or more axes, each of which has an eigenvalue (Table 8.16). According to Kent and Coker (1992), eigenvalues represent the relative contribution of each of the species components to the explanation of the total variation in the data. The higher the eigenvalue for each axis, the better that axis should be for displaying maximum variation within the data.

Table 8.16: Summary of eigenvalues for each axis of each data-set used to ordinate samples in the following sections. Standard runs shown unless indicated.

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
Northern United	0.852	0.650	0.572	0.392
Northern United (dominant run)	.378	.269	.183	.145
Cannop A & B	.733	.635	.261	.153
Cannop A	.923	.537	.211	.103
Cannop B	.521	.404	.123	.084
New Fancy A & B	.599	.349	.261	.203
New Fancy A	.850	.5.3	.350	.168
New Fancy B	.633	.224	.087	.028
Lightmoor	.573	.204	.177	.111
True Blue	.321	.087	.042	.021

Initial examinations of the data revealed that Axes I and II had the highest eigenvalues (Table 8.16). Of all of the different axis combinations Axes I and II did appear to display the data to its maximum variation. The components were more spread out across the axes, and more clusters revealed. Axes I and II were therefore used for all data-sets.

8.3.2 All sites

8.3.2.1 Standard Run

Figure 8.26 is the second DCA run with outlying species and samples omitted. There would appear to be at least two distinct gradients influencing the samples on

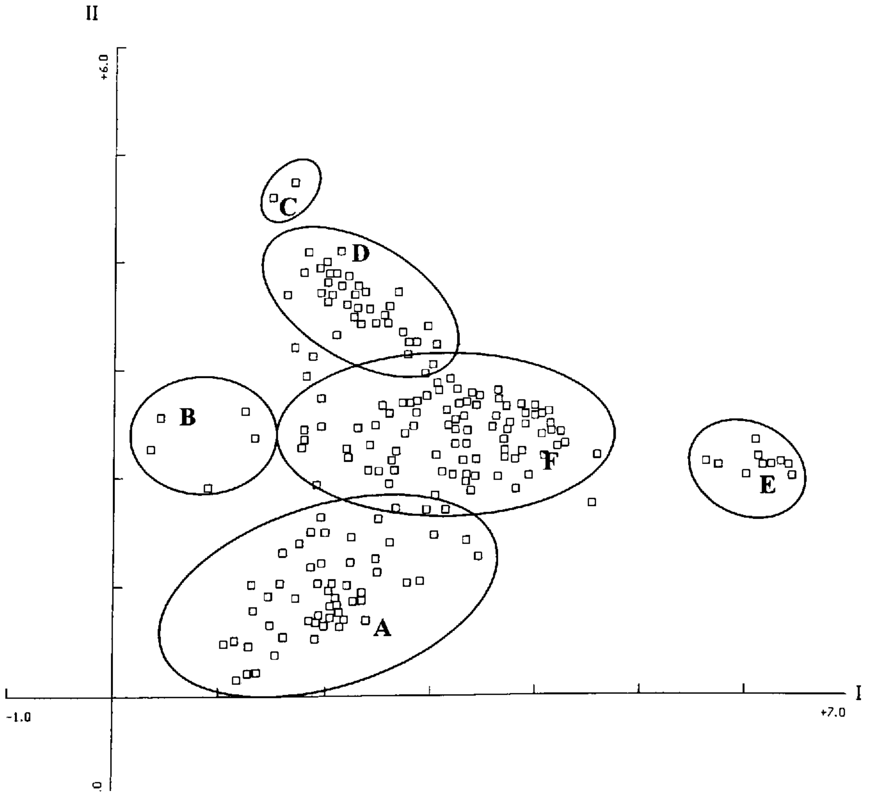


Figure 8.26: DCA run on all samples, with outlying species and samples removed and floristic groupings highlighted

this site, as data is spreading along both the x and y axes. Between 4-6 floristic groupings may be distinguished from the diagram, as highlighted. Groups C and E are clearly separated from the bulk of the samples. Groups A, B, D and F also centre on clusters of samples, but the groups intergrade with each other. Two sample points lie between the group F and group E clusters. They have been classified with group F as they lie closer to this group.

8.3.2.2 Rare-species down-weighted

Figure 8.27 shows the DCA run of all samples, where no species or samples were removed, but all rare species were down-weighted. More groupings can be distinguished than in Figure 8.26, despite the scale being the same.

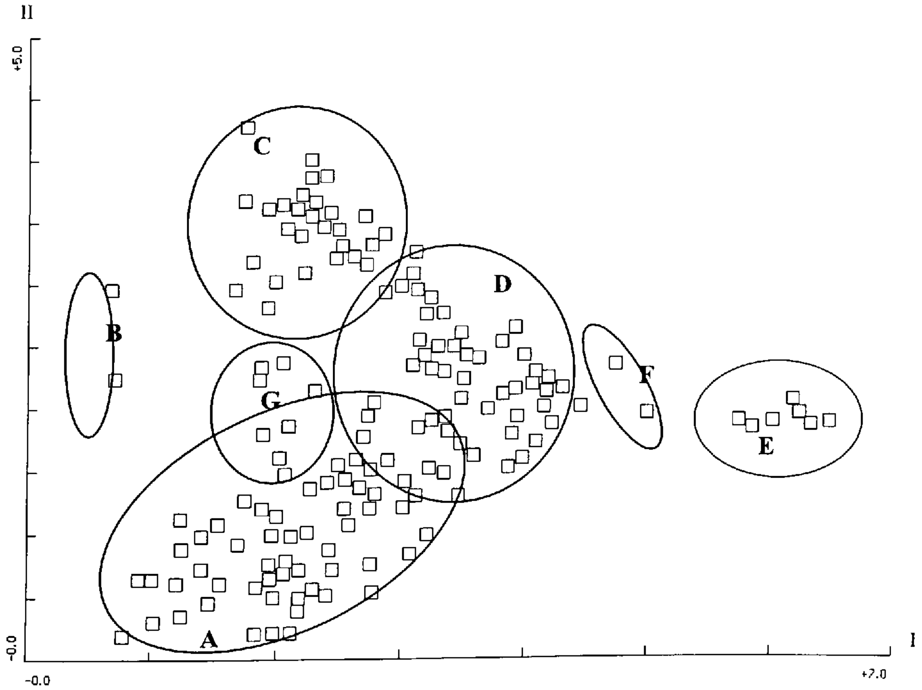


Figure 8.27. DCA ordination of all samples with rare species down-weighted, with floristic groupings highlighted.

Group E is still very separate from the other samples, but generally the samples are closer together, less clustered, and intergrade more. Two samples still remain half-way between the middle group D and group E, and here has been classified as a separate group F.

The outliers-removed ordination data-run (Figure 8.26) was used as the basis for diagrams 8.28- 8.33. It was considered to display the data-set better than Figure 8.27 because the data points were less densely clustered.

8.3.2.3 Samples identified by plot

It can be seen from Figure 8.28 that some of the groupings highlighted in Figure 8.26 describe floristic differences between plots. The samples from Northern

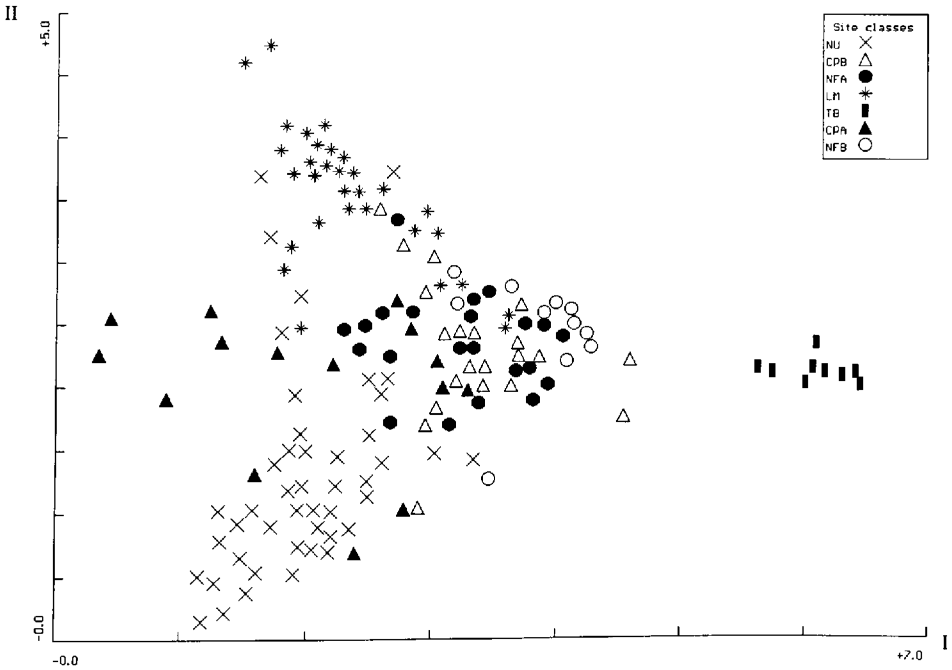


Figure 8.28: DCA ordination of all samples, with outlying samples and species omitted, showing samples identified by plot

United, Lightmoor and True Blue form a triangle on the diagram, with samples from the New Fancy and Cannop sites lying in between. The diagram indicates that True Blue, Lightmoor and Northern United are most floristically different to each other, and the New Fancy and Cannop sites most similar. All of the True Blue samples are located to the extreme right of the diagram, indicating a very different flora to the other plots. Northern United and Lightmoor samples also tend to spread away from the central samples cluster, but intergrade with samples from other sites much more than True Blue samples. Samples from Northern United are largely encompassed by Group A, identified in Figure 8.26, those of Lightmoor by Groups D and C, and those of True Blue by Group E.

As found in Section 8.1.5, samples from New Fancy B form a spatially close but very separate cluster to the right of the New Fancy A sites.

8.3.2.4 Samples identified by pH

Figure 8.29 shows the samples ordination in relation to acidity, where 4 pH classes were distinguished, pH 3-3.9, pH 4-4.9, pH 5-5.9, and pH 6+. The samples appear to be ordinated in a triangular pattern in relation to pH, with those of pH 4-4.9 lying to the bottom left, those of pH 5-5.9 to the top left, and those of pH 6+ lying to the centre of the triangle. The True Blue sites to the far right are again outliers to this pattern being the most acid plot, but lying closest to sites of lower acidity pH 6+.

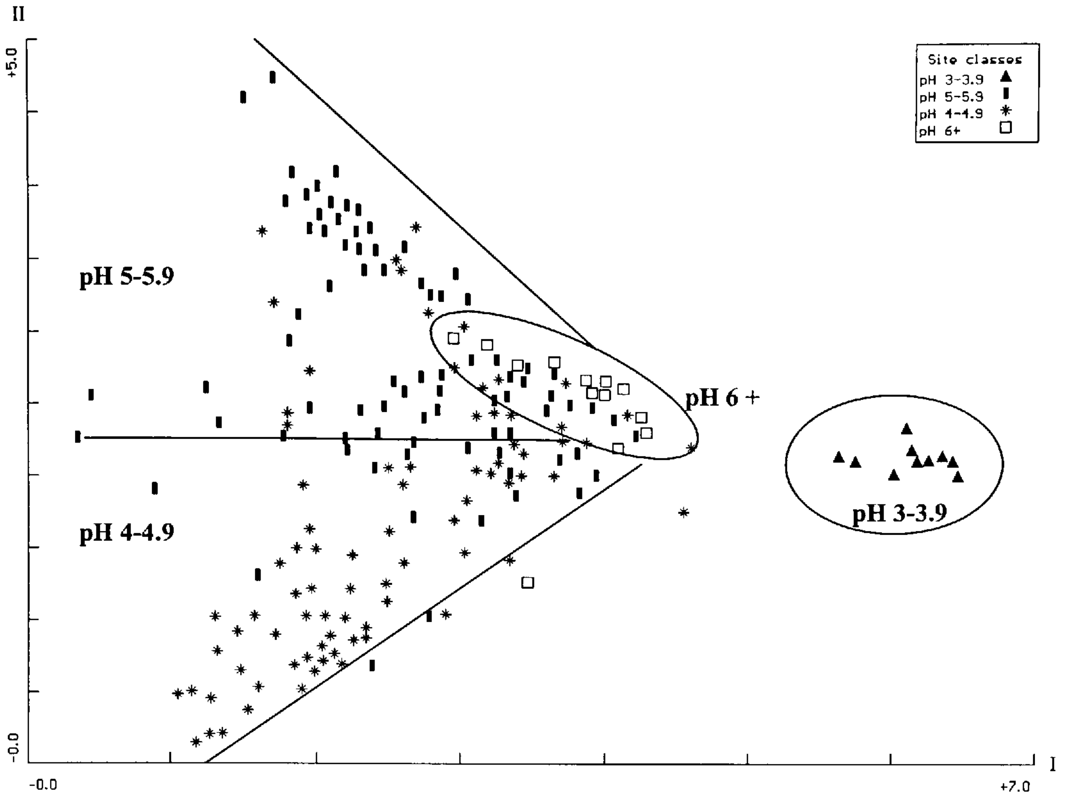


Figure 8.29: DCA ordination of all samples, with outlying samples and species omitted, showing samples identified by acidity classes

8.3.2.5 Samples identified by age

Figure 8.30 shows that the youngest samples tend to lie to the bottom left of the diagram, those of medium age between 30-40 in the middle of the diagram, and those of 60+ to the top left of the diagram. Again, the True Blue samples form the exception to this trend, being of age 100+ but lying to the far right of the diagram.

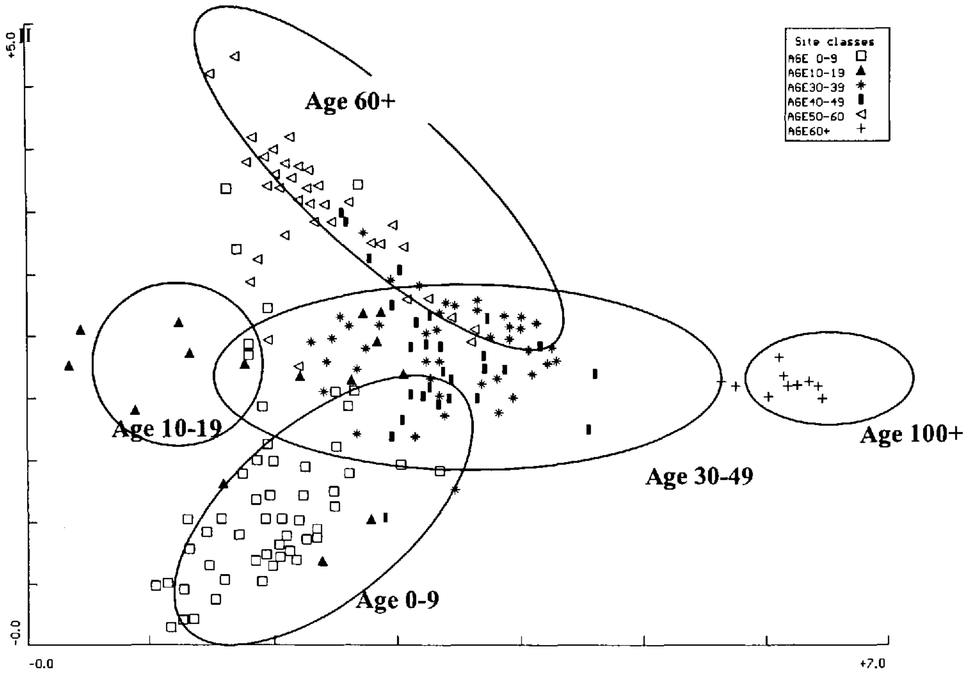


Figure 8.30: DCA ordination of all samples, with outlying samples and species omitted, showing samples identified by age

8.3.2.6 Samples identified by % canopy cover

Table 8.17 defines the canopy cover categories used to identify the samples. A trend can be seen in Figure 8.31 from left to right, with samples on the left hand side of the diagram having a low mean canopy cover of less than 25%, those on the right having a medium cover of 25-49%, and those to the upper right having a high canopy cover of 50% and over. The True Blue sites on the far right of the diagram form the exception to this rule however.

Table 8.17: Classes of % tree cover (woody species over 2m) used to identify samples in the DCA graphs

Class	% Cover
1	0-24
2	25-49
3	50-74
4	75+

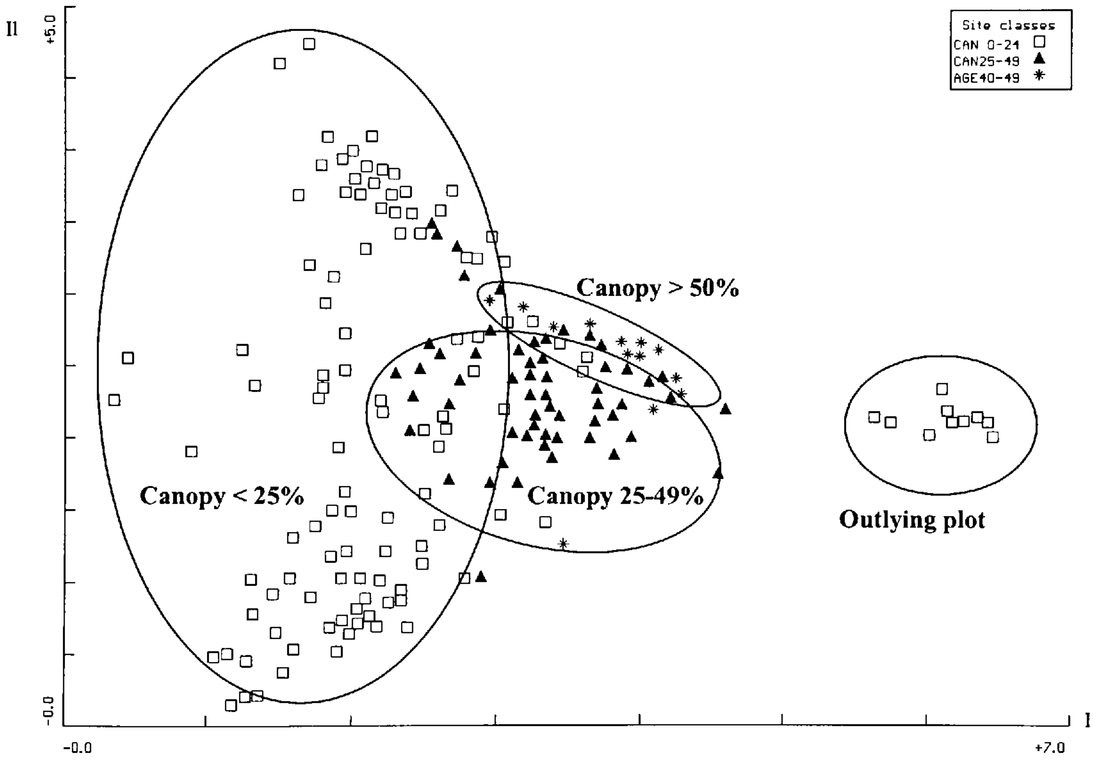


Figure 8.31: DCA ordination of all samples, with outlying samples and species omitted, showing samples identified by % canopy cover

8.3.2.7 Samples identified by TWINSPAN group

Figure 8.32 shows that the TWINSPAN classification technique (taken from Figure 8.5) has identified similar floristic groupings to the DCA ordination technique.

True Blue samples remaining totally separate from the rest of the samples, (classes A-F), Northern United sites mostly lying to the bottom of the diagram (Classes U-AA), Lightmoor samples mostly at the top of the diagram (class M), and the Cannop and New Fancy sites being less well separated in the centre of the diagram. The TWINSPAN classes which are at the extreme ends of the dendrogram, classes A-F and U-AA are also at extreme ends of the ordination.

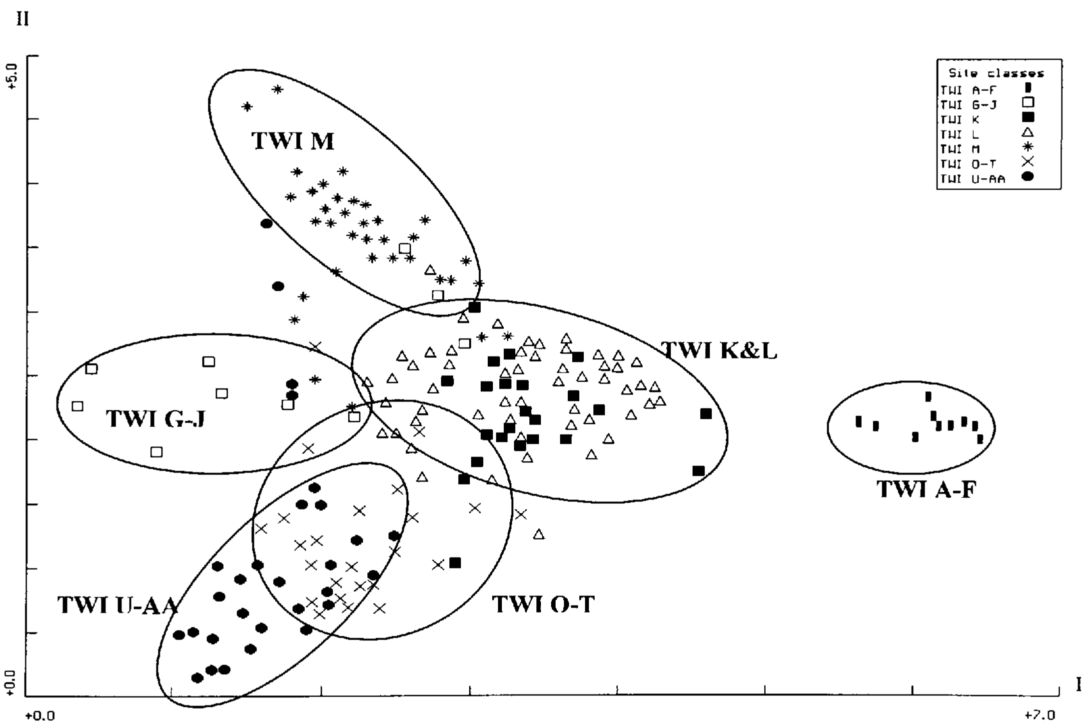


Figure 8.33: DCA ordination of all samples, with outlying samples and species omitted, showing samples identified by TWINSPAN groupings

8.3.3 Northern United

The standard run of DCA on Northern United data was constrained by sample 65 (also identified as an outlier in Sections 8.1.2 and 8.1.3). This outlier still constrained the data-set on a run with all rare species down-weighted, so was therefore removed from subsequent data-sets. The standard run was constrained by many species outliers even with sample 65 removed, so the rare species down-weighted, outliers-removed data-set was used to construct ordination plots in this section because the axes were less constrained (Table 8.16). However, this run produced the lowest eigenvalues for all axes, indicating that it did not describe the variance amongst the samples as well as the standard run.

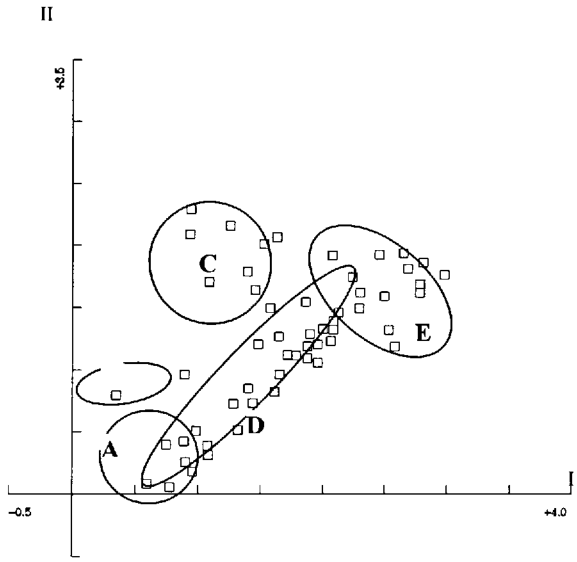


Figure 8.34: DCA samples ordination of Northern United data with rare species down-weighted and sample 131 and species 65 removed

In Figure 8.34, five main groups can be distinguished. Groups A, D and E are inter-graded with each other, and difficult to interpret, whilst groups C and B are separate from the main cluster of samples.

Figure 8.35 shows the samples identified by transect. The samples within transect 1 appear to be ordinated in a band from bottom left to top right of the diagram. Samples from transect 2 however are widely distributed across the diagram with some clustering towards the top right of the diagram. Samples from transect 3

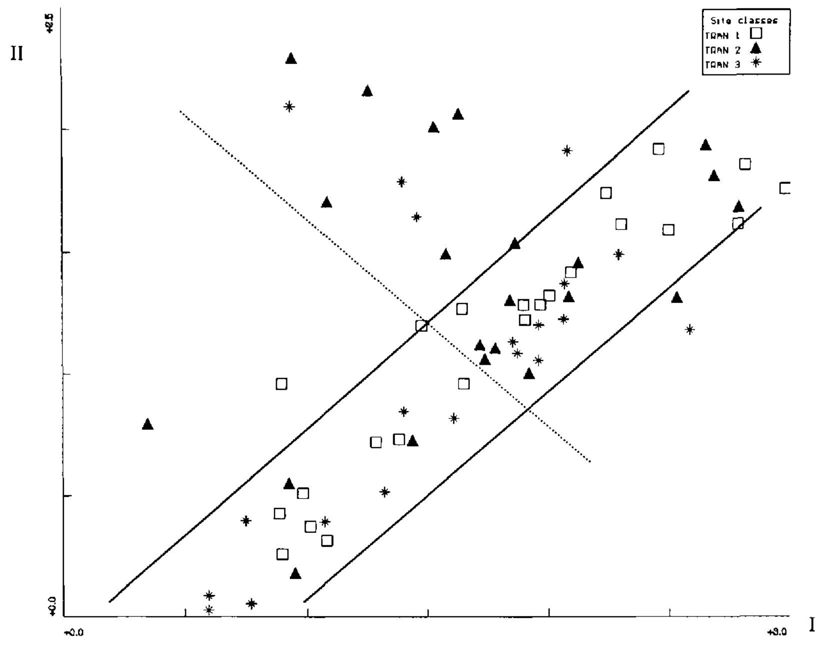


Figure 8.35: DCA run on Northern United with rare species down-weighted showing samples identified by location within transects

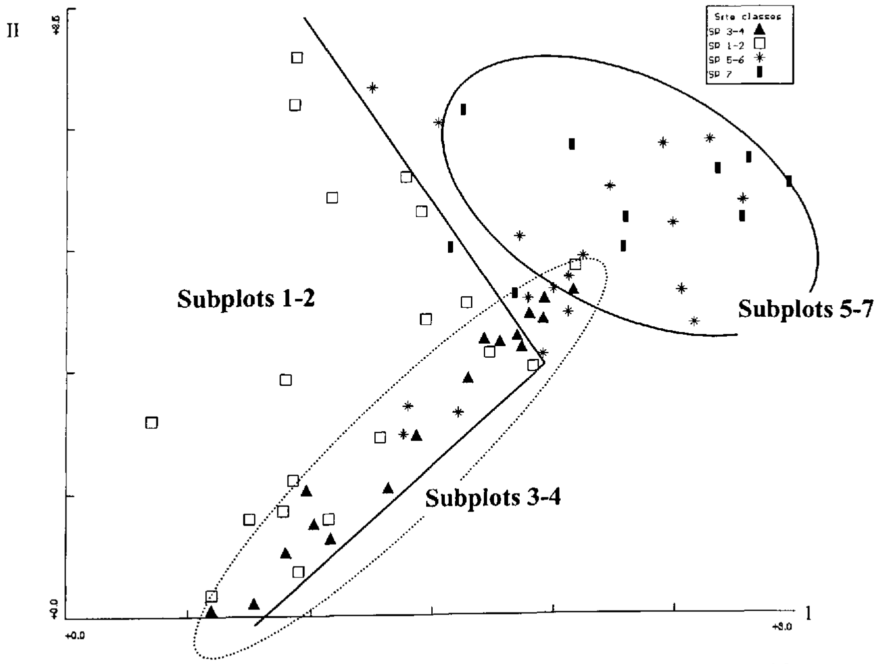


Figure 8.36: DCA ordination of samples taken from Northern United, samples identified by location on the slope

would appear to be distributed in a more triangular pattern between the other two groups. There is however considerable overlap between the samples, and the transect identifiers do not explain the samples variation examined in Figure 8.34. This would indicate that location by transect alone does not adequately describe the ordination results.

Figure 8.36 shows that samples from lower slope subplots 1 and 2 are all located to the left hand side of the graph, and samples from mid-slope subplots 3-4 are distributed in a band from bottom left to top right of the diagram. Subplots from upper slopes 5-7 are mainly distributed in the top right hand corner of the diagram. However, there is still considerable overlap between the samples of each group and no distinct transect/slope patterns, indicating that whilst both variables may be influencing the ordination results, further environmental variables may be affecting the vegetation on this site.

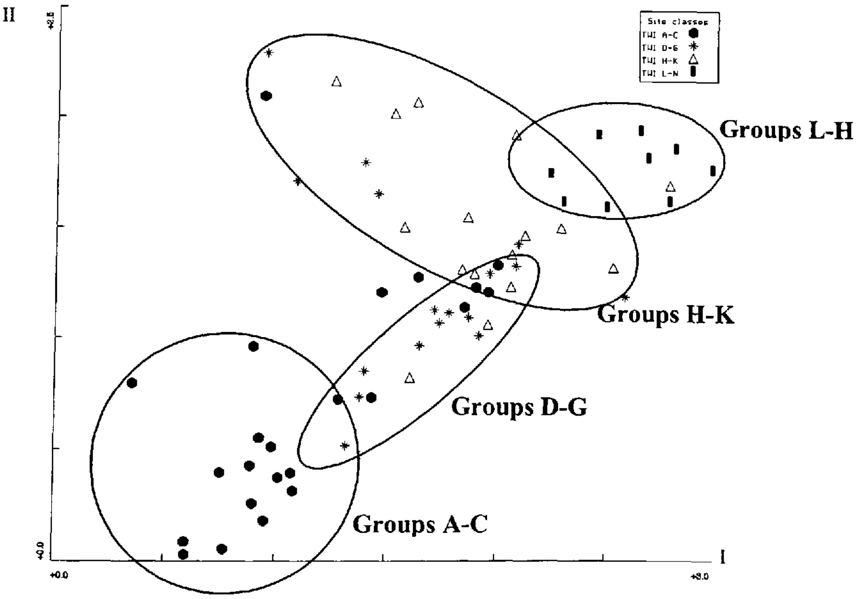


Figure 8.37: DCA ordination of samples taken from Northern United with rare species down-weighted, showing samples identified by TWINSPAN groupings.

Figure 8.37. shows that TWINSPAN groups A-C (Figure 8.8) form a distinct cluster in the bottom left of the diagram, and groups L-H a distinctive cluster in the top right of the diagram. Two further groups can be identified in the middle of the diagram, one group containing TWINSPAN groups D-G and one containing TWINSPAN groups H-K. However, there is a lot of overlap between the samples belonging to different TWINSPAN groups in these last two clusters. Of all the diagrams however, the TWINSPAN groupings appear to most closely reflect the initial clusters distinguished in Figure 8.34. The results are discussed further in section 9.6.2.

8.3.4 Cannop A & B

Figure 8.38a and b shows that five distinct clusters of samples can be distinguished. It can be seen from Figure 3.39 that the Cannop A samples are distributed in a clear curve, indicating that the sets of environmental variables represented by both axis I and axis II are influencing species composition. Cannop A samples correspond with groups A, B and C in Figure 3.38, and Cannop B samples with groups D and E. There is very little overlap between the clusters from the two different plots, indicating that they are floristically distinct from each other. The results are discussed further in Section 9.6.3.

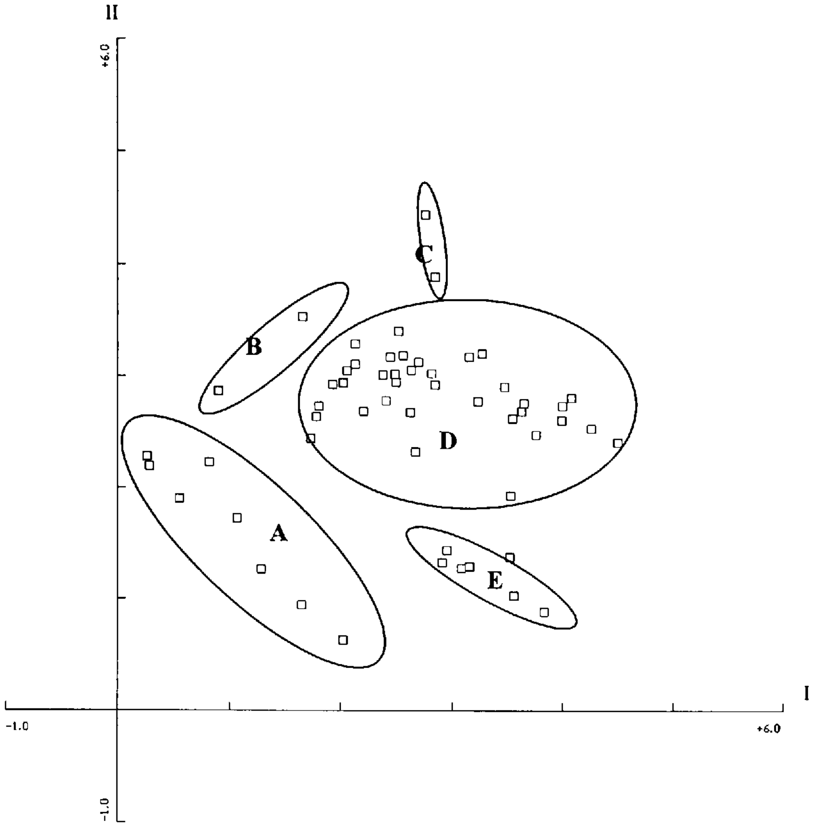


Figure 8.38: standard DCA ordination of samples taken from Cannop A and B with distinctive clusters highlighted

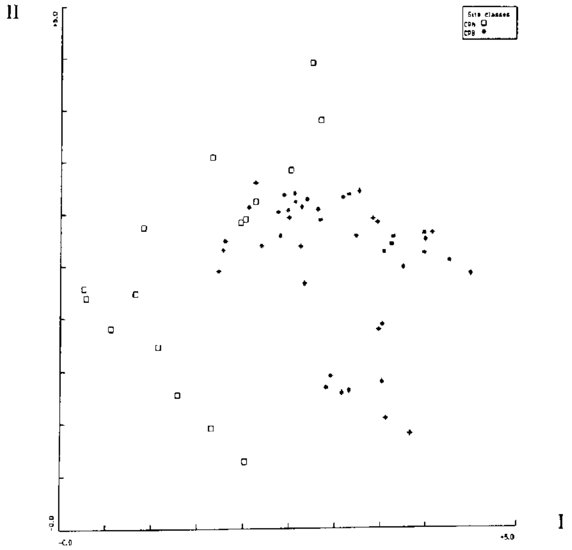


Figure 8.39: DCA ordination of samples taken from Cannop A (□)and Cannop B(*), showing samples identified by plot

8.3.5 Cannop A

As seen from Figure 8.40, the DCA analysis of the Cannop A plots has produced four distinctive groupings of samples. Figure 8.41 shows that the groupings from Figure 8.40 correspond well to location by transect. Samples to the left of the diagram (corresponding with Groups A and B) are all from transect 2, and those to the left (corresponding with Groups C and D) are from transect 1. Moreover, Figure 8.42 also shows a clear upper and lower slope division within each transect. Samples on the upper slope of Transect 2 form group A, those on the lower slope form Group B, those of the lower slope of Transect 1 form group D, and those of the upper slope correspond with group C.

Figure 8.43 shows that both the DCA and TWINSPAN analysis techniques have picked up the same floristic patterns on this site, as the TWINSPAN groups also explain the variation in the DCA diagram well. TWINSPAN groups A-C correspond with DCA groups C and D, TWINSPAN groups D-G with DCA group B, and TWINSPAN groups H-I with DCA group A. Only one sample, 112, is outlying from this pattern. The results are discussed further in Section 9.6.4.

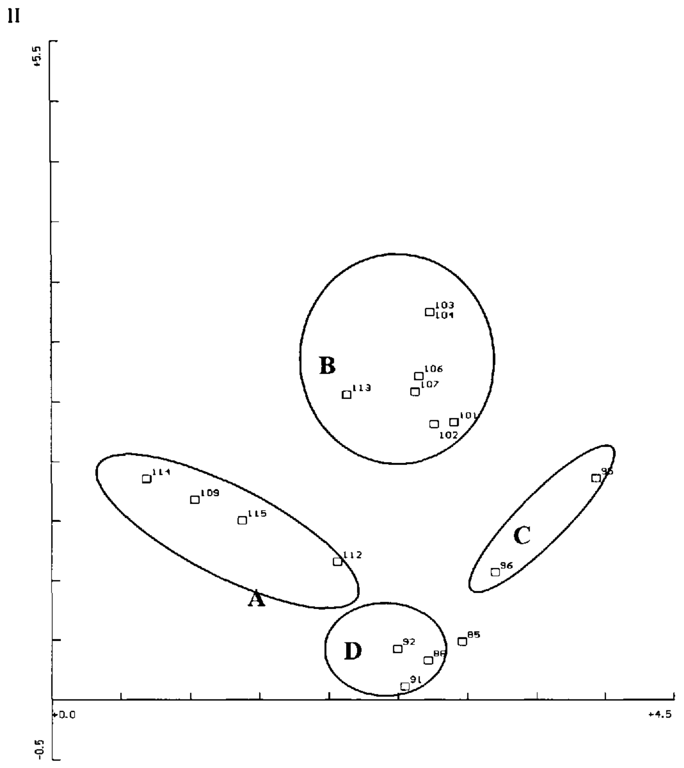


Figure 8.40: standard DCA ordination of Cannop A samples, with groupings of samples highlighted

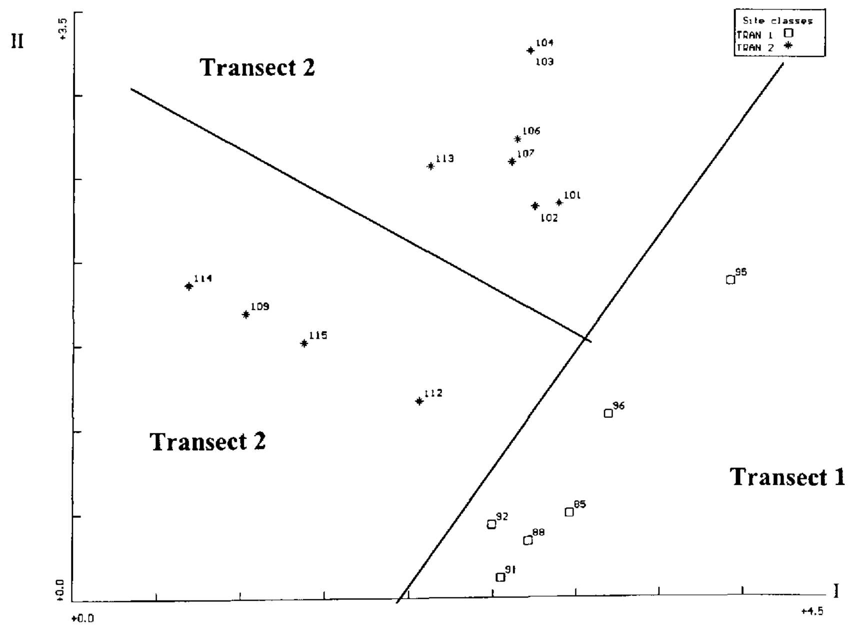


Figure 8.41: standard DCA ordination of Cannop A with samples identified by transect

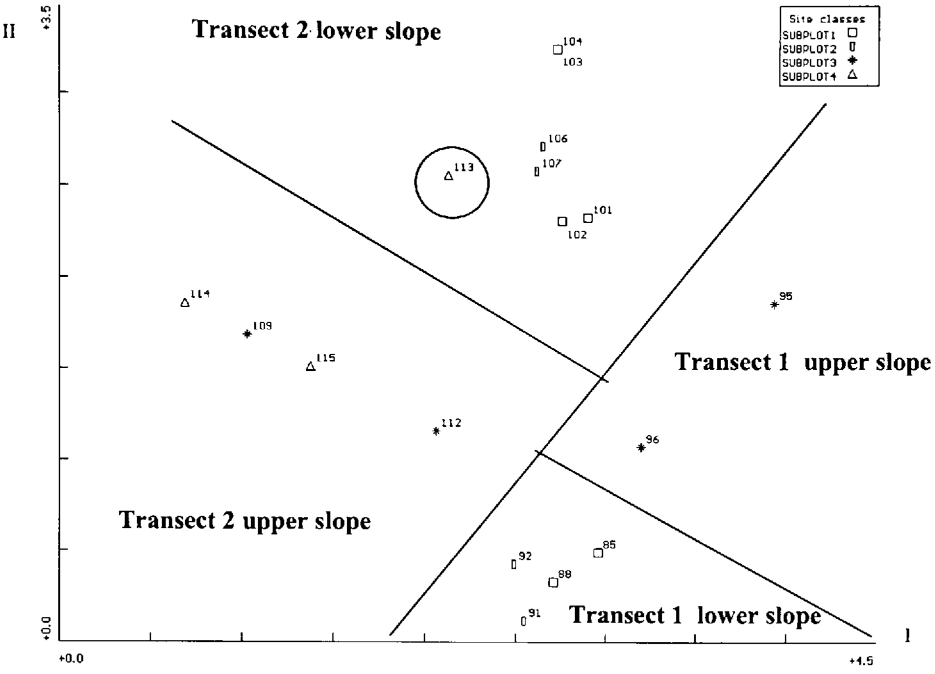


Figure 8.42: Standard DCA ordination of Cannop A with samples identified by slope position

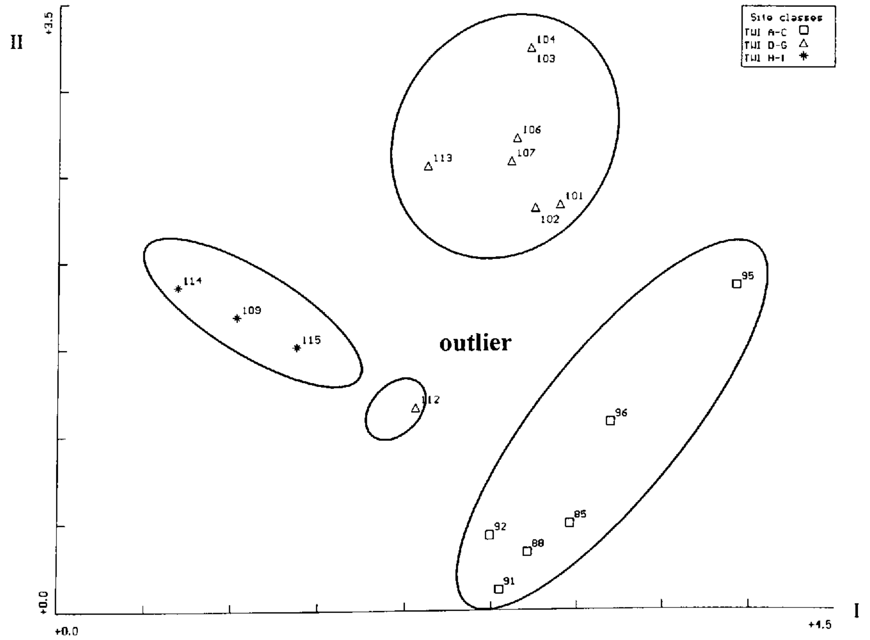


Figure 8.43: Standard DCA anlysis of Cannop A data with samples identified by primary and secondary TWINSPAN divisions

8.3.6 New Fancy A&B

Six clusters of samples can be distinguished in Figure 8.44. The New Fancy B samples tend to occur to the left of the diagram, corresponding with groups D and E, as shown in Figure 8.45. Samples from New Fancy A Transect 2 correspond well with groups A B and C, and samples from New Fancy A Transect 1 correspond with Groups E and F. The occurrence of both New Fancy A and New Fancy B samples within Group E would indicate that some of the samples are floristically very similar. However, there is very little overlap between the Samples within cluster E. Samples from New Fancy A occur to the left, and those from New Fancy B to the right. Figure 8.46 shows that slope also appears to have some impact on the ordination of the samples, and distinct bands of samples from different slope locations can be identified within the clusters.

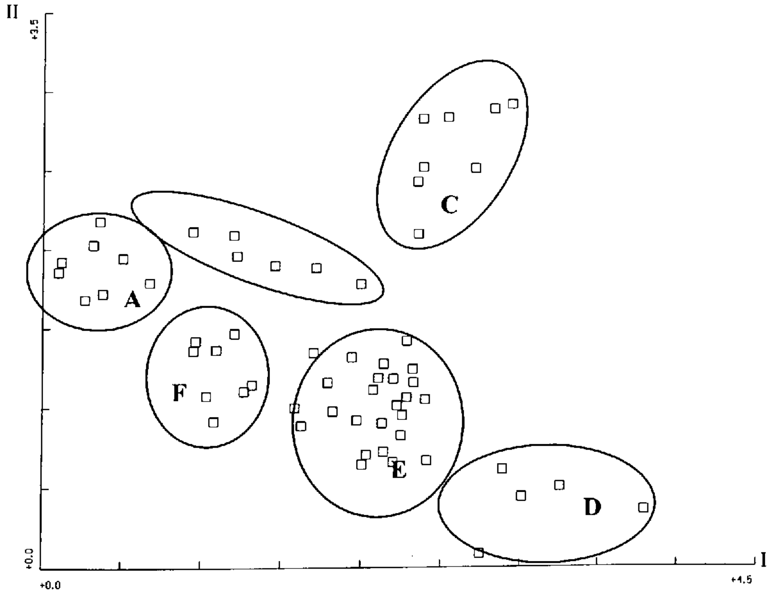


Figure 8.44: DCA ordination of samples from New Fancy A and B with clustering of samples highlighted

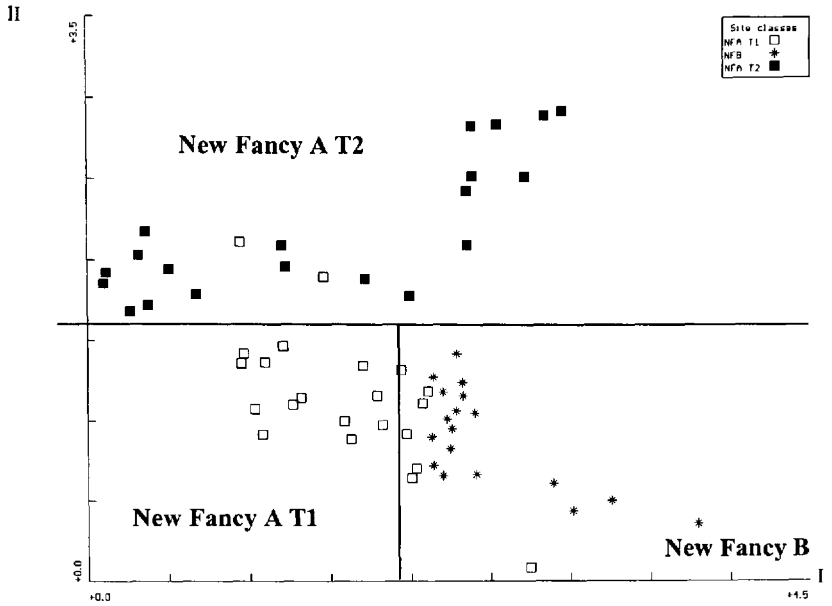


Figure 8.45: DCA ordination of samples from New Fancy A and B with samples identified by plot and by transect number (T)

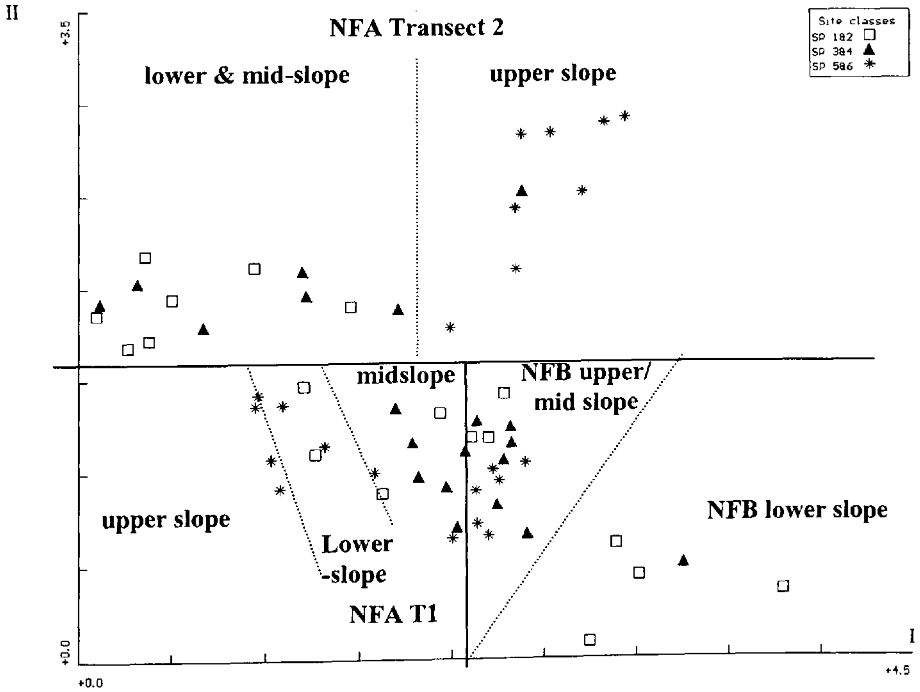


Figure 8.46: DCA ordination of New Fancy A & B with samples identified by location on the slope (Subplot 1&2 = lower slope, Subplots 5&6 = upper slope)

The % canopy cover of the samples is shown in Figure 8.47. New Fancy A Transect 1 quadrats are mainly low in shade cover, below 25%. Samples from Transect 2 have a wide ranging % canopy cover, although there is a distinct cluster of samples with high canopy cover of more than 75% to the right of the diagram corresponding with group A in Figure 8.44. The samples in New Fancy plot B tend to have a high % canopy cover of more than 50%.

The samples in Figure 8.48 are identified by TWINSPAN groupings separated at the third division (Figure 8.13). The TWINSPAN results appear to complement the ordination results for these sites, with New Fancy A transect 1 samples mostly corresponding to TWINSPAN groups A-G, New Fancy A transect 2 samples corresponding to TWINSPAN groups H-O, and New Fancy plot B sites corresponding to TWINSPAN groups P-T and U-X.

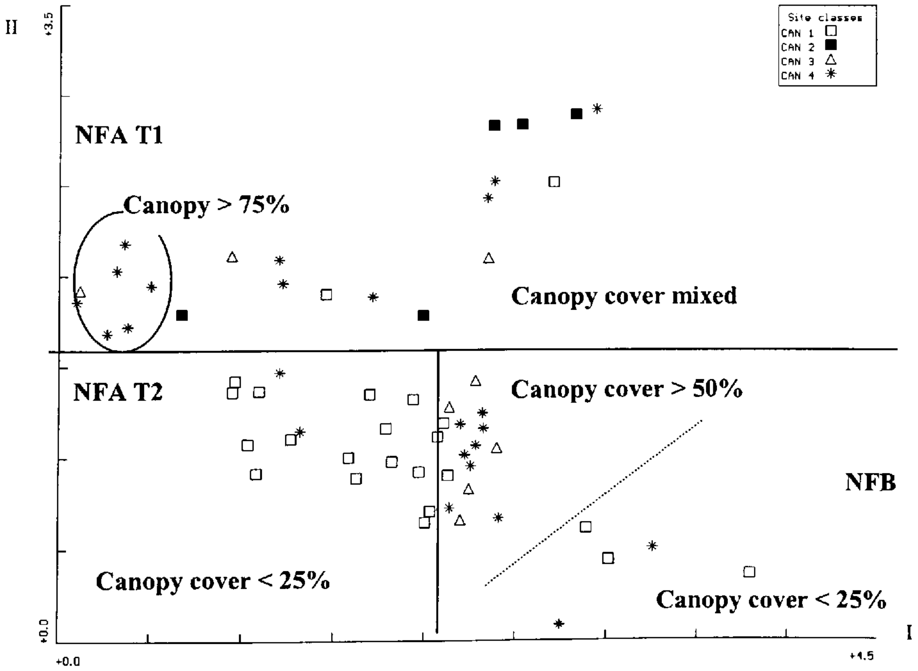


Figure 8.47: DCA ordination of New Fancy A & B with samples identified by % canopy cover

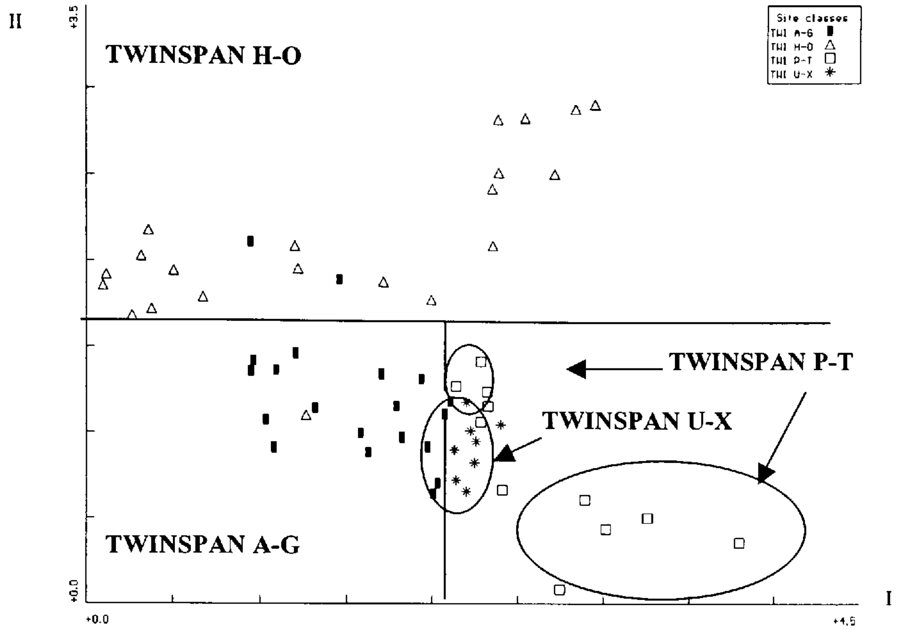


Figure 8.48: DCA ordination of New Fancy A & B with samples identified by TWINSPAN group.

8.3.7 New Fancy A

Examining floristic groups on New Fancy A in more detail, Figure 8.49 shows four distinct groupings. These groups correspond well with divisions identified in Figure 8.50a between samples from transects 1 and 2, showing a clear floristic divide between the two transects. This division corresponds with % canopy cover classes (Figure 8.50b), with most samples from Transect 2 having 25% or above canopy cover, and those from Transect 1 less that 25%.

Identifying samples by location on the slope (Figure 8.51) also distinguishes floristic differences between samples from lower slope subplots and those from mid-slope and upper-slope transects. This is particularly distinct within the Transect 2 data

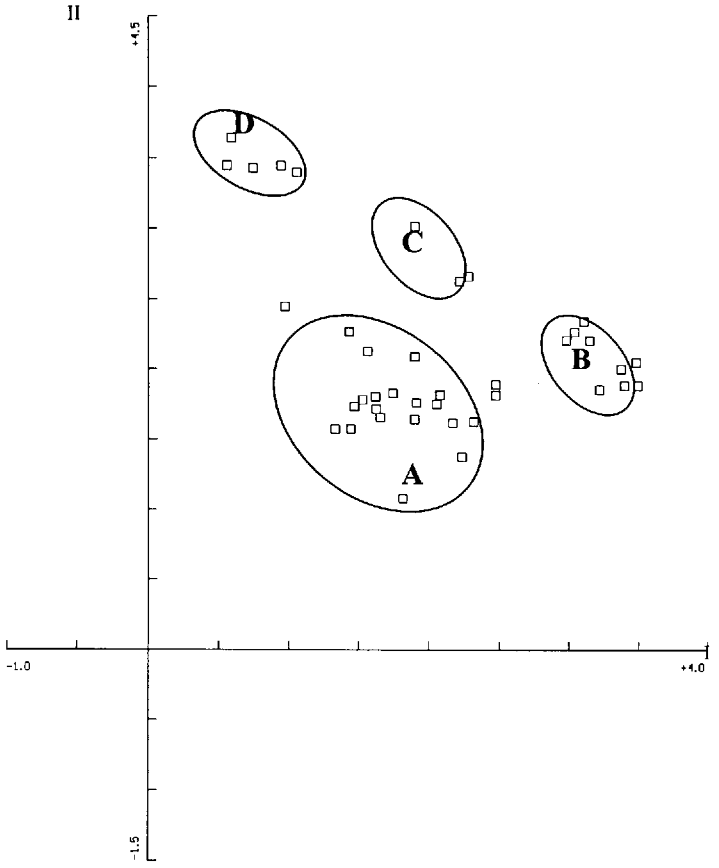


Figure 8.49: standard DCA ordination of New Fancy A samples, with groupings of samples highlighted

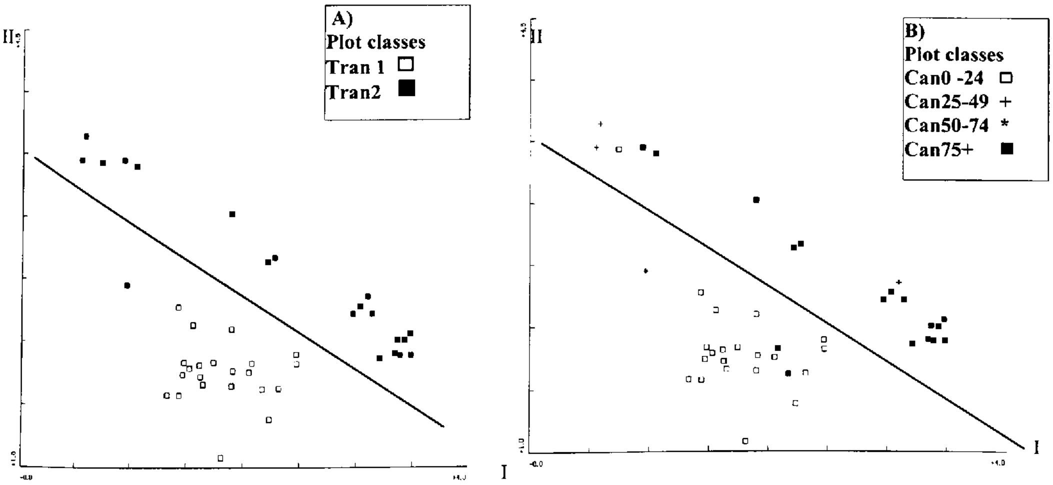


Figure 8.50: Graphs to show A) samples identified by transect and B) samples identified by % canopy cover class

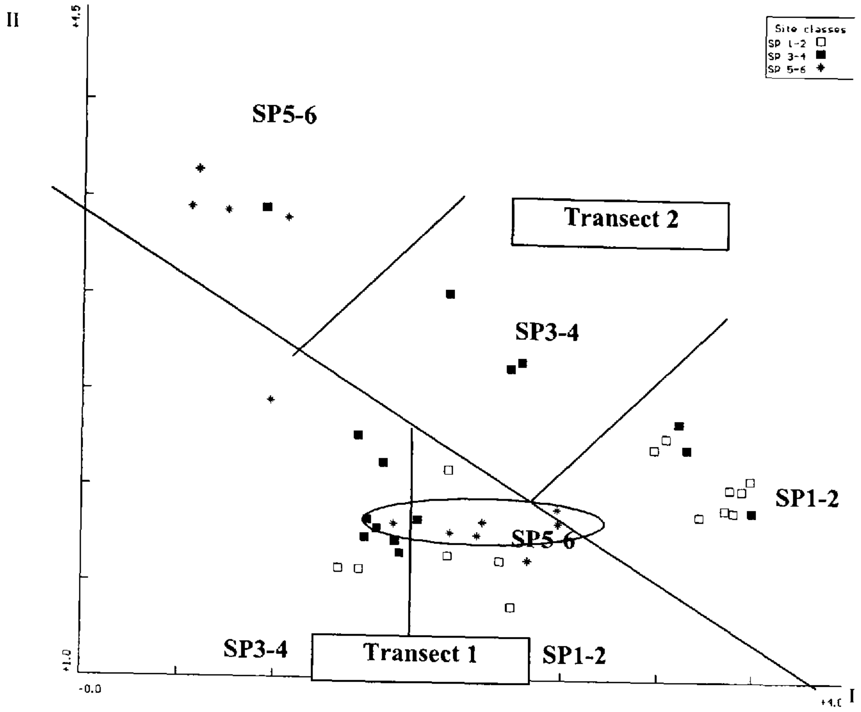


Figure 8.51: DCA ordination of New Fancy A with samples classified by location on the slope

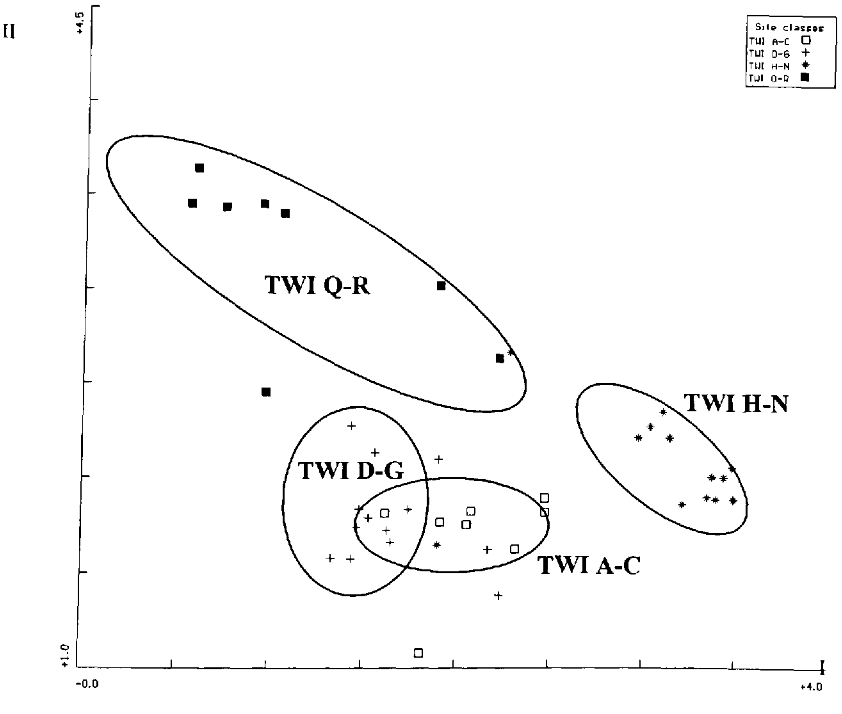


Figure 8.52: DCA ordination of New Fancy A with samples identified by TWINSPAN group

where samples from each of the three classes are clearly separated. Transect 1 data is less clear, with samples from the lower slopes tending to be ordinated towards the right of the diagram, those from the mid-slopes towards the left, and upper slope samples clustered in the middle.

Figure 8.52 shows that the TWINSPAN analysis (Figure 8.15) has also picked up on the main trends identified by ordination with transect 1 and transect 2 data clearly separated into different TWINSPAN groups and the main slope divisions also picked up. These results are discussed further in Section 9.6.6.

8.3.8 New Fancy B

Figure 8.53 shows the standard samples ordination for New Fancy B. Three floristic groupings have been highlighted, plus two outliers. Figure 8.54 shows that

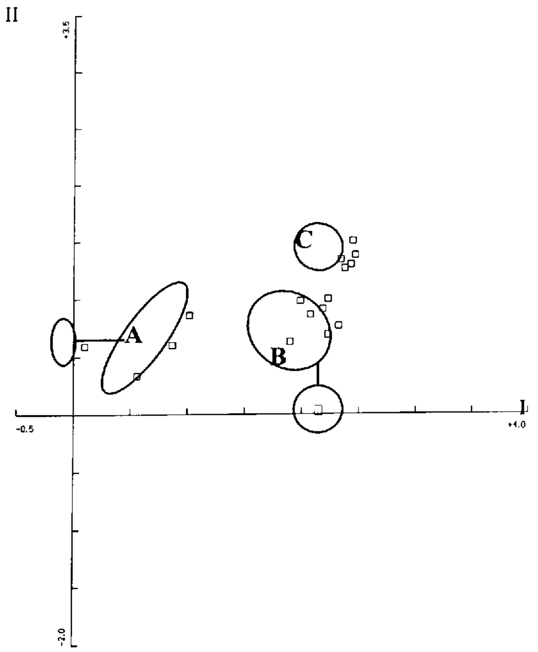


Figure 8.53: Standard samples ordination for New Fancy B with floristic groups highlighted

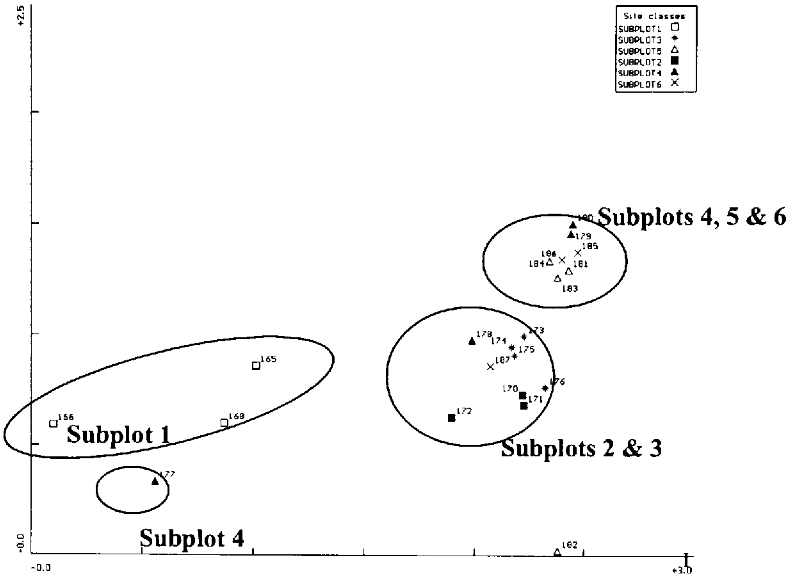


Figure 8.54: DCA ordination on New Fancy B with samples identified by location on the slope, where subplot 1 is lowest on the slope, and subplot 6 is highest.

Group A, plus the outlier from Group A both contain samples that occur within subplot 1, with one sample from subplot 4. Group B mainly contains samples that occur in the middle slopes subplots 2 and 3, except for the outlying Group B sample, which is from subplot 5. Group C mainly contains upper slope samples that occur within subplots 4,5, and 6. However, there is some overlap within this pattern.

The % canopy cover also explains some of the variation seen within Figure 8.53 (Figure 8.55). Samples with a low overlying canopy cover of less than 25% are distinct from those with a higher canopy cover of more than 50%.

Figure 8.56 shows the New Fancy B samples identified according to TWINSPAN groupings separated at the 2nd division (Figure 8.17). It can be seen that the TWINSPAN groupings do not reflect the ordinations clusters identified in Figures 8.54-55, particularly TWINSPAN groups F-J which are distributed in a band from left to right. These results are discussed further in Section 9.6.7.

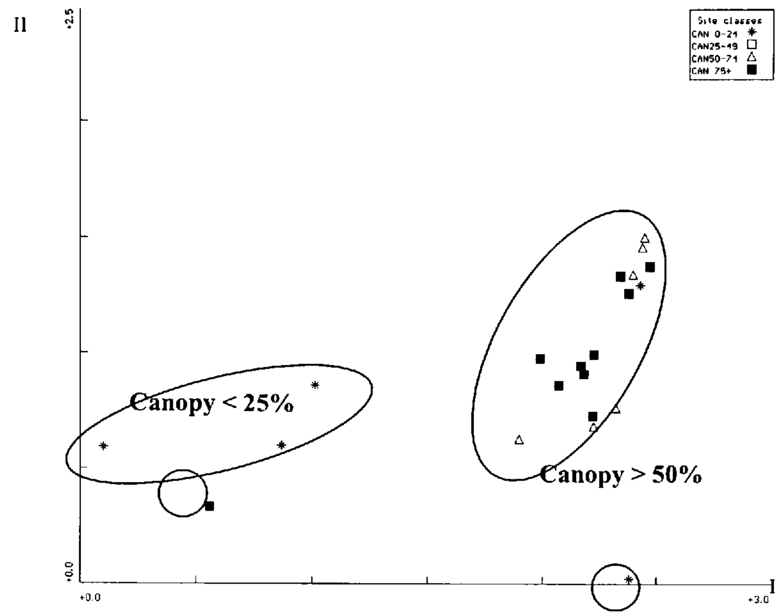


Figure 8.55: DCA ordination of samples from New Fancy B with samples identified by % canopy cover

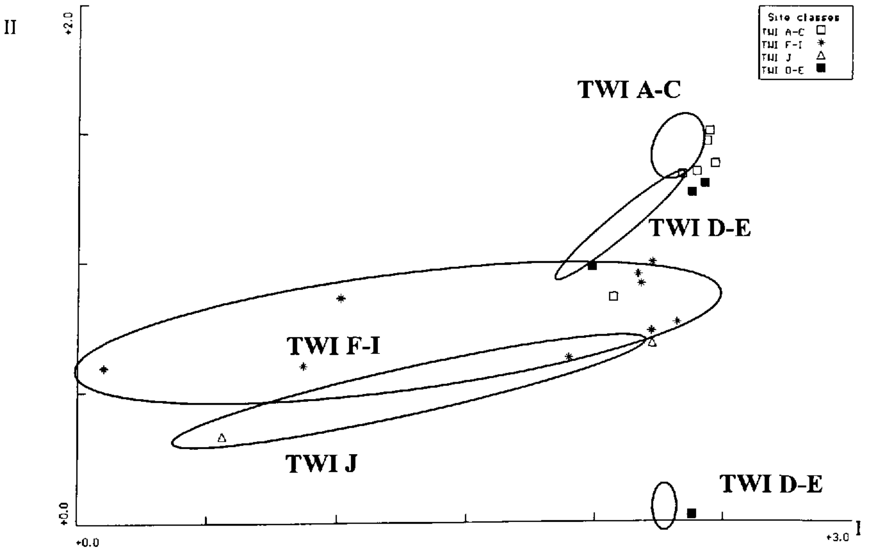


Figure 8.56: DCA ordination of samples from New Fancy B with samples identified by TWINSPAN groups at the 3rd division

8.3.9 Cannop B

Figure 8.57 shows the standard samples ordination for Cannop B. Four main groups were distinguished. Figure 8.58 shows that Groups B and C lie mainly within transect 1, and Group A is a combination of transects 1 and 2. Samples from transect 3 also form a distinct cluster within Group D. However, there is a lot of overlap between the samples, and this parameter did not completely describe the ordination patterns.

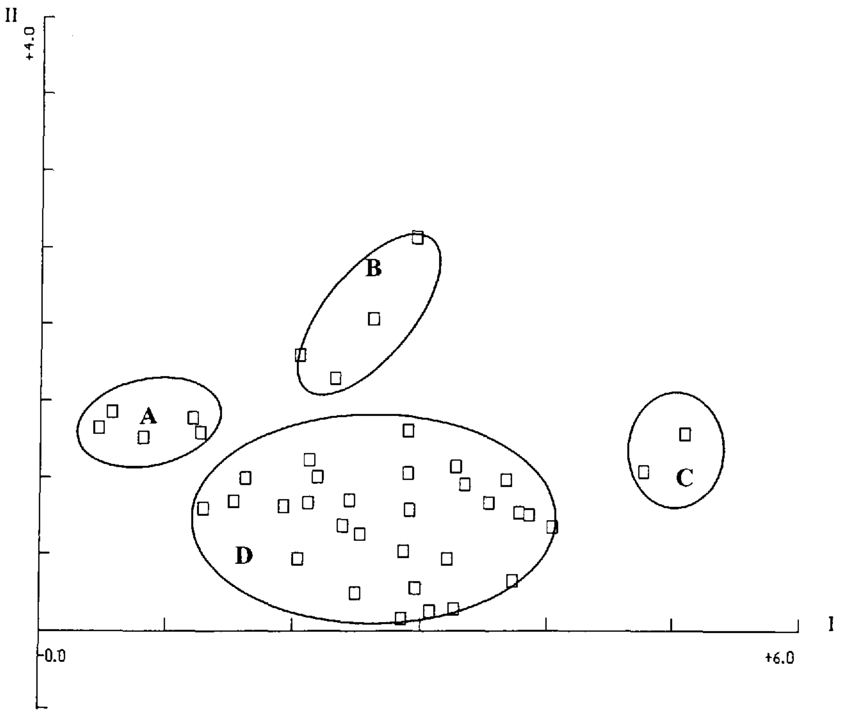


Figure 8.57: DCA ordination of Cannop B showing a) species ordination with labels, and b) samples ordination with groupings highlighted

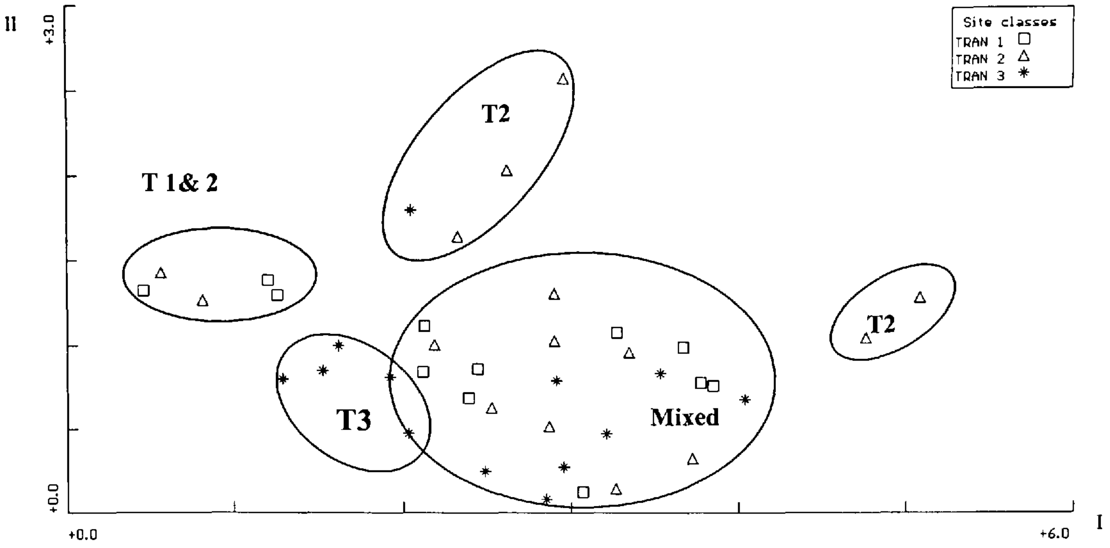


Figure 8.58: DCA ordination of Cannop B showing samples identified by transect

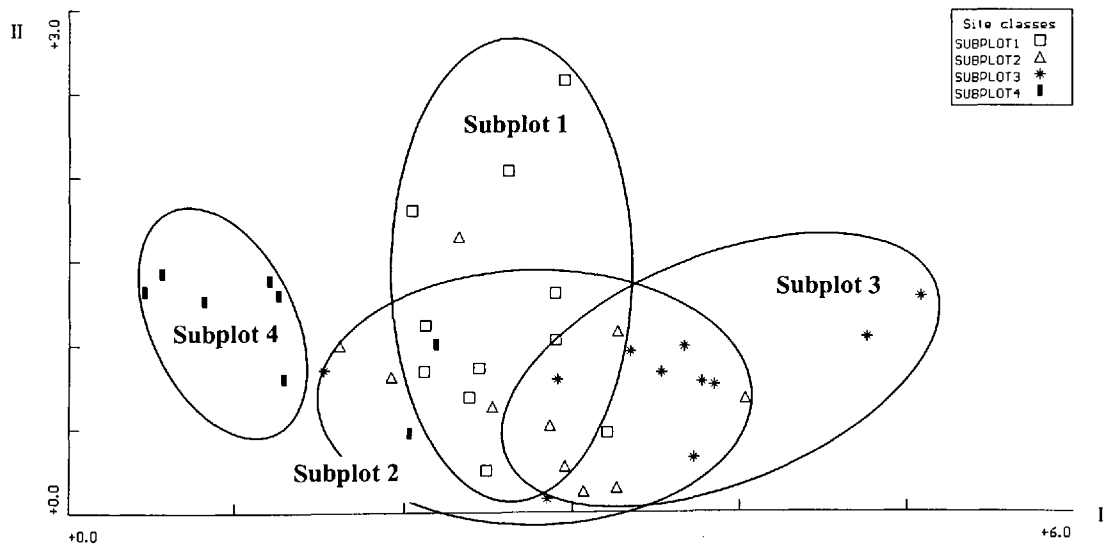


Figure 8.59: DCA ordination of Cannop B data showing samples identified by location on slope, where Subplot 1 = lower slope and subplot 4 = upper slope

Figure 8.59 shows that clearer patterns do emerge when the samples are identified by slope location. Group A samples all tend to occur in subplot 4, Group C in subplot 3, and Group B in subplot 1. However, no clear patterns emerge that describe the ordination of samples in the middle group D.

Figure 8.60 identifies similar patterns to those found in Figure 8.59. Samples with a low canopy cover are mainly located in a cluster to the left of the diagram, which corresponds with the upper slope cluster. Samples with a high canopy cover stretch in a band that broadly corresponds to Supblot 3, and samples of medium canopy cover are clustered in the middle of the diagram, corresponding with subplots1 and 2.

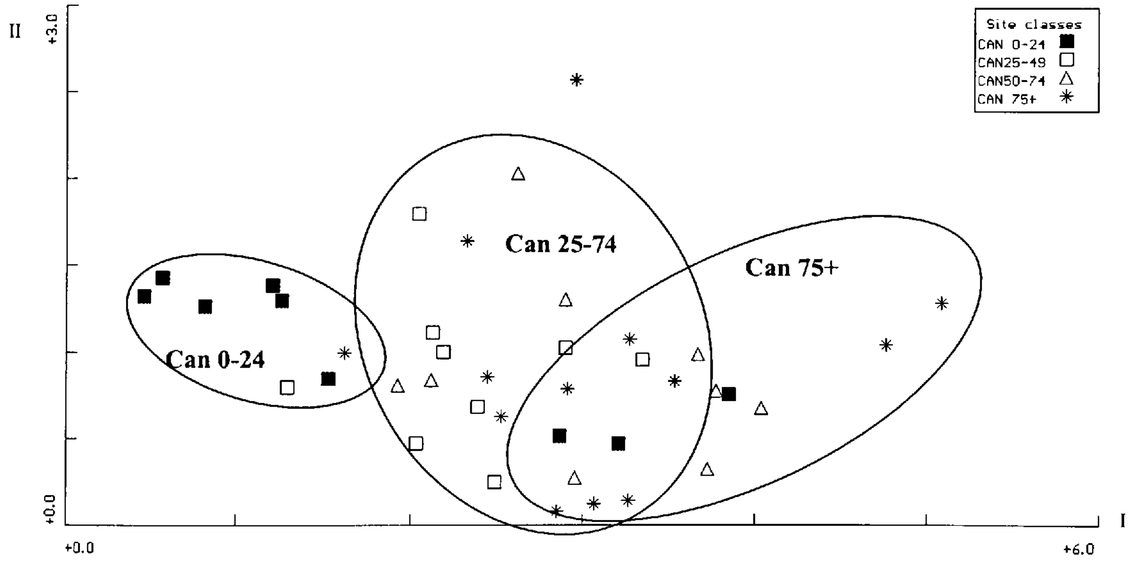


Figure 8.60: DCA ordination of Cannop B data showing samples identified by location on slope

Figure 8.61 identifies the samples by TWINSPAN groups separated at the 2nd division (Figure 8.19). The TWINSPAN analysis and the DCA analysis (Figure 8.57) identify similar patterns. TWINSPAN groups J-L correspond with DCA group A

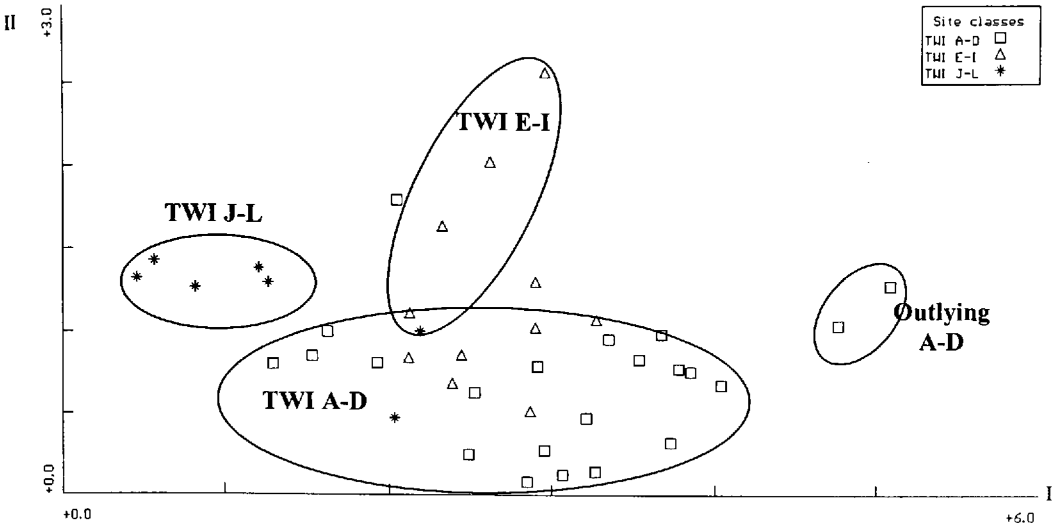


Figure 8.61: DCA ordination of samples taken from Cannop B, with samples identified according to TWINSPAN group separated at the 2nd division

and TWINSPAN groups E-I with DCA Group B. There is a mixture of TWINSPAN groups within the central cluster (DCA group D), but this predominantly consists of TWINSPAN groups A-D. However, the TWINSPAN analysis has not picked out DCA group C as being floristically different. These results are discussed further in Section 9.6.8.

8.3.10 Lightmoor

The scale of the standard Lightmoor ordination diagrams was constrained by sample 251 and by Species 65 *Brachythecium rutabulum* (Table 8.17). The outliers were therefore removed from the standard analysis (Table 8.16), and this data-run was used to form Figures 8.62-8.65. A data-run with rare species down-weighted was also undertaken but did not display the data well, as it was still constrained by outliers.

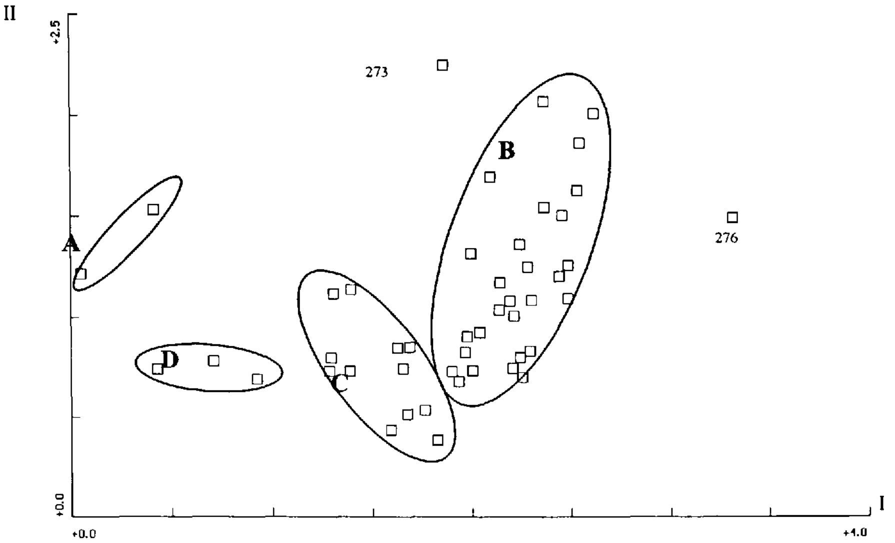


Figure 8.62: DCA samples ordination of Lightmoor with outliers removed and groupings highlighted

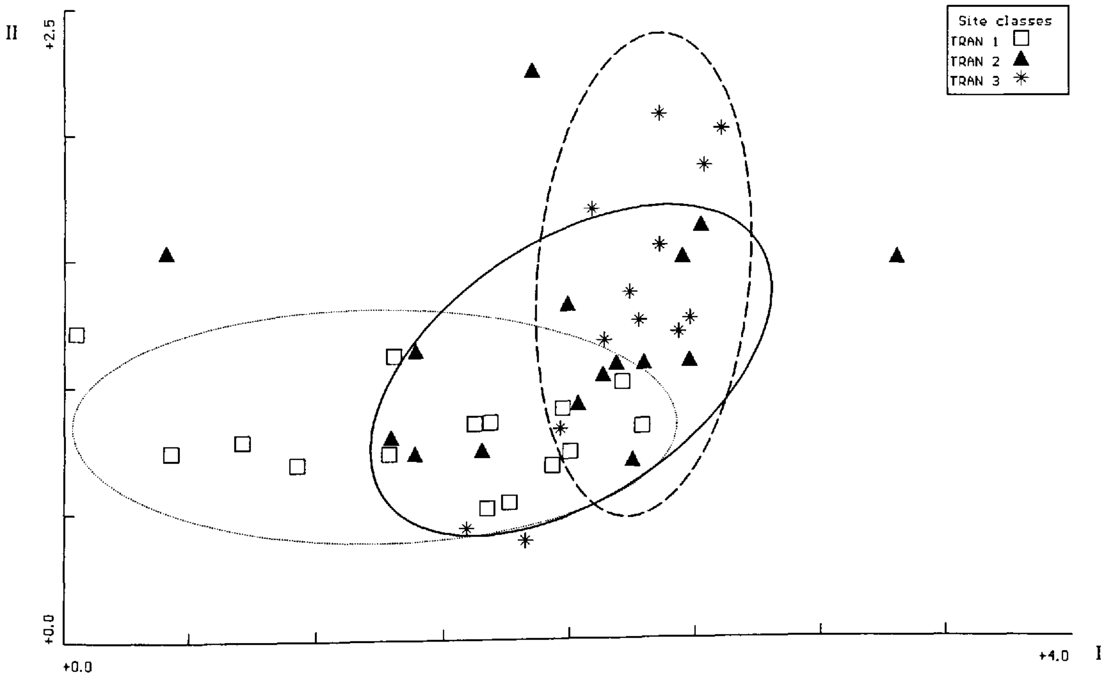


Figure 8.63: Samples ordination of Lightmoor with outliers removed, and samples identified by transect

Four main clusters were identified (Figure 8.62), and two outliers. It can be seen from Figure 8.63 that transect location affects the samples ordination, as three broad trends can be distinguished. Samples from transect 1 are distributed horizontally along axis I, and are largely separate from transect 3 samples which are spread vertically along axis II (corresponding with DCA group B). Transect 2 samples have a broader distribution in the middle of the diagram, intergrading with both transect 1 and 2 samples.

Location on the slope (Figure 8.64) also partially describes the groupings identified in Figure 8.62. Samples from subplot 1 correspond to Groups A D and C. Samples from subplots 3-5 are clustered in the centre of the diagram, corresponding with Group B. However, there are many outliers from this trend.

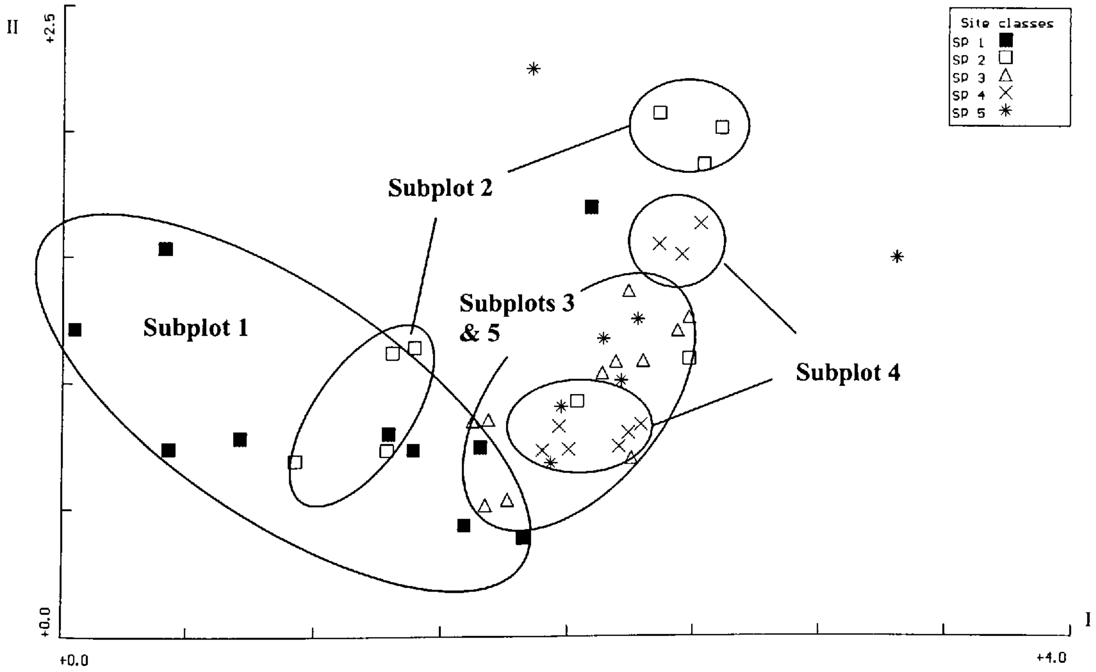


Figure 8.64: Samples ordination of Lightmoor with outliers removed, and samples identified by slope, where subplot 1 = lower slope and 5 = upper slope.

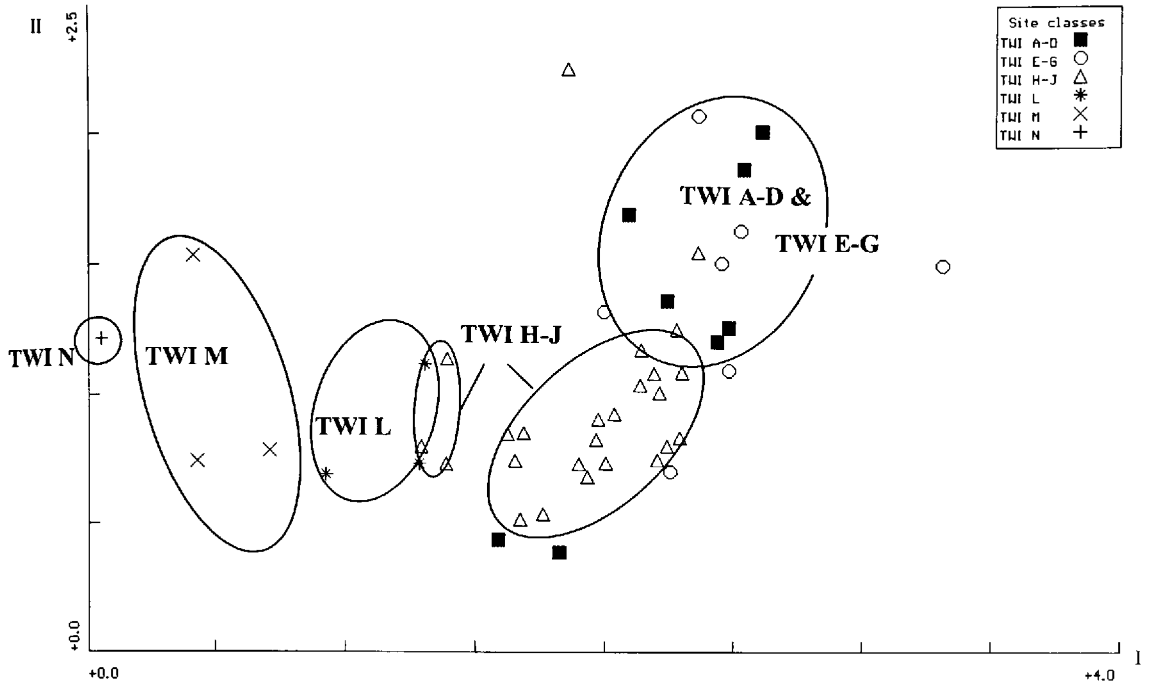


Figure 8.65: Samples ordination of Lightmoor with outliers removed, and samples identified by TWINSPAN groupings separated at the 3rd division

Figure 8.65 shows that TWINSPAN groupings separated at the 3rd division (Figure 8.25) also partially reflect clusters apparent within Figure 8.63. The TWINSPAN groups are distributed in distinct clusters within the DCA diagram (except for Groups E-G), but these do not always correspond with the DCA groups. TWINSPAN Groups M and N lie within DCA Groups A and D. TWINSPAN Group L lies within DCA Group C and D. DCA Group C predominantly corresponds with TWINSPAN Groups H and J, and DCA Group B is a mixture of TWINSPAN groups A-J. These results are discussed further in Section 9.6.9

8.3.11 True Blue

Figure 8.66 shows the standard DCA samples ordination for True Blue. Five distinct clusters of samples were identified.

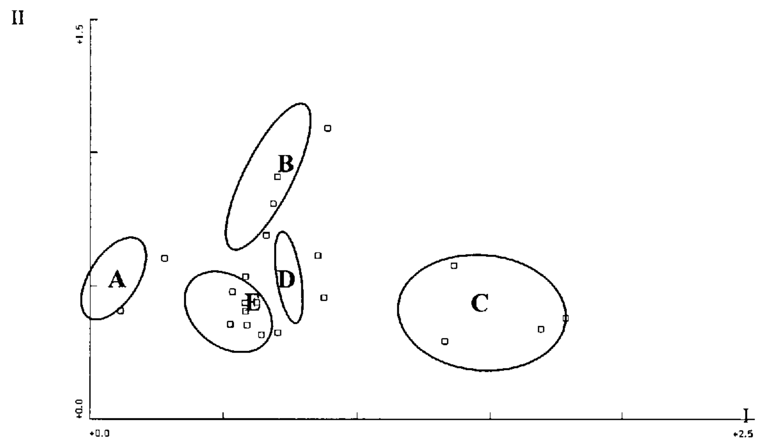


Figure 8.66: Standard DCA ordination of True Blue samples with groupings highlighted

Figure 8.67 shows that transect location describes some of the variation seen in Figure 8.66. Transect 2 samples tend to be distributed in a horizontal band along Axis 1, and Transect 1 samples in a horizontal band along Axis 2.

Figure 8.68 shows samples classified by location on the slope. The upper slope samples tend to be distributed towards the top of the diagram, whilst the lower slope samples in the left hand corner of the diagram, and samples from the middle subplot form in a band in between.

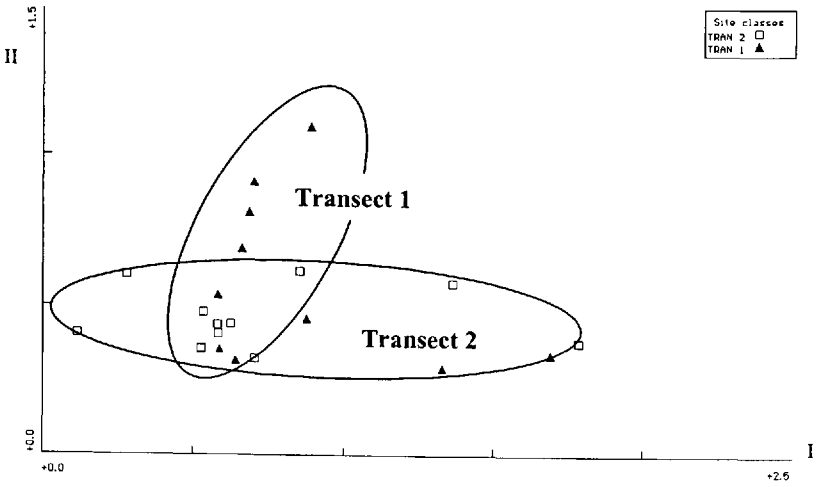


Figure 8.67: Samples ordination of True Blue with samples identified by transect

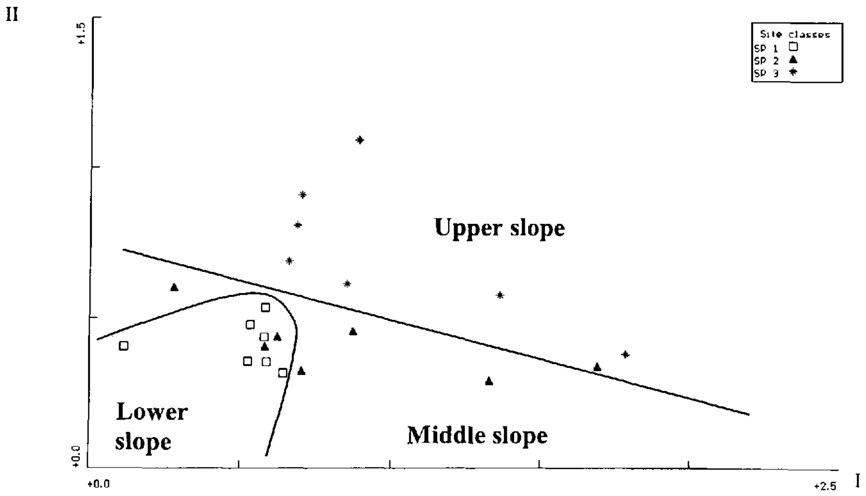


Figure 8.68: Samples ordination of True Blue showing location by slope

Figure 8.69 shows a clear distinction between TWINSPAN groups separated at the second division. TWINSPAN Groups F and G are distributed to the right, corresponding with DCA groups C and D. TWINSPAN Group H corresponds with DCA group B, and TWINSPAN groups A-E correspond with DCA group A and E.

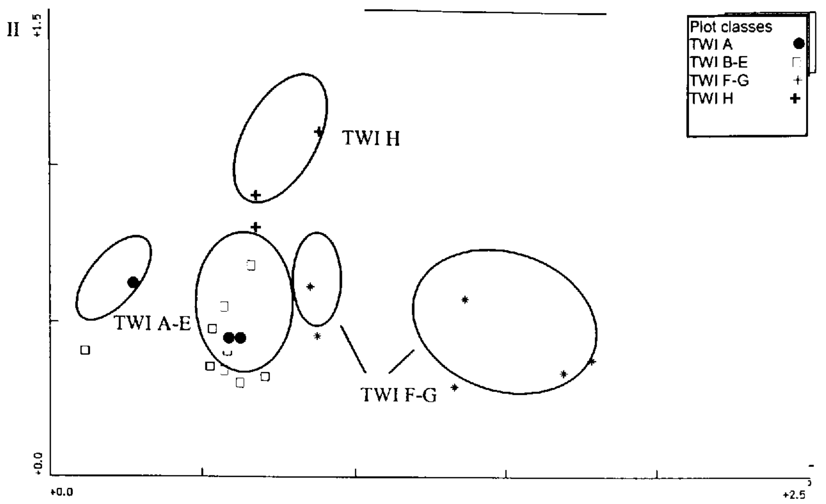


Figure 8.69: Samples ordination of True Blue showing TWINSPAN groupings separated at the 2nd division

Figure 8.70 shows the samples identified by the percentage heather cover each of the samples contained. This diagram also describes the clusters initially identified

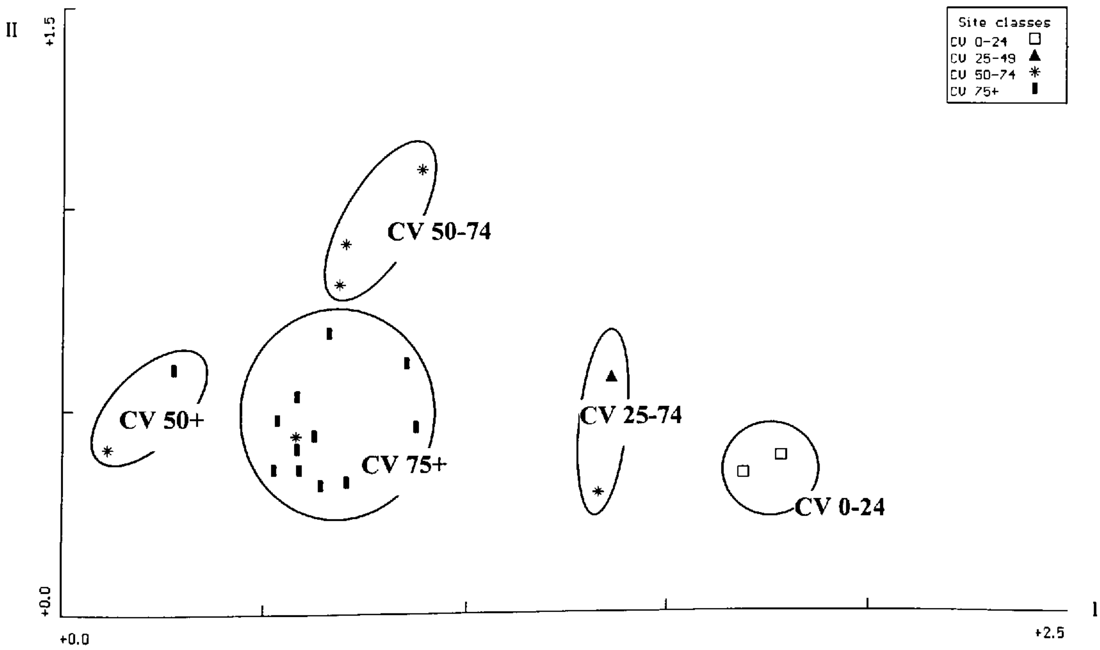


Figure 8.70: Samples ordination of True Blue showing samples classified by the % cover of *Calluna vulgaris* (CV).

in Figure 8.66 well, with Group A having more than 50% heather cover, group B having more than 75% heather cover, group C having 50-74%, and group D mainly having less than 49% cover.

8.4 Summary

Ten data-sets were analysed using TWINSPAN classification and DCA indirect ordination. Each of the plots were analysed, plots from the same plotwere analysed together, and one data-set comprised samples from all sites. The standard settings of the TWINSPAN and DCA were used to produce standard, comparable, data-sets. One TWINSPAN run on the 'all sites' data-set was manipulated to emphasise the floristic similarities between sites. Anomalous samples and species were removed from data-sets where they skewed results, as listed in Tables 8.1 and 8.16. Axes I and II were used for all DCA diagrams. The results are summarised by data-set in Sections 8.4.1-8.4.10.

8.4.1 All plots

The floristic groups produced by both TWINSPAN runs separated samples on a plot-by plot basis. Northern United samples were separated from other samples at the first division based on the absence of 4 indicator species *Brachypodium sylvaticum, Fragaria vesca, prunella vulgaris* and *Festuca ovina*. True Blue samples were separated at the second division, based on the presence of *Calluna vulgaris*. Samples from Lightmoor, New Fancy A and New Fancy B were also classified into distinct floristic groupings. Cannop A and Cannop B samples were also classified into distinct floristic groups, but the groups were more dispersed within the dendrogram.

Clusters also broadly corresponded to plots in the DCA bi-plots. The samples from Northern United, Lightmoor and True Blue form a triangle on the diagram, with samples from the New Fancy and Cannop sites lying in between, indicating that True Blue, Lightmoor and Northern United are most floristically different to each other, and the New Fancy and Cannop sites most similar. Identifying the samples by Age, pH and canopy cover also showed pattern within the clusters. Age appeared to affect samples along the vertical axis (II), the percentage canopy cover of the plots along Axis I, and pH along both axes. These results are discussed further in Section 9.6.1.

8.4.2 Northern United

TWINSPAN groups A-G are species poor (3-4spp), and are found on the lower 2 slopes of the plot. Groups H-N are more species rich (5-10spp), and are found on the upper 2 subplots of the slope. Groups L, M and N contain between 10-20 species, and are located around the upper two subplots of transect 1.

For the DCA results, classifying the samples by transect partially describes the clustering patterns of the samples. Classifying samples by distribution on the slope better describes the patterns, with different clusters formed by samples from subplots 1&2, 3&4 and 5-7, although there is still a lot of overlap and mixing within the clusters. The TWINSPAN groupings identify different clusters from those identified by slope or transect. These results are discussed further in Section 9.6.2.

8.4.3 Cannop A & B

The first division separates TWINSPAN groups A-J from groups K-N. Groups K-N are characterised by *Tussilago farfara* and all occur on Cannop A. Groups A-J are characterised by *Fragaria vesca* and *Brachypodium sylvaticum* and occur on both plots. Groups A, C and J occur exclusively on Cannop A. One sample from Group H occurs on Cannop A and one on Cannop B. There are two totally bare sample on Cannop B, and 8 on Cannop A.

In the DCA diagrams, the majority of the Cannop B samples lie spatially close to each other. The Cannop A samples form distinct clusters separate from each other, and separate from the Cannop B clusters except for points represented by samples 101, 102, 105, 108. Cannop A samples lie in a curve, indicating that more than one environmental variable is affecting the distribution of results. These results are discussed further in Section 9.6.3.

8.4.4 Cannop A

Distinct TWINSPAN groupings occur on different parts of the plot. Groups H-I are species poor, and are distributed in the upper two subplots. Group A-C samples are distributed on the lower slopes of Transect 1. Groups B and C are characterised by *Pteridium aquilinum*, the only plot in the study to contain this invasive species. Groups D-G are the most species rich, containing a mean of 10 species per quadrat, and are distributed on the lower slopes of Transect 2. More bare samples occur on transect 1 than transect 2, but slope does not appear to affect their distribution.

DCA analysis has produced a diagram with three distinct clusters of samples, and two outliers, represented by samples 95 and 96. Classification of the samples by transect and by slope describes the clusters very well, with separate clusters of samples occurring on the upper and lower two subplots of each transect. The TWINSPAN groups tend to correspond well with the DCA clusters. These results are discussed further in Section 9.6.4.

8.4.5 New Fancy A &B

TWINSPAN analysis separates samples from New Fancy A (A-O) from those of New Fancy B (P-X) at the first division. New Fancy B samples are characterised by *Ulex europaeus* (1). New Fancy A samples are characterised by *Deschampsia flexuosa* (1), *Hypnum cupressiforme* (1) and *Crataegus monogya* (3).

DCA analysis shows that samples from New Fancy A Transect 1 lie very close to those of New Fancy B spatially, yet there is no mixing of samples within the cluster. Samples from New Fancy Transect 2 form separate clusters to New Fancy A Transect 1, or New Fancy B samples, again with very little mixing of samples. Distribution on the slopes appears to describe the variation in the diagram well. Differences in % canopy cover also describes some of the variation. These results are discussed further in Section 9.6.5.

8.4.6 New Fancy A

TWINSPAN analysis shows distinct floristic groupings occuring on different parts of the plot. Groups A-H occur on transect 1, and groups I-R on transect 2. Within each transect, the floristic groupings occur on different parts of the slope.

Within Transect 1, Groups A-C are distributed on Subplots 5 and 6; Groups D-F in Subplots 3-4; and Groups H and G in subplot 2, whilst subplot 1 is floristically very mixed with all 4 samples classified into different groups. Within transect 2, groups I-K are distributed within subplots 1-2, L-M in subplot 3, and O-R in subplots 4-6.

The percentage canopy cover class describes the separate clusters formed by samples from Transect 1 and 2 well. Transect 2 samples having a much higher canopy cover. Location on slope also describes variation in Transect 2 sample clusters, but the Transect 1 samples to a lesser extent, as the samples are more highly clustered, and there is more overlap. These results are discussed further in Section 9.6.6.

8.4.7 New Fancy B

TWINSPAN groups A-E are separated at the first division from groups F-J. Groups A-E are predominantly distributed within upper slope subplots 4-6 and characterised by *Cynosurous cristata* and *Crataegus monogya.* Groups F-I are distributed within the lower slopes 1-3. The two Group J samples, characterised by *Hypnum mammillatum* are distributed in subplots 2 and 4.

Three main clusters of samples are produced by the DCA analysis, with two outliers (166, 182). Classification of samples by location on the slope describes the clusters well, with subplot 1 samples forming separate clusters to those from subplots 2&3 and 4-6. Classifying samples by % canopy cover describes the clusters less well, although those from subplot 1 have a lower canopy cover than samples from subplots 2-6. The TWINSPAN groups do not describe the DCA clusters well, with the groupings being distributed more in horizontal bands than clusters. These results are discussed further in Section 9.6.7.

8.4.8 Cannop B

TWINSPAN groups A-I are distributed on subplots 1-3, separated from groups J-L at the 1st division. Groups J-L are all distributed in subplot 4, and are species poor (mean = 5.8 species/quadrat). Groups A-D are predominantly distributed within subplots 2&3 and are less species poor (e.g. mean of group B= 9 species/quadrat). Groups E-I are distributed within subplots 1 and 2 of transects 1 and 2 and are the most species rich sites (e.g. mean of group G = 18.75 species/quadrat).

Four main clusters are produced by the DCA ordination. Group A samples predominantly occur within subplot 4 and have a low canopy cover <24%. Group B samples tend to be distributed on transect 2 subplot 1, and have a moderate-high % canopy cover. Group C consists of two sample points that are distributed in Transect 2, subplot 3 and have a high % canopy cover. The middle cluster of samples are of mixed subplots, transects, and canopy cover values. The TWINSPAN groupings describe the clusters relatively well, but there is much overlap within the samples of the middle DCA cluster D. These results are discussed further in Section 9.6.8.

8.4.9 Lightmoor

The 1st TWINSPAN division separates Groups L-N from Groups A-K. Groups L-N are distributed in Subplots 1 and 2 of Transects 1 and 2, have a mean vegetation cover of 115% and a mean 27 species/quadrat. Groups A-K have a mean of 50% vegetation cover and a mean of 19 species per quadrat. Groups A-D occur on the lower slopes of Transect 3. Groups E-G occur on the upper slopes of Transect 2. Group I samples are distributed on subplots 3-5 of Transect 1, and group H samples on subplots 4 and 5 of Transect 3, and subplots 2 and 3 of Transect 2.

The DCA diagrams were initially constrained by *Brachythecium rutabulum*, which was removed. Three main clusters were identified. Location by transect and slope both effectively described variation within the diagram, indicating that environmental factors related to these variables may affect samples distribution. The TWINSPAN groupings also broadly correspond with the DCA clusters. These results are discussed further in Section 9.6.9.

8.4.10 True Blue

The 1st TWINSPAN division separates groups A-E from F-H. Groups A-E are characterised by high abundances of mosses. Groups A-D occur on the lower 1-2 subplots of both transects. The 1 sample that comprises Group E occurs subplot 3 of Transect 1. Groups F-H are characterised by a lichen and two grass species, and tend to occur on the upper slope subplots.

The DCA analysis produced four main clusters of samples. These were partially described by classification according to transect and subplot. Upper and middle slope samples are distinct from lower and middles slope samples. The TWINSPAN classification groups corresponded well with the DCA diagram. Classification according to heather cover described the clusters best.

Chapter 9.0 Discussion of results

This chapter examines the results that were analysed and set out in Chapters 7 and 8. These results are discussed in relation to theories of plant succession and previous studies on colliery spoil, as specified by Objective vi (see Section 1.1). The results of uni-variate analyses on non-floristic data from Chapter 7 are discussed in Sections 9.1-9.4 in relation to Sections 2.3.1-2.3.4 and the "expected trends" set out in Table 2.2 (Section 2.2). Species strategies are discussed in Section 9.5 in relation to theories and previous studies described in Section 2.3.6. Finally, floristic results and association analysis are discussed in Section 9.6 in relation to the literature on floristics outlined in Section 2.3.7, theories of how succession occurs described in Section 2.1, and other relevant literature.

9.1 Substrate factors

This section discusses substrate results that were displayed and analysed in Section 7.1 in relation to substrate results found in previous studies, as outlined in Section 2.3.1.

9.1.1 pH.

Figure 9.1.a shows that the modal pH for the Forest of Dean sites is pH 5-6. The modal pH result (Figure 9.1) is 1 pH value more than that of the

neighbouring Somerset Coalfield (Down, 1975). Kent (1982) meanwhile found that the mode

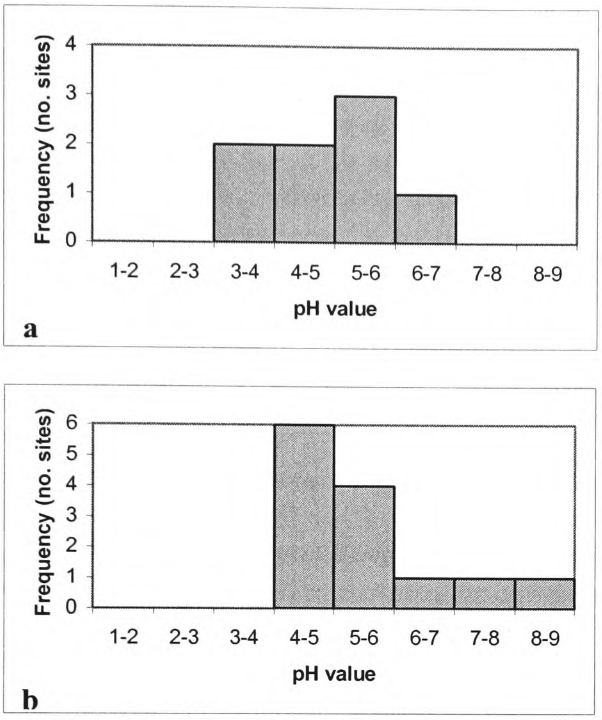


Figure 9.1: Frequency (number of sites) of pH values in surface colliery spoil samples in a) the Forest of Dean coalfield(8 sites) and b) the Somerset coalfield (13 sites more than 10 years old – data from Hall (1957)

pH of spoil heaps of the Yorkshire Coalfields (weathering for more than 10 years) was pH 3-4 Authors such as Richardson (1957) and Doubleday (1975) also report low pH values of pH 2-4 on the Northumberland coal spoil heaps. The Forest of Dean sites would therefore appear to be relatively neutral in pH value compared to spoil heaps of similar ages in other coalfields of the UK. This finding may be a function of different coal seam chemistry and mineralogy, known to vary greatly even between seams in the same coalfield (Table 2.4) as well as between coalfields. Hall (1957) however, noted that some of the Forest of Dean spoil heaps were still burning at the time of his survey, including Cannop (Moore, 1952).

Combustion affects pyrites and therefore acidity (Section 2.3.1.2). The pH between different areas of Northern United for example, varied from pH 2 on non-combusted black material, to pH 6.5 on the combusted red shale areas (Section 2.3.1.1). This may be a further reason why the Forest of Dean spoil heaps have lower modal values that other spoil heaps. Further tests and comparisons of spoil heap chemistry and mineralogy would need to be undertaken however, to prove this (Section 10.4.2.1).

Gemmell's assertion that the concentration of hydrogen ions begins to be directly harmful to plants below pH 4.0 (Gemmell, 1977) may explain the negative correlation between pH and % herb cover ($P < 0.01$), and pH and % canopy cover ($P < 0.025$) (Table 7.31). The correlations between pH and the other vegetation layers however, were not significant at $P< 0.05$, and nor was the correlation between pH and % bare ground. The results indicate that pH may affect vegetation layers differentially. This would be difficult to show conclusively however, without extensive growth experiments on a range of different species (Section 10.4.6).

9.1.2 Pyrites

Table 7.31 shows that increasing pyrites colouration has a strong correlation with decreasing vegetation factors such as moss cover and height (r_s = -0.65 / -0.79) and species richness per quadrat (0.83). This may indicate that increasing pyrites levels have a negative effect on vegetation. It would be difficult to distinguish exact cause and effect however, without undertaking an extended pyrites data collection and comparing this with vegetation data per quadrat

(Sections 10.4.2.1 and 10.4.5). There are also strong correlations between increasing pyrites and other environmental factors such as decreasing soil depth (0.86) and age (0.74). It is difficult from correlation analysis alone to ascertain how these environmental factors interact with each other, and whether pyrites in isolation from age or aspect affects vegetation and soil development. Sections 10.4.2.1 and 10.4.5 therefore describe further tests that may be undertaken to develop this area of the research.

The colour of test papers gained from pyrites analysis (Section 7.2) was light when compared to the interpretation guidelines (Section 5.2.3.3), suggesting that a weak level of iron pyrites was found on all sites. This result is expected given that the spoil heaps have a history of combustion, which burns pyrites and renders it inactive (Section 2.3.1.4). The literature review (Table 2.4) however, shows that Forest of Dean seams have a pyritic sulphur content that ranges from

Table 9.1: Shows pyrites results from this study alongside the coal seams that each mine worked (1). The results of the chemical analysis of each seam (2) is given where possible.

Site	Pyrites rank	Pyritic sulphur (%)	Coal seam	Date of HMSO Register
CPA	1	1.16	CHD (E)	1936
		3.19	WHT	1895
HW	2	0.41-1.37	CHD	*Pers. comm.* (3)
NU	3	0.41-1.37	CHD	*Pers. comm.*
CPB	4	1.16	CHD (E)	1936
		3.19	WHT	1895
NFA &B	6/5	N/A	RO; NC	1936
		N/A	CHD(e);RO; ST; 20”	1922, 1895
LM	7.5	N/A	RO; ST; 20”	1936,
		N/A	LO; RO ChHD	1898,1895
TB	7.5	0.41-1.37	CHD	1936, 1922

(1): His/Her Majesty’s Inspectors of Mines, as dated. *List of Mines in Great Britain and the Isle of Man.* London: HMSO;
(2): Ministry of Fuel and Power (1946); (3) John Harvey. Deputy Gaveller, Forestry Commission. 1999.
(4) Key to seams: CHD = ; ChHD = Churchway high delf; LO = Lowery; NC = No Coal; RO = Rockey; ST = Starkey;
WHT = Whittington

0.41 to 3% (Table 9.1). This may be sufficient to limit vegetation growth on sites such as True Blue, Northern United and Cannop (Section 2.3.1.4).

The finding that increasing pyrites colouration is strongly correlated with increasing age, with r = 0.74 (Section 7.1.2, Table 7.34) fits with the findings of Costigan *et al.* (1981) where weathering over time was found to decrease the amount of pyrites remaining in the spoil (Section 2.3.1.4).

9.1.3 Soil depth

Soil depth is significantly positively correlated with age (r_s = 0.80 $P<0.025$), as shown in Figure 9.3. The results for this parameter therefore would support the prediction of Whittaker (1975) and Odum (1971) (Table 2.2) that substrate develops with age. However, further tests would be needed to isolate the effects of time from the effects of other environmental factors that were correlated with soil depth such as pyrites (Table 7.31).

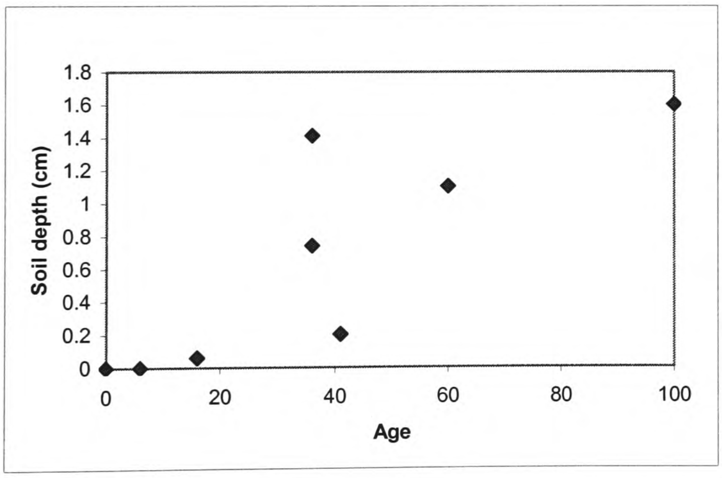


Figure 9.3: Scattergram to show the strong positive relationship between soil depth and age of the plot, where r_s = 0.80 $P<0.025$ (Tables 7.31, 7.34).

Table 2.2 also predicts increasing differentiation of horizons over time. Transect 1 on Lightmoor was the only location where there was some horizon differentiation between the organic matter layer (0.5cm), the A Horizon (9.5cm, a silty-clay layer) and the disturbed colliery spoil B horizon (Section 9.6.9). On other sites, such as New Fancy A and B, the surface organic matter layer lay directly over the colliery spoil. The lack of substrate development indicates that sites may be sensitive to disturbance, and should therefore be managed to minimise disturbance to give substrates time to develop (Section 10.2).

A further expectation discussed in Section 2.3.1.4 is that substrate and vegetation develop together, as nutrients and organic matter build up over time. Tables 7.31- 7.35 show that increasing soil depth is negatively correlated with decreasing moss cover (r_s = -0.95, $P<0.01$), shrub cover (r_s = -0.762, $P<0.025$), moss cover (r_s = -0.881, $P<0.01$), and biomass (r_s = -0.81), which would indicate that this trend is also occurring in the Forest of Dean.

A significant correlation that was not noted in previous studies (Section 2.3.1.4) is between increasing soil depth and an increasingly westerly aspect (r_s = 0.69, $P<0.05$). This correlation may have occurred because environmental factors related to differential aspect, such as insolation and microclimate appear to affect vegetation development (Section 9.2.2), which in turn may affect soil development. An extended programme of data collection (Section 10.4.2.1) could be developed for further research that would investigate this correlation further.

9.1.4 Plant vigour

Plant vigour was found to have very strong or strong negative correlations with bare ground, and positive correlations with shrub cover, moss height, herb height and species richness as described in Tables 7.31 and 7.36. This was an expected result supporting the findings of Section 9.1.3, that vegetation and substrate develop together. The scale was therefore felt to provide a quick and valuable means of recording field conditions, against which floristic or other results can be checked (e.g. Sections 9.2.1, 9.6.4, 9.6.9). The significance of the correlation analyses could not however, be calculated as the data is ordinal (Section 6.1.1.1). Section 10.4.2.1 discusses improvements that could therefore be made to the index to create a more robust and quantitative technique.

9.2 Microclimate

This section discusses substrate results that were displayed in Section 7.2 in relation to the literature on microclimatic conditions discussed in Section 2.3.2.

9.2.1 Slope factor

Increasing slope factor is significantly correlated with increasing pH (r_s = 0.74, $P<0.025$) and decreasing % canopy cover (r_s = -0.83, $P<0.025$) (Section 7.5). This result was not expected from reading literature from previous studies (Section 2.3.2.1). Further research could therefore be undertaken to establish whether pH and canopy cover differ within plots by slope location as well as between plots (Sections 10.4.2.1, 10.4.5).

To investigate relationships between slope factor and vegetation that were identified by the TWINSPAN distribution diagrams (e.g. Figure 8.12), but not by the correlation analysis, the percentage of samples occurring in each plant vigour

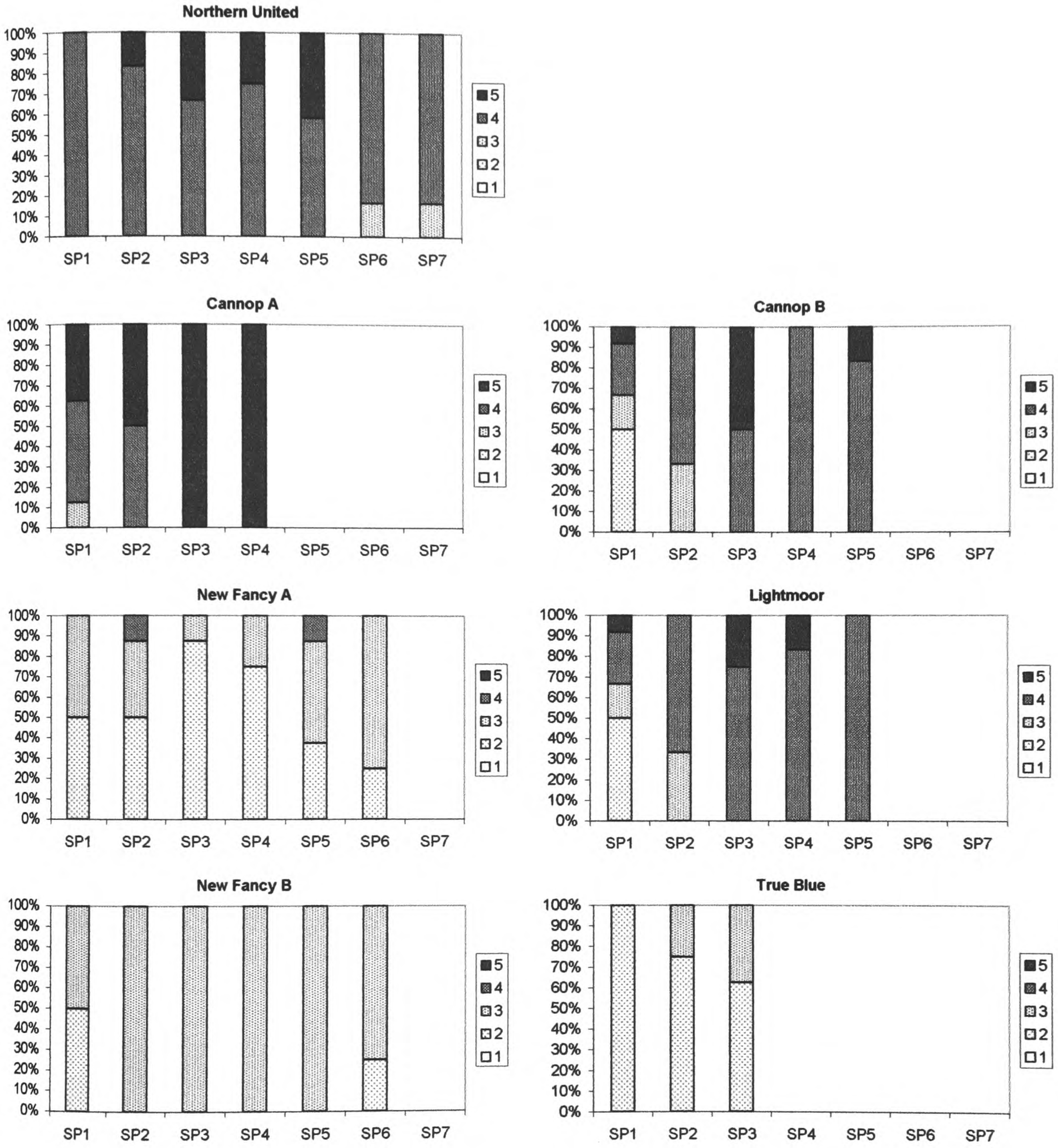


Figure 9.4: The frequency (%) of plant vigour index scores (1-5) by location on slope (subplot)

category was plotted against slope location (Figure 9.4). In can be seen that quadrats with poor plant vigour scores (4 and 5) occur at higher frequencies on the upper slopes of Cannop A, Cannop B and Lightmoor, whereas on Northern United the quadrats of the upper two subplots tend to be healthier. Environmental factors related to slope appear to influence the pattern of vegetation development differentially on each plot, which is why the correlation analysis did not pick up a linear relationship. The effects of slope on the vegetation of individual plots are discussed in Section 9.6, and the management recommendations made in relation to this finding are discussed in Section 10.2.

9.2.2 Aspect

Section 7.5 found a significant correlation (P<0.05) between vegetation cover increases (and % bare ground decreases) and a westerly aspect. This result was expected from the literature review in Section 2.3.2.2, as southerly slopes in the UK receive higher insolation levels, which results in a hotter, drier micro-climate. To investigate the correlation further, Figure 9.5 was constructed. This

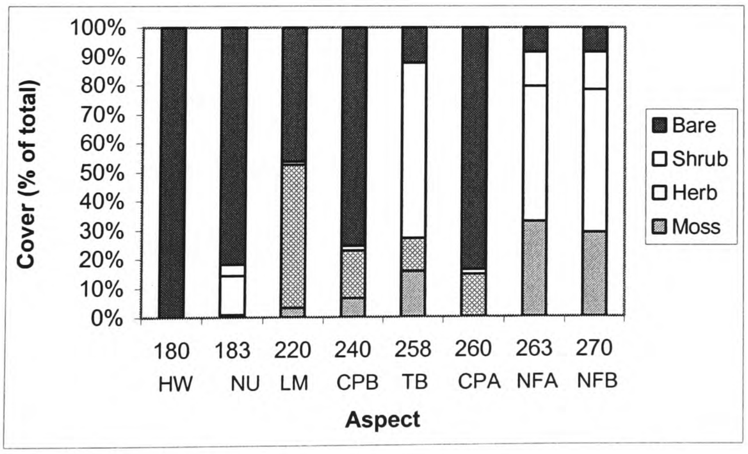


Figure 9.5: mean moss, herb, shrub and bare spoil cover expressed as % of the total, on the 8 Forest of Dean sites.

shows that sites with an aspect between 180-240° have a much higher incidence of % bare ground than sites with an aspect between 258-270°, except for Cannop A (260°). The percentage of moss increases in a linear fashion from south to west, again except for Cannop A.

Figure 9.6 shows the potential effect of differing microclimate on vegetation development within a plot. Lightmoor was used to construct Figure 9.6 because aspect varies by 20° for each of the three transects, and no canopy cover is present that may provide differential shade from insolation. It can also be seen here that the proportion of bare ground is higher on the most southerly-facing transect than the more westerly facing transect. The proportion of moss cover also increases on the westerly slope.

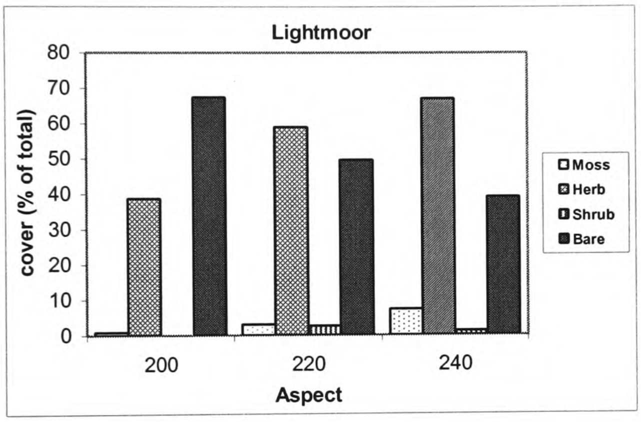


Figure 9.6: The mean composition of quadrats taken from three transects of differing aspect on Lightmoor

This finding supports the results of previous studies reviewed in Section 2.3.2.2, but does not support the Clementsian viewpoint of succession (Section 2.1.1.1) which predicts that lower plants such as bryophytes establish early in a succession as a 'sere' or community, which is replaced by communities of higher species as succession develops. The results from this study indicate that plants (and mosses in particular) are sensitive to environmental gradients affected by aspect and are slower to colonise southerly facing slopes. Southerly facing slopes may therefore need to be managed more sensitively to ensure that further disturbances do not exacerbate the lack of vegetation development, as outlined in Section 10.2.

9.2.3 Canopy Cover

Canopy cover results (Section 7.5) did not support the expected trend in Table 2.2, which predicts that vegetation will become increasingly massive over time. This trend was therefore investigated further in Figure 9.7. These results

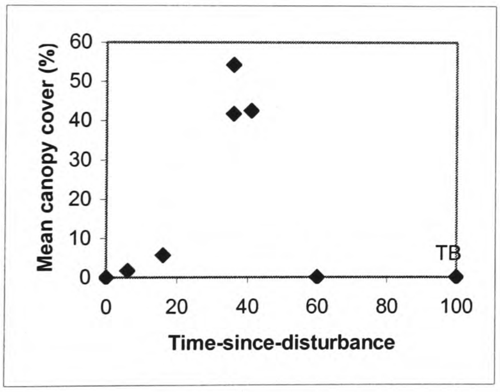


Figure 9.7: Scattergram to show the relationship between the mean % canopy cover of each site and a) time-since disturbance (spearman rank = 0.05)

show that some of the older sites are able to support trees, and trees are starting to develop on younger sites (except Hawkeswell at year '0'). However, whilst sources of propagules of tree species certainly lie within 5m of Lightmoor and within 50m of True Blue, trees have not been able to develop on either site. Environmental conditions not measured within this study or combinations of conditions such as substrate physical conditions, moisture balance or seed-rain may therefore affect the establishment and development of tree species on these sites (Sections 10.4.2.1, 10.4.2.2).

Canopy cover is used in this study to measure both the effects of environmental factors on vegetation growth and succession, but also as an environmental factor that may itself affect floristic pattern (Section 2.3.2.3). The relationship between diversity and shade cover within a community was therefore been investigated further using New Fancy A (Figure 9.8). This plot was chosen as there was a wide variation in canopy cover-abundance scores on this plot which New Fancy B does not have, and unlike Cannop B floristic pattern does not appear to be affected by slope factor (Section 9.2.1).

Figure 9.8 shows that the mode number of species within the 0-24% shade category is higher than the 25% and above categories. More samples would however need to be taken on different parts of this plot to confirm this trend, as the number of samples is not evenly distributed amongst the shade classes. Floristic pattern on New Fancy is discussed further in Sections 9.6.5 and 9.6.6. It is also difficult to know whether Figure 9.8 is representative of all plots without examining these findings further (Section 10.4.2.1).

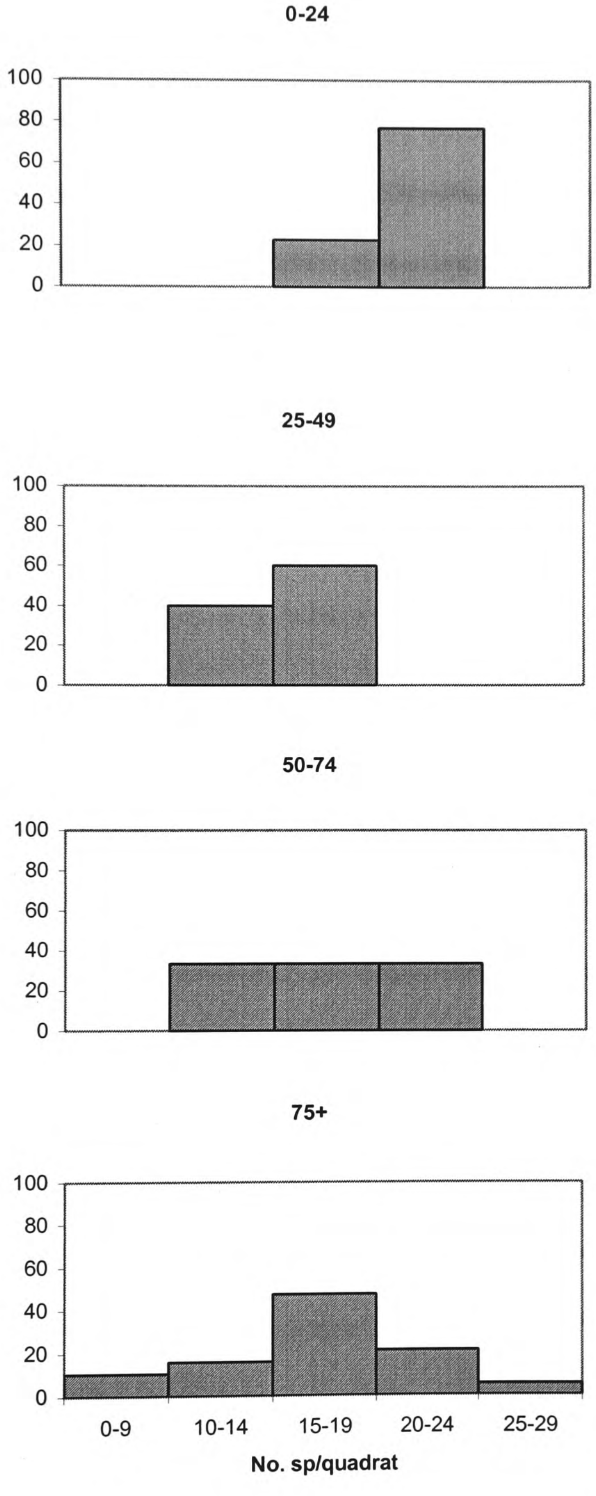


Figure 9.8: Histogram to show the number of species per quadrat of samples that occur within one of 4 different shade categories (0-24%, 25-49%, 50-74% and 75%+) on New Fancy A (expressed as % frequency of quadrats).

9.3 Non-floristic vegetation factors

This section discusses the results of the non-floristic vegetation factors such as vegetation height, cover and biomass from Section 7.3 in relation to the expected trends outlined in Table 2.2. Relevant trends include increasing massivity, stratification of vegetation, biomass, diversity and evenness (Section 2.3.3).

9.3.1 Height and cover

Section 7.5 shows that increasing age was not significantly correlated with vegetation height or cover parameters except increasing moss height ($r_s = 0.7$, $P<0.05$). This does not support the expected trends (Table 2.2) that vegetation cover-abundance is likely to increase over time and become more evenly distributed over time or that the vegetation becomes more massive over time. The effects of age on the percentage cover and height of the different vegetation layers was examined in further detail, shown in Figure 9.9.

It can be seen from Figure 9.9a that moss cover is more developed on older plots, and the % bare ground tends to decline. The older sites may have a more complex structure than the younger plots. The ground-layer is poorly developed on the 6 and 16 year old plots and bare ground cover also declines from above 80% on the 0-16 year plots to below 60% (except Cannop B).

Figure 9.9b shows that increasing massiveness of vegetation does not appear to be a function of age for the Forest of Dean sites. The vegetation of the older (41-100 year) plots appears shorter overall than the younger (6 - 16 year) plots.

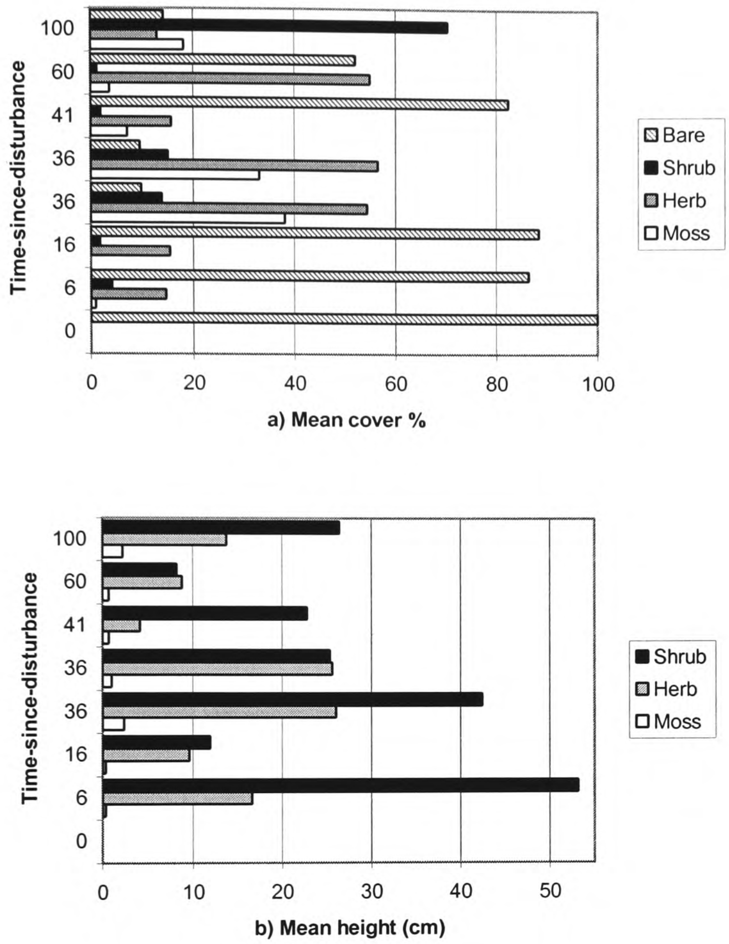


Figure 9.9: Mean % cover (a) and height (cm) of the three under-storey vegetation layers of each site arranged by increasing age

Factors other than age may therefore affect the different vegetation layers on older sites, cause mean vegetation cover on some sites to remain low, and affect vegetation height. For example, as discussed in Sections 9.1 and 9.2 environmental factors such as canopy cover, pH, soil depth and aspect may affect vegetation development. Further experimental tests would however, need to be undertaken to see if each factor in isolation does affect vegetation development, and whether different vegetation layers are particularly affected by different environmental factors (Section 10.4.6).

9.3.2. Biomass index

The biomass index was constructed to estimate biomass without the need for destructive sampling (Section 5.4.2), so that predictions that vegetation becomes increasing 'massive' over time (Table 2.2) can be tested, as well as predictions that species diversity decreases as biomass increases (Section 2.3.3.1, 2.1.2.3).

Figure 9.10 supports results in Section 9.3.1 that the biomass index is not a function of time. This does not match the prediction expected in Table 2.2. Two distinct peaks can be seen, the first at 36 years-since disturbance, and the second at 100 years since disturbance.

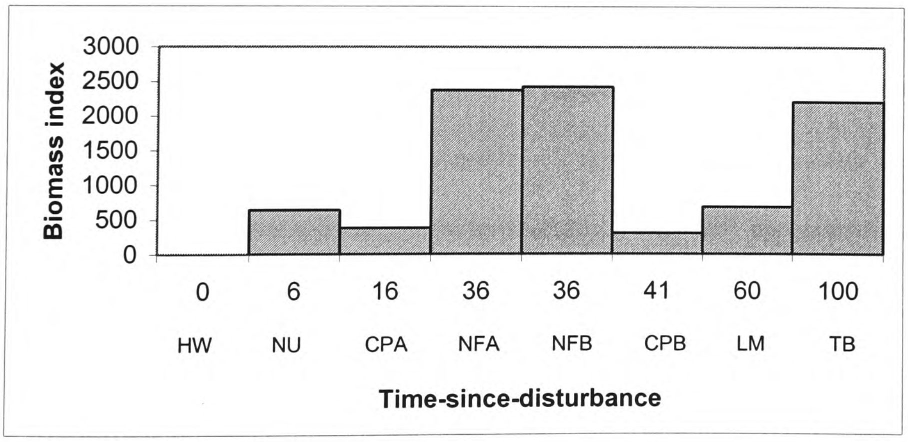


Figure 9.10: graph to show the correlation between biomass and time-since-disturbance

Species diversity and biomass index results are discussed in Section 9.4.2.

9.4 Species diversity

The objective of gaining information on diversity is so that the data can be used for management purposes (Objective viii, Section 1.1.2). The questions asked of the diversity data to fulfil this objective are "does diversity change with increasing time?" (Section 2.3.5.2; Table 2.2), "do environmental variables such as pH affect species diversity", and "does grazing affect diversity?" (Section 2.3.5.2).

The species-richness indices used in the correlation analyses ((S)/Qudrat and (S)/subunit) were significantly positively correlated ($P<0.05$ level or above) with time-since-disturbance and soil depth (Section 7.3.4.3). There was also a strong negative correlation between species richness and pyrites rank, although the significance of this could not be tested (Section 6.1.1.1). These environmental variables are therefore explored further in this section. Biomass and pH were included to enable the results to be compared with previous studies such as Tilman (1982) and Bradshaw and Chadwick (1980) (Section 2.3.4.1). The (S)/quadrat index is used to explore the results further. Shannon 'E' has also been included. Shannon 'E' provides a measure of species-evenness, and Section 7.3.4.3 shows that the correlation with species-area was not significant at the $P<0.05$ level ($r_s = 0.29$).

9.4.1 Does diversity increase with time?

Figure 9.11a shows a positive linear relationship between species-richness/quadrat and time up to 60 years-since-disturbance, but species richness then declines between 60-100 years.

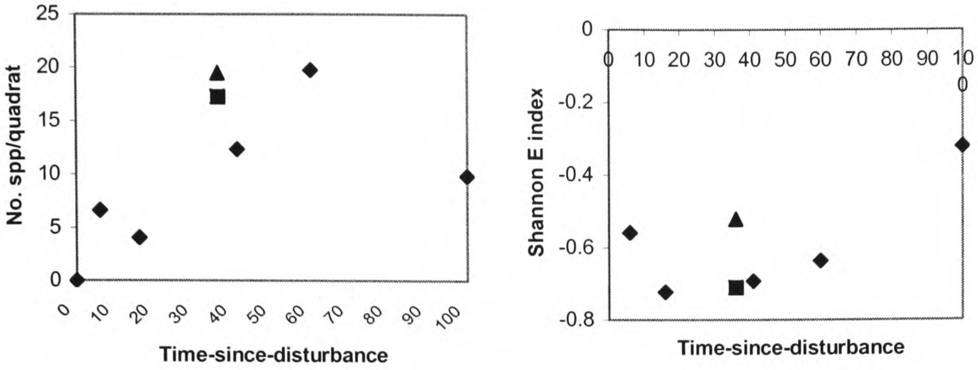


Figure 9.11: Graph to show the correlation between two measures of species diversity and time-since-disturbance: a) No. spp/quadrat and b) Shannon E index. ▲ highlights New Fancy A (enclosed from grazing), and + New Fancy B(open to grazing).

The relationship between age and evenness (9.11b) is less clear. Species-evenness appears to be highest in the 16 and 36 year-old plots. This does not altogether match the findings of Prach (1987), who found that diversity was greatest at 12-16 years but had declined by year 30 of the chronosequence (Section 2.3.4.1). It does not increase with age in a linear fashion either (as expected from Table 2.2).

The predictions in Table 2.2, that species diversity increases over time are therefore only partially true of the Forest of Dean data. Species richness increases in a linear fashion until 60 years, but species evenness is not correlated with age. The oldest plot, True Blue, is less species rich and less diverse. This result may be a function of the heathland habitat, as the dominance of heather species tend to make heathlands botanically less rich than other vegetation types (Harris *et al.*, 1996). The habitat is still nationally valuable for nature conservation however, (Sections 4.2.3, 2.3.4.1) and may support a high diversity of animal species (Gimmingham, 1992). It is therefore important to take the overall biodiversity contribution a habitat makes when discussing management (Section 10.2).

9.4.2 Do other environmental variables influence diversity?

Figure 9.12a illustrates the $r_s = 0.76$ ($P<0.025$) trend between species-richness and increasing soil depth (Section 7.5). As with Figure 9.11 however,

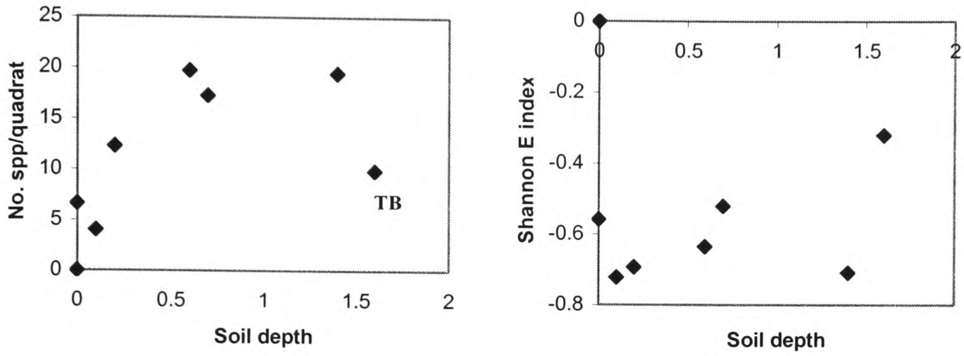


Figure 9.12: Graph to show the relationship between two measures of species diversity and soil depth : a) No. spp/quadrat and b) Shannon E index.

True Blue does not fit this trend. This plot has a much lower species richness than other plots of similar soil depth. Species-evenness does not show a clear pattern with increasing or decreasing soil depth (Figure 9.12b).

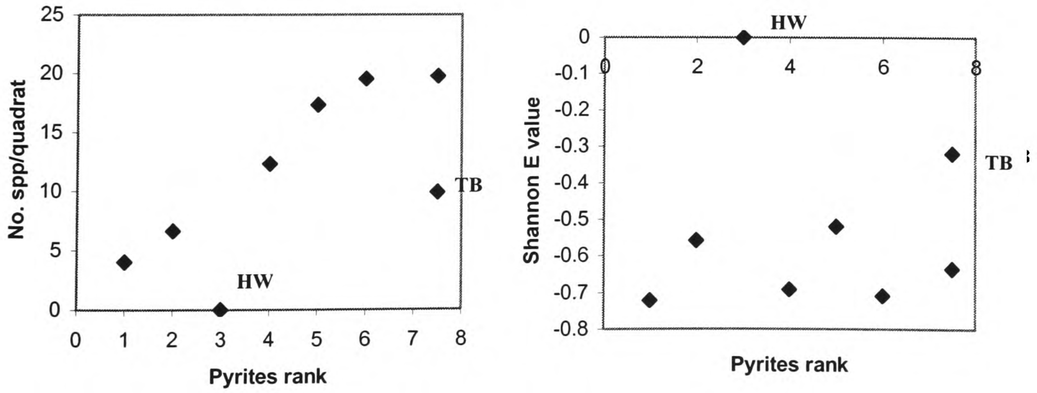


Figure 9.13: Scattergram to show the relationship between two measures of species diversity and pyrites rank: a) No. spp/quadrat and b) Shannon E index.

Figure 9.13.a shows the strong correlation between increasing species richness and deceasing pyrites rank ($r_s = 0.83$). As discussed in Section 9.1.2, this may indicate that environmental conditions caused by pyrites strength do affect vegetation growth. Further experiments would need to be undertaken to quantify the level of pyrites in the substrates (Section 10.4.2.1) so that effects on diversity could be investigated further. Species-evenness (Figure 9.15b), shows no clear pattern with pyrites.

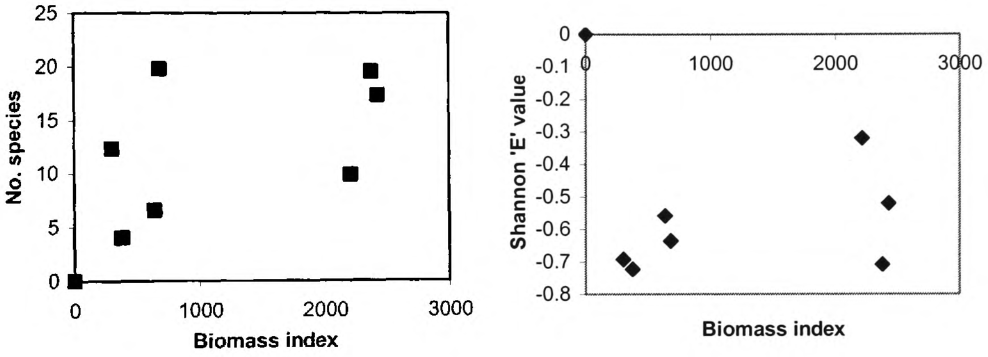


Figure 9.14: scattergraph to show the relationship between biomass and three measures of diversity: a) species richness and b) Shannon evenness

Figure 9.14.a confirms a strong correlation between species richness and biomass (-.081). However, the Shannon Evenness index has a less clear pattern. Neither graph supports the hypothesis of Tilman (1982) (Section 2.3.5.2), that as biomass increases, diversity may decrease due to increasing dominance of species better able to compete for light.

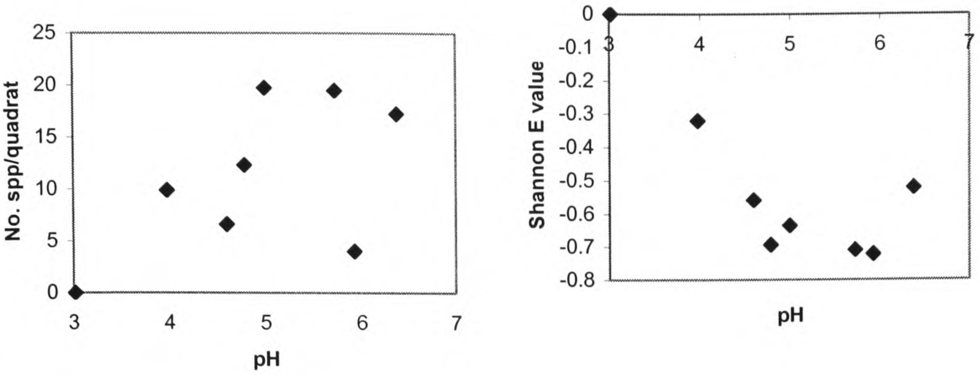


Figure 9.15: Scattergram to show the relationship between two measures of species diversity and pH: a) No. spp/quadrat and b) Shannon E index.

Figure 9.15 shows that the relationship between species richness and pH is much less clear for the Forest of Dean than the results found by Bradshaw and Chadick (Figure 2.8, Section 2.3.4.1). The correlation was not significant at the P<0.05 level or above (r =0.43). The Shannon E index shows that evenness-diversity declines with declining pH (r_s = 0.62, P< 0.1). This is not significant at the chosen P<0.05 level (Section 6.1.1.3), but is still 90% unlikely to be a result of sampling error. The results indicate that Forest of Dean sites quadrats with low species evenness are likely to occur on plots with a low pH. If further pH samples were taken per quadrat however, it would be possible to investigate the relationships between pH and species diversity further, and to establish whether some factors examined n Figures 9.12 and 9.15 appear to affect diversity more than others (Section 10.4.2.1, 10.4.5, 10.4.6).

9.4.3 Does grazing affect diversity?

It was not possible to quantify the levels of grazing on the different plots due to Foot and Mouth Disease and the nature of Commoner's grazing rights in the Forest of Dean (Section 4.3), which is why New Fancy A and B were deliberately included within the study. New Fancy A was enclosed from grazing and New Fancy Plot B was open to grazing.

The results show that the grazed plot has lower species-richness and species-evenness than the non-grazed plot. Table 7.17 shows that species-evenness (Shannon E) is much lower on New Fancy B than A (-0.52 and -0.71). Species-richness per quadrat and per sub-unit is higher on New Fancy A than B (19.50 and 17.28 spp./quadrat, 5.81 and 4.16 spp./subunit). Figure 7.20 shows that New Fancy B is dominated by 2 species with a combined abundance of over 60%, whereas New Fancy A has a more even species-abundance distribution pattern.

The results support the findings of previous studies (Section 2.3.4.1). Proulx (1988) found that nutrient poor communities exhibit lower diversity under high grazing intensity than under low grazing intensity (Figure 2.7). Kent (1987) noted that as environmental conditions are initially poor on colliery spoil, grazing exerts additional pressure on establishing vegetation that may suppress development.

These findings have implications for the management of vegetation on the Forest of Dean spoil heaps, and would suggest that decreasing grazing pressure may decrease the level of stress, and therefore increase diversity (Section 10.2). Grazing is thought by English Nature (1997) however, to have prevented natural succession to woodland from occurring on some spoil heaps (Section 4.3.2.1).

9.4.4 Species-area effect

The results from Section 7.3.4.3 agree with the results from previous studies such as Gray (1982) (Section 2.3.5.3), that the number of quadrats sampled has a direct effect on number of species recorded on each site. However, the sampling area does not seem to affect species-evenness as much as richness. As shown in Section 7.4.3, an increased sample size means that more rarely-occurring species are recorded, but does not affect the mean abundance of the more frequently-occurring species, and their relative dominance within the plot. Evenness may be more affected more by other factors such as grazing, pH, and the type of habitat (Sections 9.4.2, 9.4.3).

9.5. Species strategies

This section discusses results of the species strategies analyses that were undertaken and described in Section 7.4 in relation to the literature review that was undertaken in Section 2.3.5.

In this study it was found that perennials consistently dominated all plots, forming between 83-96% of all species (Section 7.4.1). The % of each of the Raunkaier (1937) life form categories did not change with variables such as increasing time (Section 7.4.3). These results are therefore very different from those of Prach and of Brierley, described in Section 2.3.6.2, whereby annuals and biennials dominated in the first 5-10 years of succession, and perennials dominated thereafter. Whilst Prach and Brierley's results support the r- and K hypothesis (Section 2.3.6.1), the results from this study do not.

The results from this study on species strategies (Section 7.4.2) do not match the Grime continuum theory either. Species with an intermediate or "generalist" CSR strategy were found to be consistently the most numerous on all sites. Stress-tolerant species showed a slight increase over time, rather than being most frequent on younger sites that are more highly stressed.

Both the r- and K- hypothesis, and Grime's continuum assume that environmental conditions for plant growth will ameliorate over time during the course of a succession which is not necessarily the case in the Forest of Dean, as found in Sections 7.1. Whilst soil depth does increase, and overall plant health appears to increase, pH does not, with the oldest site having one of the lowest pH values. This could explain the increase in stress-tolerant species. However, when Grime's allocated strategies are examined in relation to pH, stress tolerant species are no more consistently frequent on the most acid sites, or competitive species on more neutral sites.

The studies of Hall (1957) and del Moral and Wood (1993), described in Section 2.3.6, may therefore be more applicable to the findings of this study. These studies both found that surfaces available for primary succession tended to be colonised by species growing close to the site, as these provide a ready propagule source to the new surface. The life-form of the species may therefore be less relevant to colonisation and succession than whether a species is growing in close proximity to the site, and the propagules have the ability to get there.

Of the specific reproductive strategies examined, having the ability to reproduce vegetatively is consistently successful amongst the species growing on all sites. Between 51-68% of species on the plots were able to reproduce vegetatively (the most frequent reproductive category), and between 42-58% of species on each site have a high capacity for lateral spread (categories 4 and 5). These results support the findings of Prach *et al.* (1999) who noted the importance of species with a clonal growth form in being able to colonise colliery spoil tips in the Czech public.

The proportion of species with a low capacity (Category 1) for lateral spread tends to increase with time, whilst those with a high capacity for lateral spread (Category 5) tends to decrease with time (Section 7.4.6). This may indicate that species able to spread quickly over a surface are more successful at colonising the younger sites.

Down (1973) found that species which grow in a rosette were more common on younger spoil heaps than older ones, and thought that the long tap-root which these species have may confer a competitive advantage over other species on younger tips where moisture regimes tend to be more variable due to lack of substrate structure.

In this study, it was found that the percentage of species that are known to have long tap-roots rather than being shallow-rooting species are relatively frequent, between 22-44% of species on each site (Section 7.4.5). However, this figure is relatively consistent throughout all sites, meaning that there is no evidence of strong increases or decreases with measured environmental factors such as time, pH or slope gradient.

Given the lack of variability between sites of life-form, reproduction or "special" strategies, further research would be useful to ascertain whether the proportions of species with particular strategies found on spoil heaps in the Forest of Dean are significantly different to the proportions of each strategy, growth- or life- form are in "normal" plant communities of similar habitat (Section 10.4.2.3).

9.6 Floristics (classification & ordination)

This section discusses the results that were produced by TWINSPAN and DCA multivariate analyses, described in Chapter 8. The results from the different techniques are discussed together for each data-set. Because the different techniques analyse data in different ways, they may emphasize different qualities in the data. The techniques are therefore complementary to each other (Section 6.3.1.2), because they help to analyse trends more fully than is possible using one technique alone. Where relevant, the results are discussed in relation to univariate findings (Sections 9.1-9.4), and theories of succession (Chapter 2).

9.6.1 All plots

The results gained from the analysis of this data-set do not support the Clementsian viewpoint of succession (Section 2.1.1.1), but do support the Gleasonian viewpoint, that plant communities are influenced as much by environmental gradients present on a site than by time (Section 2.1.1.2).

Figure 8.33 shows that TWINSPAN and DCA results identify similar floristic groupings but emphasize different patterns within the data. The TWINSPAN diagrams (Figures 8.3 and 8.5) indicate that samples within plots tend to be more floristically similar than samples between plots. Samples from Cannop A and B are the exception, as they are more dispersed amongst the groups (Figure 8.5). This anomaly is explored further in Section 9.7.6.3.

The location of samples within the DCA diagrams meanwhile, emphasize similarities between the samples. Figure 8.28 shows how the samples ordination has a central cluster, with samples radiating outwards to form a triangle. When these results were analysed it was found that samples with a high percentage vegetation cover (and relatively high species-richness) are located towards the centre of the diagram. Samples with a lower percentage vegetation cover (and a lower species-richness) were placed towards the outer edges of the diagram. Samples from the upper plots of Northern United for example, lie in the centre of the diagram, and samples that are very species poor lie on the outer edges (Section 9.6.2).

This pattern may be a function of the Sørenson association analysis findings (Table 8.10) whereby species-rich samples are more likely to contain species in common than species-poor samples. Samples from plots with a high percentage similarity to each other in Section 8.3 (e.g. New Fancy A and B) tend to lie within the centre of the cluster; those with a lower percentage similarity (e.g. Northern United) lie outside the main cluster. The location of True Blue samples reflects the low % similarity of the heathland habitat with other plots.

Of the environmental gradients examined in relation to DCA samples, Figures 8.29 and 8.31 indicate that % canopy cover and pH gradients may influence floristic pattern. Correlation results discussed in Sections 9.1.1, 9.2.3 and 9.4.2 support this finding. Figure 8.30 however, does not show a clear pattern within the samples that relates to time. The results therefore do not fit with the Clementsian viewpoint of succession (Section 2.1.1.1), but do support the Gleasonian viewpoint (Sections 2.1.1.2 and 2.1.1.3). The separate plot groupings identified by TWINSPAN analyses emphasize that plant communities are likely to remain unique on each site, due to differences in environmental gradients. Environmental factors rather than time appear to influence plant colonisation and establishment (e.g. Section 9.6.2). The fact that plots such as New Fancy A and B are shown to be floristically very close to each other as well as spatially close may also support the viewpoint of Whittaker (1967) that plant communities will similar where environmental gradients are also similar (Section 2.1.1.3). The continuum of samples both between and within plots from 100% colonised to poorly developed indicates that over time, species from the developed samples on each plot are more likely to colonise the rest of the plot as environmental conditions ameliorate rather than the plant community changing completely towards a different 'climax' vegetation type. The results therefore support the findings of Egler (1954), who found that 95% of the species dominating the later stages of succession were also present in the initial stages.

9.6.2 Northern United

The results from sections 8.1.2 and 8.3.3 support Section 9.6.1. They show that succession is not occurring on Northern United in an orderly, Clementsian manner (Section 2.1.1.1). The establishment of vegetation occurs where environmental gradients within the plot are more favourable to plant growth, with acid-tolerant grass and tree species starting the succession rather than mosses.

Both ordination and classification results show that slope factor and aspect (location by transect) reflect some of the variation pattern found within Figures 8.8, 8.35 and 8.36. They do not clearly describe the patterns and clusters seen in Figures 8.7 and 8.34 however, indicating that further environmental gradients not measured in this study may also be influencing plant communities.

Figure 9.18. Photograph taken on Northern United showing how vegetation growth is much greener and more vigorous on patches of substrate where animal activities have improved nutrient status.

Observations made on the site (Figure 9.18), as well as expert opinion (e.g. Dr Moffat and Dr Fourt, see Appendix 1.3) and previous literature (Section 2.1) suggest that the most important factors are pH, nutrient status and drought. Insolation is also likely to be high on the site as the black substrates attract heat and the slope faces south (Section 2.3.2.2). Substrate surface temperatures recorded on the plot during a sunny day in July 2000 were regularly over 40°C, throughout the day. TWINSPAN results (section 8.1.2) show that the rate of colonisation and vegetation development is occurring faster on the upper slopes of the site than the bottom because environmental conditions are ameliorated here. The conifer plantation present at the top of the slope (Figure 4.2) may confer some shade protection to the upper slopes. The trees also intercept more rainfall, which reduces soil erosion at the top of the slope - the gullies at the top of the slope were much less steep and eroded than those occurring down-slope. Patterns of water availability were observed to affect species distribution. *Agrostis stolonifera* was predominantly found in the shallow gullies at the top of the slope, whereas *A. capilaris* and *Deschampsia caespitose* were able to colonise drier areas.

As shown in Table 9.2, the three most abundant species growing on Northern United are acid-tolerant, reflecting the pH results of 4.98 recorded on the plot (Section 9.1.1), and indicating that the ability to survive in acidic conditions may be a key factor determining species abundances on this site. Lower plants such as mosses, which Clements predicted are the first species to start a succession, only occurred on the upper slopes of the site.

Table 9.2: The 5 most abundant species occurring on Northern United*, and a summary of their respective growth strategies (Appendix 3.10).

% cover	Species	Grime strategy	PH preference	Capacity for lateral spread
8.75	*A. capilaris*	CSR	4	4
1.70	*Betula pendula*	SC	3	5
0.92	*Rubus fruticosus*	SC	4	5
0.65	*A. stolonifera*	CR	7	5
0.57	*Hypochoeris radicata*	CSR	7	2

* Does not include *Pinus sylvestris*, which was planted

9.6.3 Cannop A and B

The results show that similar to Northern United (Section 9.6.2), colonisation and vegetation development is occurring at different rates within the plot due to differing environmental gradients found. As discussed further in Sections 9.6.4 and 9.6.8, slope erosion, high slope factors and a substrate with a predominantly large particle-size were observed on this site, causing the substrate surface to be highly unstable on both plots. Appendices 3.3 and 3.8 show that the upper slopes of both plots were particularly poorly colonised, along with the lower slope of Transect 3 on Cannop B (Figure 4.5). Slope factors on these parts of the plots were 40°, which may exacerbate substrate surface instability.

The species-poor samples occurring on parts of the slopes with high slope factors of each site are likely to cause the Cannop A and B samples to inter-grade more within DCA and TWINSPAN diagrams than quadrats taken on other plots (Section 9.6.1). As found on Northern United (Section 8.1.2), the lack of species make these samples are very difficult to analyse floristically.

DCA results discussed in Section 9.6.1, indicate that there is a continuum of samples both between and within plots from those where vegetation is poorly developed to samples that are 100% colonised. Succession on Cannop A and B may therefore diverge over time towards the composition of the species-rich samples within each plot rather than converging to become more floristically similar. *Pteridium aquilinum* is dominant in TWINSPAN groups K-L on Cannop A (Figure 8.9). This is known to be an aggressive competitor (Marrs *et al.* 2000) and may therefore cause a different flora to develop here unless management of this plot changes (Section 10.2.2.3.1).

9.6.4 Cannop A

Plant vigour scores of 5 were recorded within 23 of 32 quadrats, illustrating that vegetation growth is extremely poor across the plot (Appendix 3.3). Subplots 1-2 on Transect 2 are the only location where a thin humus layer has developed (Table 7.3), and where plant vigour scores rise above 4. Observations on this plot indicate that high slope factors combined with substrate surface instability are likely to be growth-limiting factors on this site. The upper two subplots of Cannop A have a mean slope factor of 40° (Appendix 3.4). In addition, the substrate was observed to be extremely unconsolidated and unstable, consisting predominantly of large (2-10cm) shale and cinders particles. Down (1975a) noted the difficulty that plants have rooting in such substrates, and that water deficiency can be a problem as rainfall percolates straight through the large particles. Further tests would however, need to be undertaken on substrate physical characteristics to establish cause and effect (Section 10.4.6)

Table 9.3: The 5 most abundant species occurring on Cannop A, and a summary of their respective growth strategies (Appendix 3.10).

Species	**% cover**	**Grime strategy**	**PH preference**	**Capacity for lateral spread**
Fragaria vesca	4.19	CSR	7	4
Brachypodium sylvaticum	3.10	SC	7	3
Pteridium aquilinum	1.82	C	3	5
Agrostis capilaris	1.55	CSR	4	4
Rubus fruticosus	1.33	SC	4	5

Table 9.3 complements these observations as 4 out of 5 species have a high capacity for clonal spread, which would provide a competitive advantage for colonising an unstable substrate.

9.6.5 New Fancy A & B

The floristic and environmental data show that colonisation and succession processes have been much more spatially even on the New Fancy plots than on Cannop, Northern United and Lightmoor. Both plots have developed a closed sward, with less than 10% bare ground. One reason for this may be that environmental conditions are less harsh than on other plots. Neither plot faces due south for example (Section 9.2.2), pH is above 5.5 on both plots (Section 9.1.1), neither appears to have high levels of pyrites (Section 9.1.2), and slope is below 40° (Section 9.2.1).

New Fancy A and B lie within 5m of each other, yet DCA and TWINSPAN analyses show that the samples from each plot are separate floristically (Sections 8.1.5 and 8.3.5). Section 9.4 shows that New Fancy B has a lower species diversity than New Fancy A. Figure 8.47 shows that % canopy cover appears to influence floristic composition on the plots, but does not appear to explain why the samples do not inter-grade. The main difference between the plots that is the grazing regime. Although Foot and Mouth Disease (2002) prevented grazing differences from being quantified (Section 4.3), the differences between the plots are consistent with the results of previous studies, which suggest that grazing pressure on sites with a low-nutrient status can reduce diversity (Section 9.4.3).

Association analysis (Table 8.15) shows that New Fancy A and B have a relatively high percentage floristic similarity to each other, indicating that if management of grazing was changed, the sites may converge floristically over time. Further experiments would need to be undertaken on grazing however, to quantify the effect on floristic composition (Section 10.4.2.2).

9.6.6 New Fancy A

Both DCA and TWINSPAN results (Sections 8.3.7 and 8.1.7) clearly separate samples taken from Transects 1 and 2 of New Fancy A floristically. This pattern is described well by differing canopy cover categories (Figure 8.50). Figure 8.15 shows that that Transect 1 samples, taken from a more open habitat, are characterised by a high number of dicotyledon (herb) indicator species. Transect 2 samples are characterised by a higher number of grass and shrub indicator species. These findings are supported by results discussed in Section 9.2.3, which show that samples with lower shade categories are also more species-rich. The implications for the management are discussed in Section 10.2, alongside the frequency of woody species found on the site such as *Crataegus monogya* – an indicator species for many samples (Figure 8.15).

As shown in Table 9.4 the moss species *Hypnum cupressiforme* is the most dominant species on New Fancy A, and *Pseudoscleropodium purum* is also abundant. Mosses appear to be more dominant on New Fancy than other plots (Tables 9.2, 9.3, 9.6-8). The results on aspect discussed in Section 9.2.2 indicate that mosses are more abundant on plots such as New Fancy that have a more westerly aspect.

Table 9.4: the five most abundant species that have established on New Fancy A, and a summary of their respective growth strategies (Appendix 3.10).

% cover	Species	Grime strategy	PH preference	Capacity for lateral spread
16.5	*Hypnum cupressiforme*(1)	N/a	Widespread	?
14	*Brachypodium sylvaticum*	SC	7	3
12	*Pseudoscleropodium purum* (1)	N/a	Widespread	?
8	*Festuca rubra*	CSR	7	4
7	*Fragaria vesca*	CSR	7	4

9.6.7 New Fancy B

Figure 8.55 suggests that shade also influences floristic pattern on New Fancy B. Samples with a relatively low canopy cover (of less than 25%) are spatially separate from the samples with a cover of 50% or more. Figures 8.17, 8.18 and 8.54 also show that location on the slope partially describes the groupings. Neither shade nor slope categories however, fully describe the variations in pattern, which may indicate that a further environmental factor not measured here may also be influencing the samples (Section 9.4.3). Further research would need to be taken to ascertain whether shade cover, grazing, or a combination of both factors is most affecting floristic pattern (Section 10.4.6).

As discussed in Sections 9.6.5 and 9.4.3, New Fancy B is less species rich than New Fancy A, dominated by two main species *Brachypodium sylvaticum* and *Pseudoscleropodium purum* (Table 9.5). Figure 8.17 and Table 9.5 also show that many of the samples are characterised by woody shrub species such as *Ulex europaeus*. These results have implications for the management of the site, discussed further in (Section 10.2).

Table 9.5: the five most abundant species that have established on New Fancy B, and a summary of their respective growth strategies (Appendix 3.10).

% cover	Species	Grime strategy	PH preference	Capacity for lateral spread
37	*Brachypodium sylvaticum*	SC	7	3
24	*Pseudoscleropodium purum* (1)	n/a	Widespread	?
11	*Ulex europaeus*	SC	5	5
10	*Festuca ovina*	S	Widespread	3
3.5	*Eurhynchium praelongum* (1)	Shade tolerant	Indifferent	Not known

Source (1): Watson (1981)

The DCA and TWINSPAN groupings did not complement each other as well as they have done for other plots (Figure 8.56), due to 2 anomalous samples, 177 and 172. These samples contain *Hypnum mamillatum*, a moss occurring on *B. pubescens* trunks. TWINSPAN grouped the two samples containing this species together (Figure 8.17). DCA however, highlights the similarity of these samples to neighbouring samples that have a higher overall floristic similarity. The New Fancy B data-set is smaller than other plots, so the anomaly shows up more. This type of anomaly could be avoided in future by excluding moss on trees as a non-"rooted' species (Table 5.10), or removing the species from multivariate data-runs (Section 10.4.5).

9.6.8 Cannop B

TWINSPAN analysis (Figure 8.20) shows that location on the slope describes floristic pattern within the data well (Section 9.6.3). Samples that are relatively species rich tend to occur on the lower slopes of the plot. Samples that are species-poor tend to occur on the upper slopes (Section 9.6.3), and have been separated floristically from the other samples by both DCA and TWINSPAN (Figures 8.19, 8.20 and 8.59). There is little canopy cover above these samples and bare ground is much higher, due to high mean slope factors (39.3° for subplot 4), and poor substrate physical factors. The highly unstable substrate medium noted on parts of this plot has implications for its management (Section 10.2.3.4.2).

DCA analysis (Figure 8.60) indicates that % canopy cover affects species composition as well as substrate physical factors. This finding would support data taken from New Fancy A (Figure 9.8), although further analysis would need to be undertaken to evaluate this finding (Section 10.4.2.1, 10.4.5).

Table 9.7 the five most successful (abundant) species that have established on Cannop B, and a summary of their respective growth strategies (Appendix 3.10).

Species	**% cover**	**Grime strategy**	**PH preference**	**Capacity for lateral spread**
F. vesca	7.3	CSR	7	4
Atrichum undulatum (1)	2.33	Shade tolerant	Moderately acidic	Unknown
P. purum (1)	2.16	Unknown	Widespread	Unknown
R. fruticosus	2.04	SC	4	5
B. pubescens	1.73	SC	3	5

Table 9.7 illustrates the lack of vegetation cover that has developed on this site over the past 41 years. None of the five most abundant species have developed a mean cover above 10%. All of the vascular species occurring on the plot site have a high capacity for lateral spread, and 3 species show a preference for acidic conditions. These strategies may reflect the acidic (pH 4.79), unstable substrate found across the plot. Further experiments would however, need to be undertaken to investigate this (Section 10.4.3)

9.6.9 Lightmoor

Environmental and floristic data show that most of the samples taken from Lightmoor have plant vigour scores of 4 (Section 7.1.4), have developed little or no surface substrate layers (Section 7.1.3), no trees (Table 7.9) and a low % shrub cover (Table 7.13). The mean herb height is only lower on Cannop B (Table 7.12), and vegetation covers on average less than 50% of the plot (Table 7.14). These results indicate that environmental conditions present on the plot may be highly stressful for plant growth, even after 60 years-since-disturbance.

The substrate has a pH of 5 (Section 7.1.1). This is less acidic than the pH level of 4 that Gemmell suggests is directly harmful to plant growth (Section

2.3.1.1). Table 9.8 shows that four of the five most dominant species on the site prefer pH neutral substrates, which would support the evidence that pH is not a growth-limiting factor on this site.

Table 9.8: the five most successful (abundant) species that have established on Lightmoor, and a summary of their respective growth strategies (Appendix 3.10).

Species	% cover	Grime strategy	PH preference	Capacity for lateral spread
Agrostis stolonifera	13.74	CR	7	5
Medicago lupulina	8.00	S	7	1
B. sylvaticum	7.62	SC	7	3
F. vesca	7.3	CSR	7	4
Deschampsia caespitosa	3.81	SC	5	4

Observations made on the slope suggest that compaction of the substrates and related water problems are likely to be growth-limiting factors. The substrate was difficult to penetrate with a finger or thumb. The substrate surface was dry and cracked on the surface when hot, and waterlogged following rain. Compaction has been identified as a potential problem on colliery substrates characterised by a small particle size (e.g. Bradshaw and Chadwick, 1980; Ayerst, 1978). The floristic results support this observation. Both DCA and TWINSPAN results analyses identified samples occurring on the lower slopes of Transect 1 as floristically distinct (Figures 8.21, 8.22, 8.65), due to a higher abundance of grasses and mosses, increased species richness, and a 100% vegetation cover (Section 8.1.9). The slope profile is concave rather than convex at this point as shown in Figure 9.20, so is likely to be 'receiving' increased water, soil or nutrients rather than 'shedding' (Section 2.3.2.1). This part of Transect 1 is also the only place within the plot where substrate is present at a depth greater than 0.02cm. Growth experiments would however, need to be undertaken to ascertain whether substrate physical factors or nutrient deficiencies were the main growth-limiting factors (Section 10.4.6).

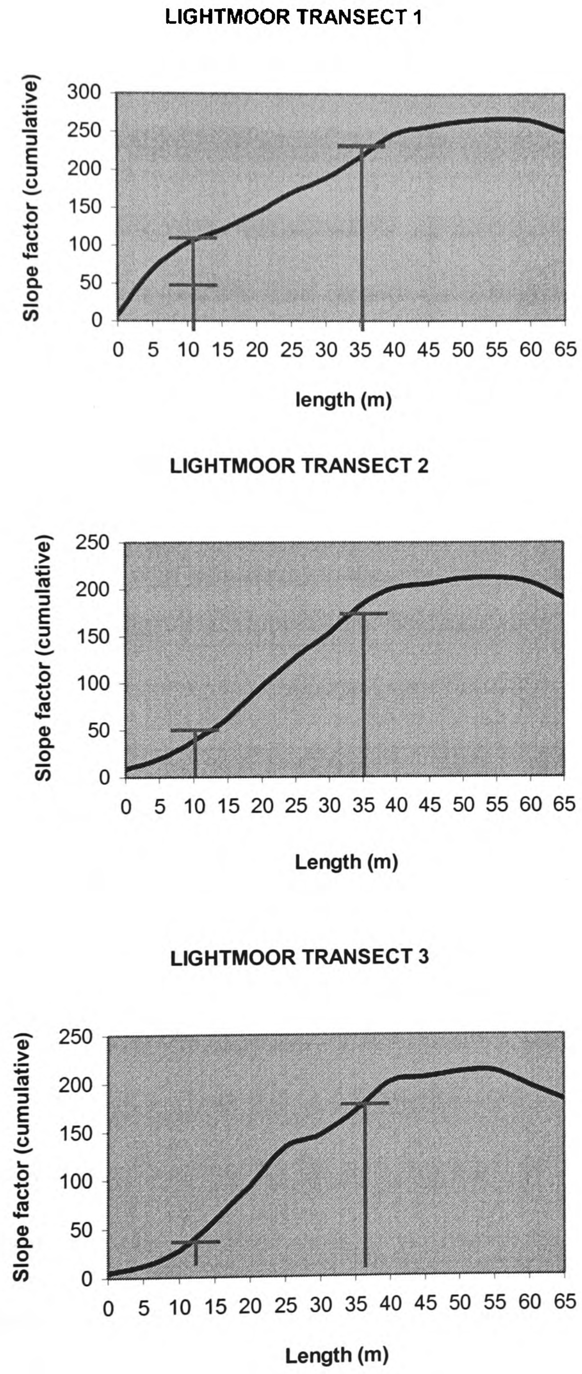


Figure 9.20: Slope profile of the 3 transects taken on Lightmoor, with transect start and end points indicated by ⊤.

9.6.10 True Blue

DCA and TWINSPAN show that location on the slope and % heather cover best describe floristic variation on True Blue (Figures 8.23, 8.67, 8.68, 8.69). Samples with a high % heather cover (75%+) and a high % moss cover tended to be distributed on the lower subplots of both transects. Samples taken on the upper slopes of the plot were characterised by lower heather cover (under 75%) and higher herb cover (20%). The results indicate environmental factors relating to slope affect floristic composition. Further experiments would however, need to be undertaken to test this hypothesis (Section 10.4.2.1).

Table 9.9: the five most successful (abundant) species that have established on True Blue, and a summary of their respective growth strategies (Appendix 3.10).

Species	**% cover**	**Grime strategy**	**PH preference**	**Capacity for lateral spread**
Calluna vulgaris	70.3	SC	3	4
F. rubra	6.3	CSR	7	4
P. purum	5.0	n/a	widespread	?
F. ovina	4.8	S	Widespread	3
Pleurozium schreberi	3.3	n/a	Acidic	?

Table 9.9 shows that *C. vulgaris* is a stress-tolerant competitive perennial, that can survive in acidic substrates. As the plot has a pH of 3.98 (low enough to directly limit plant growth), acid-tolerance is likely to provide a strong competitive advantage. *C. vulgaris* is a cyclical species, and according to Gimingham (1992) usually forms a transitory plant community during succession unless managed. The low pH of the plot may have helped this acid-tolerant species to dominate the plot, as local residents said that sheep did not graze on

True Blue, and the site was not actively managed (Appendix 1.3). They also said however, that the plot only developed a closed sward around 20 years ago. *C. vulgaris* may not have always dominated the plot. This has implications for the management of True Blue (Section 10.2), as *C. vulgaris* may not continue to dominate this site unless management is introduced onto this plot.

9.7 Summary

9.7.1 Substrate factors

The pH of the Forest of Dean spoil heaps ranges from 3.02-6.38. The modal pH value of 5-6 is less acidic than that of the Yorkshire spoil heaps (pH 3-4). There are strong correlations between increasing acidity and decreasing herb cover and (S), and a strong positive trend between increasing pH and increasing bare ground cover. This indicates that the low pH experienced on sites such as Hawkeswell, True Blue, and Northern United may be suppressing vegetation colonisation and development. The plots do not become less acid over time.

The substrate analyses indicated very weak levels of pyrites. Previous studies however, indicate that iron pyrites is likely to be present at moderate levels, as pyritic sulphur content is up to 3%. Pyrites levels in the Forest of Dean could be tested further in future studies (Section 10.4.2.1).

Soil depth is significantly correlated with age, and matches the expected results of Whittaker and Odum (Table 2.2). However, soil on all plots is still thin. Decreasing soil depth is also correlated with decreasing biomass index, indicating that vegetation development and substrate development may be inter-related.

9.7.2 Microclimate factors

Slope appears to affect plant vigour results, but in different ways in different plots. Samples taken from Northern United have a higher species diversity and cover-abundance at the top of the slope than the bottom. Samples taken on Cannop A and B have a higher species diversity and cover-abundance at the top of the slope than the middle or bottom.

The percentage of bare ground cover tends to increase on plots which are more southerly in aspect. Mosses have a greater percentage cover on plots with a more westerly aspect. The moss layer may therefore be particularly affected by differences in moisture and temperature regimes caused by differences in aspect, as southerly slopes tend to be hotter and drier.

Canopy cover results partially conform to the expected trend that vegetation becomes increasingly 'massive' over time (Table 2.2), with canopy cover increasing on plots until 36-41 years, but other factors may inhibit tree growth on plots such as Lightmoor and True Blue. For example, canopy cover is strongly correlated with increasing pH. Canopy cover and (S) was examined on New Fancy A. Mean (S) per quadrat is higher within samples that have a low canopy cover (under 24%).

9.7.3 Vegetation height, cover and biomass

Herb height and cover increases with increasing pH, indicating that low pH may particularly affect the growth of the herb-layer species. Moss height and cover are partially related to age and to aspect. Mosses have a low % cover and height until 36 years. Biomass increases on the younger sites, but declines after 36 years. The 41 and 60 year sites have biomass value as low as the youngest two sites, but biomass increases on the 100 year site. Plots with a high pyrites rank have a low biomass. Biomass and soil depth are strongly correlated.

9.7.4 Species diversity

Species-richness (S) increases between the 0-60 year plots, but declines after this for the 100 year old site. pH and soil depth also increase as richness increases, and pyrites rank decreases. Species-evenness declines with time, and is highest on the 16 and 36 year old sites. Species-evenness tends to increase as pH increases. These results do not conform to the expected trends outlined in Table 2.2, where both richness and evenness increase with time.

The plot where grazing has been excluded is both more species rich and species-even than a similar plot where grazing in not excluded. The number of quadrats sampled is strongly correlated with species-richness, as more rare species are recorded on larger sites. Sample-size does not affect species-evenness, as the abundances of the more frequently-occurring species are more important to determine evenness.

9.7.5 Species strategies

Perennials consistently dominated all plots with the proportion of annuals and biennials not changing with age or pH. The highest proportion of species were generalist CSR strategies. The proportion of species with the ability to reproduce vegetatively was consistently high on all plots. The number of plants with a high capacity for lateral spread declined over time, and mean slope factor did not appear to influence the capacity for lateral spread.

9.7.6 Floristic results

9.7.6.1 All plots

The results gained from the analysis of this data-set support the Gleasonian viewpoint of succession, which argues that plant communities are influenced as much by environmental gradients present on a site than by time.

TWINSPAN shows that samples within plots are more floristically similar to each other than samples between plots. Within the DCA diagrams, samples form a continuum, with species-rich, 100% vegetated samples from each plot clustered towards the centre of the diagram, and species-poor samples radiating outwards. There was no clear pattern within the samples relating to time, indicating that species from the species-rich samples on each plot are more likely to colonise the rest of the plot over time rather than a series of different vegetation types developing towards a 'climax'. The results therefore support the findings of Egler (1954).

9.7.6.2 Northern United

The establishment of vegetation on this plot is more dependent on environmental factors rather than time, with acid-tolerant species starting the succession rather than mosses. Observations, expert opinion, and previous literature suggest the growth-limiting factors on this site are pH, nutrient status, water shortages, and high surface temperatures in the summer. The rate of colonisation and vegetation development is occurring faster on the upper slopes of the plot than the bottom due to the presence of a conifer plantation that is likely to create a more favourable microclimate. Lower plants such as mosses, which Clements predicted are the first species to start a succession, only occur on the upper slopes.

9.7.6.3 Cannop A and B

Both DCA and TWINSPAN analyses show that Cannop A and Cannop B samples taken from the upper slopes are not as clearly separated from each other as samples from other plots. The species-poor samples occurring on the upper slopes make these samples very difficult to analyse floristically. The upper slopes of Cannop had high slope factors. Substrate instability was also observed to be a problem for plants trying to colonise these areas. Results from the 'all-plots' data indicate that these species-poor samples are likely to become floristically closer to the more species-rich samples within each plot over time rather than converging to become more floristically similar.

9.7.6.4 Cannop A

Plant vigour scores show that vegetation growth is extremely poor growth across the plot, except on the lower slope of Transect 2. Observations and previous studies indicate that high slope factors (40°), a large substrate particle-size, and substrate surface instability are likely to be growth-limiting factors on this site that affect floristic composition. 4 out of the 5 most common species on the plot have a high capacity for clonal spread, complementing these findings.

9.7.6.5 New Fancy A and B

Both multivariate techniques show that New Fancy A and B samples are very floristically similar, but yet the samples remain separate spatially, and there is no overlap or mixing of the samples from each site on either the DCA or TWINSPAN diagrams. The differing grazing regime may be a reason for these differences, as New Fancy A is enclosed and New Fancy B is not.

Colonisation and succession have been much more even on both New Fancy plots than on plots of similar age such as Cannop B. The percentage of bare ground is low across the plots, and the species richness, plant vigour and percentage bare ground results have low standard deviations, indicating that the results are evenly distributed across the plot. Except on True Blue, these two plots are the only plots to have developed a closed vegetation sward, with a diverse and complex structure that comprises the canopy, shrub, herb and moss layers.

9.7.6.6 New Fancy A

Both multivariate techniques floristically separate samples taken from Transects 1 and 2, a pattern that is described well by differing canopy cover categories. Transect 1 samples are from a more open habitat and are characterised by a high number of dicotyledon (herb) species. Transect 2 samples are characterised by a higher number of grass and shrub indicator species. The abundance of woody species on this plot has implications for the management of the plot. Mosses appear to be more dominant on New Fancy than other plots, indicating that species composition may also be affected by aspect.

9.7.6.7 New Fancy B

DCA analysis suggests that shade influences floristic pattern on New Fancy B. Samples with a relatively low canopy cover (of less than 25%) are spatially separate from the samples with a cover of 50% or more. Neither shade nor slope categories fully describe the variations in pattern, which may indicate that a further environmental factor is influencing the samples. This may be shade cover, grazing, or a combination of both factors.

New Fancy B is less species rich than New Fancy A, dominated by two main species. Many of the samples are characterised by woody shrub species, which has implications for the management of the site.

The DCA and TWINSPAN groupings did not complement each other as well as they have done for other plots due to 2 anomalous samples, that contain *Hypnum mamillatum*, a moss occurring on *B. pubescens* trunks. This type of anomaly could be avoided in future by excluding moss on trees as a non-“rooted’ species, or removing the species from multivariate data-runs.

9.7.6.8 Cannop B

Vegetation occurring within quadrats on the upper subplot tend to be more species poor than other samples. These samples have been identified by both DCA and TWINSPAN as being floristically very different from other samples. Slope factors of 40° and over were recorded on this part of the slope, and observed substrate instability may be a contributory factor to the retarded vegetation growth recorded here. Canopy cover and slope both partially describe patterns observed in the DCA data, although other factors such as substrate instability that were not measured in this study may also affect floristic composition. Overall vegetation and substrate development on this site has been low despite being 41 years-since-tipping. The most abundant species on the site, *Fragaria vesca,* is only recorded on 7% of the plot.

9.7.6.9 Lightmoor

The results on Lightmoor indicate that environmental conditions present on the plot that were not measured in this study may be highly stressful for plant growth, even after 60 years-since-disturbance. The pH of 5 is above the level at which acidity is directly harmful to plant growth. Observations made on the slope and previous literature suggest that compaction of the substrates and related water problems are likely to be growth-limiting factors, although growth experiments would need to be undertaken to confirm this. Field data however, shows that on parts of the slop with a receiving slope profile vegetation had fully colonised the samples and was relatively species-rich. This part of the slope is likely to be 'receiving' increased water, soil and nutrients rather than 'shedding'. Differing aspect on Lightmoor was also found to coincide with changes in moss cover, which also indicates that changes in microclimate such as insolation levels and related changes in moisture affects vegetation composition.

9.7.6.10 True Blue

TWINSPAN and DCA both show that location by transect and slope describe some of the variation within the data, and DCA shows that the abundance of heather dominating each samples also describes variation within the data. Samples with a higher % heather cover tend to be distributed on the lower subplots and have a lower herb cover than samples with a lower % heather cover. The plot has a low pH or 3.98, which is low enough to retard plant growth, and may be a reason why heather is able to dominate the site without management intervention.

Chapter 10: Conclusions, evaluation of research and recommendations

This chapter draws conclusions from all of the chapters, and produces recommendations for the practical management of colliery spoil heaps in the Forest of Dean to fulfil the final objective (Section 1.1.1). The aims and objectives of the research are evaluated to see whether each objective has been met. Where problems were met during the research, improvements are suggested. Ways in which the research could be developed in the future are discussed.

10.1 Conclusions

In this section, the findings of the previous chapters are drawn together to summarise why this study was undertaken, the methodology used, and the results gained.

10.1.1 Why study succession on colliery spoil heaps in the Forest of Dean?

This study is important because spoil heaps in the Forest of Dean have cultural and archaeological interest, ecological interest, amenity value, and are an integral part of a landscape that has been heavily influenced by industry. This study increases the understanding of successional processes on spoil heaps, which can help aid management decisions designed to further increase their interest.

Mining heritage is important to people within the Forest of Dean. The common right to mine coal is a tradition that has spanned at least 700 years and so mining has had a profound influence on local culture. Colliery spoil heaps are an integral part of the post-industrial landscape of the Forest of Dean, and this one of the only coalfields in the UK where spoil heaps are not intrusive in the landscape, and can even be positive features. Colliery spoil heaps can add cultural value to the landscape for local people, as they provide visible links with mining and with a past way of life. Local reports (Hobday, 1994) also argue that spoil heaps in the Forest of Dean need to be preserved and managed for this purpose.

Spoil heaps can have ecological value as open vegetation patches within the woodland matrix. Sheep-grazing is currently the only management method used to control vegetation growth on the spoil heaps, however. This is not a reliable method because grazing is un-managed, with sheep allowed to roam freely. It is therefore difficult to increase or decrease grazing numbers. This study will help to examine successional processes in more detail. The information gained can help meet the nature conservation targets of the area by increasing information on colonisation and successional processes and promoting an understanding of the wildlife value of spoil heap communities, as well as making recommendations to improve biodiversity.

10.1.2. How is succession measured?

The space-for-time substitution method was used to study succession on sites selected to form a chronosequence. As the spoil heaps occur within the same English Nature Natural Area (Section 3.1.2), variations in climate, geology, topography are minimised, meaning that time can be isolated from other environmental gradients. Current and future site management, age, source of waste material, topography, aspect, and vegetation homogeneity were used in this study as further site selection criteria to ensure that environmental heterogeneity between sites was minimised (Section 3.2).

10.1.3 Methodology

Of 29 sites considered, 8 plots from 6 sites passed the selection criteria, ranging from 0-100 years-since-disturbance (Section 4.1.1). A flexible sampling design was developed because the sites were of different sizes (Section 5.1.4). Floristic, soil depth, plant vigour, canopy cover, sward height and biomass data were collected from transects measured up the slopes of each plot. Pyrites and pH analysis were undertaken on bulked soil samples from each plot (Section 5.2). Aspect was measured per transect and slope factor by 5m subplot (Section 5.3). Floristic vegetation factors were measured using the Braun-Blanquet visual estimation technique (Section 5.7). Species strategies information was compiled on each species recorded found using literature sources such as Grime *et al.* (1988) (Section 5.6).

Correlation analysis was identified as a useful method of finding potential relationships between the non-floristic data (Section 6.1). The Spearman Rank method was selected because it is non-parametric and can be used to analyse data-sets that are ordinal in nature or do not have a normal distribution (Section 6.1.1.1).

Four indices of diversity were evaluated on the Forest of Dean data. They were selected to emphasise different properties of diversity such as richness and evenness (Section 6.2.2). Species-abundance diagrams were constructed (Section

6.2.3), to evaluate these properties. Correlation analysis using the Spearman rank method was also undertaken between species diversity indices and sample-size to investigate how the diversity data is affected by area (Section 6.2.5).

Multivariate analysis was considered to be the best statistical method to analyse the floristic data because it reduces complexity (Section 6.3.1.1). Classification and ordination were used together on the data because these techniques are complementary to each other (Section 6.3.1.2). TWINSPAN was used to classify data, and DCA to ordinate data (Section 6.3.2). Association analysis was undertaken on the data to quantify floristic similarities (6.3.3). The Soresen and Czeckanowski coefficients were both evaluated. The Czeckanowski coefficient was selected because it was less affected by the species-area effect.

10.1.4 Plant succession results

10.1.4.1 Substrate factors

The Forest of Dean plots were less acidic than those of other coalfields in the UK such as the Yorkshire, Durham or Somerset spoil heaps. Six out of 8 plots have a pH of 4+, below which pH becomes directly harmful to plant growth. Significant correlations (Section 7.5) were found at the 95% level or above ($P>0.05$) between pH, slope and aspect, whereby plots with a more neutral pH tend to have steeper slopes and face in a westerly direction. Increasing pH was also significantly negatively correlated ($P >0.05$) with decreasing % herb cover and % canopy cover, indicating that the low pH experienced on Hawkeswell, True Blue and Northern United may suppress vegetation development (Section 91.1).

Pyritic sulphur content in the Forest of Dean was found in previous studies to range from 0.41-3.19% across the coalfield, although the test papers from this study indicated a low level of pyrites. Cannop A had the highest pyrites rank. Lightmoor and True Blue had the lowest ranks (Section 7.1.2). Strong positive correlations were found between decreasing pyrites rank and increasing age, plant vigour moss height and species richness (Table 7.36).

Increasing soil depth was significantly correlated ($P>0.05$) with increasing age moss height and cover, shrub cover, species-richness and decreasing % bare ground (Section 7.5). These results therefore matched the expected results of Whittaker and Odum (Table 2.2, Section 9.1.3). Soil on all sites however, was still extremely thin.

Plant vigour scores are poor on Hawkeswell, Northern United, Cannop A, Cannop B and Lightmoor, indicating that environmental conditions may be least favourable for plant growth on these sites. Increasing plant vigour is strongly correlated with decreasing % bare ground and increasing moss height and cover (Table 7.36). These results indicate that where patches of bare ground are present the vegetation is less healthy-looking, with a shorter sward, fewer moss species, and lower diversity (Section 9.1.4). Further research would need to be undertaken however, to see which substrate parameters are the main growth-limiting factors on each site (Section 10.4.2.1, Section 10.4.6).

10.1.4.2 Microclimate

Cannop B had the highest mean slope factor of 32.3°, but 40° slopes were also recorded on Lightmoor and Cannop A (Section 7.2.1). Significant correlations (P>0.05) were found between decreasing slope and increasing % canopy cover and herb cover (Section 7.5). Slope appears to affect plant growth in different ways on different plots (Section 9.2.1). Plant growth was retarded on the upper slopes of Cannop A and B due to the steep 40° slope factors combined with observed substrate instability (Sections 9.6.4, 9.6.8). On plots such as Lightmoor, the slope had a receiving drainage pattern in some areas, which were found to be more favourable for plant growth than areas that were shedding (Section 9.6.9).

Significant correlations (P>0.05) were found between a southerly aspect and lower moss cover and height, a lower herb height, and higher % bare ground cover (Section 7.5). Aspect may differentially affect vegetation growth within plots as well as between plots (Section 9.2.2). The moss layer of the vegetation appears to be particularly affected by the potential microclimatic differences that may occur with differing aspect. On Lightmoor, moss cover was found to be decrease as the transects became more southerly facing (Figure 9.6).

As noted above, increasing canopy cover was significantly negatively correlated (P>0.05) with increasing pH, a more westerly aspect, and steeper slopes (Section 7.5). TWINSPAN and DCA results both show that the % canopy cover appears to affect species composition both between plots, and within plots (Section 9.2.3). For example on New Fancy A there is a distinct separation of samples from transect 1 which has a mean canopy cover of less than 25%, and Transect 2, where samples tend to have a mean % canopy cover of more than 50% (Sections 9.2.3, 9.6.6). The higher % canopy cover on New Fancy B may be one factor influencing species richness and composition between the two New Fancy plots (Section 9.6.5), although the effects of grazing would also need to be investigated (Section 10.4).

10.1.4.3 Vegetation height and biomass

Table 2.2 showed that vegetation is expected to gain in 'massiveity' over time and in biomass. The results found in this study did not support this expected trends. Tree (canopy) cover (Section 9.2.3) for example increases on plots until 36-41 years, but trees were not present on Lightmoor and True Blue. The development of the ground-layer (height and cover) may be partially related to age, as this layer has a low overall cover and height until 36 years (Section 9.3.1).

Significant correlations between environmental factors and vegetation factors have been noted in Sections 10.1.4.1 and 10.1.4.2. Different environmental factors appear to affect different vegetation layers. Canopy cover and herb cover for example, were significantly correlated with pH, whilst moss cover was significantly correlated with age, aspect and soil depth.

10.1.4.4 Species diversity

As discussed in Section 2.3.4.2, species diversity does not always increase with age. It has been found that diversity tends to decrease with increasing biomass unless the competitive species are suppressed by a continuous moderate-intensity disturbance such as grazing. In the Forest of Dean, it was found that the species-richness component of diversity did increase with time until 60 years. Species-evenness however, declined with time, and was highest on the 16 and 36 year old sites (Section 9.4.1). These results do not therefore conform to the expected trends outlined in Table 2.2 whereby both species richness and evenness increase with time (Section 9.4.1). The results do not conform to the Tilman hypothesis either (Section 2.3.5.2), as diversity does not appear to decrease as biomass increases (Figure 9.14).

The New Fancy A plot, where grazing has been excluded, had a higher species diversity than New Fancy B, a similar plot where grazing is not excluded (Section 9.4.3). This result may fit into the pattern discussed in Section 2.3.4.1), that nutrient poor plant communities tend to be more species-poor under high grazing intensity than low intensity. However, this is difficult to quantify, as grazing intensity could not be measured in this study (Section 10.4.2.2.1).

The different size and area of the plots did affect species-richness. The number of quadrats sampled was strongly correlated with species-richness (Section 9.4.4), because increasing sample size tended to increase the number of rarely-occurring species that were recorded. Species-evenness patterns were not affected as much because as the abundances of the more frequently-occurring species are more important in determining evenness. It was not possible to test the Island Biogeography theory that bigger spoil heaps may be more species rich (Section 2.3.4.2) because of the differing plot sizes (Section 10.4.2.2.2).

10.1.4.5 Species strategies

Tilman (1985, 1988) and Grime (1979) both state that those species likely to dominate a plant community at any given time are those best adapted to the environmental conditions present (Section 2.3.5.1). The results from this study however, show that the percentage of plant species possessing each of the different strategies examined (Table 5.10) remained similar on all plots regardless of age or pH (Section 9.5).

The *r* and *K* hypothesis predicts that shorter lived *r* strategists such as annuals will be the first type of species to colonise a bare site, followed by longer lived *K* strategists such as perennial species (Section 2.3.5.1). In this study, perennials consistently dominated all plots with the proportion of annuals and biennials not changing with age or pH (Section 9.5). The study also found little difference in the competitive strategy allocated to each species by Grime *et al.* (1988).

The highest proportion of species found on the spoil heaps were categorised as having generalist CSR strategies. The proportion of stress-tolerant species increased slightly over time, which is contrary to Grime's prediction that more stress-tolerant species will be present at the beginning of a succession, and those with more competitive strategies increasing in dominance over time (Section 2.3.5.1). This prediction is based on the assumption that environmental conditions on a site will improve over time, whereas in the Forest of Dean, environmental conditions such as pH do not necessarily ameliorate over time (Section 9.1.1).

The proportion of species with the ability to reproduce vegetatively was consistently high on all plots, which would support the observations of Prach *et al.* (1999), that species with clonal growth strategies can be important in colonising colliery spoil sites where the substrate surface is unstable (Section 2.3.5.2). Further research on plant communities in the Forest of Dean would however, need to be undertaken to ascertain whether the proportion of clonal species is similar in communities not growing on colliery spoil (Section 10.4.2.3).

10.1.4.6. Floristics

10.1.4.6.1. Expected and actual successional trends occurring on colliery spoil heaps in the Forest of Dean

Table 10.1 summarises the trends that were used to indicate whether succession was found to be occurring in the Forest of Dean (Section 2.2), and whether the vegetation communities were found to change over time.

Table 10.1: Evaluation of the expected trends outlined in Table 2.2 that were used as quantitative indicators of succession within this study, and the actual trends that occurred in the Forest of Dean

	Expected trend over time →			**Trend recorded in the Forest of Dean**
Substrate	Shallow	Deep	✓	Shallow to deep
	Horizons not differentiated	Horizons differentiated	X	Horizons started to be differentiated on one subplot of one site
Non-floristic vegetation	Low biomass	High biomass	P	Increased until 36 years, but 41 & 60 year plots have similar biomass to younger sites
	Low height	High height	X X P	-Shrub height decreased -Herb height highest on 36 years sites, but no clear pattern with time - Moss height low until 36 years.
Diversity	Poor	Rich	P	Richness increases until 60 years but oldest site has low richness.
	Uneven	Even	X	Shannon E value declines with age of site. Highest on 36 year plot NFA.
Life history	r-strategists	K strategists	X	Longer lived perennials dominant on all plots.
	Stress tolerant	Competitive	X	Generalist CSR species highest proportionally on all sites. Stress tolerant species increase over time.

Key:
✓ Expected trend occurred
X Expected trend did not occur
P Expcted trend partially occurred

The results do not support the Clementsian viewpoint of succession (Section 9.6). Clements (1916) thought that succession occurs as a pre-determined systematic process, from lower to higher plants, and ending at a stable, climax, vegetation type (Section 2.1.1.1). In the Forest of Dean however, higher plants such as grasses and shrub species were observed to be the first species to colonise younger sites such as Northern United (6 years) and Cannop A (16 years) (Sections 9.6.2, 9.6.4). Lower plants such as mosses do not form a consistent or abundant component of the flora until 36 years. Mosses also appear to be influenced by the aspect of the site as well as the age, being more abundant on sites that face in a westerly direction (Section 9.2.2).

The results gained from the analysis of this data-set support the Gleasonian viewpoint of succession, which argues that plant communities are influenced as much by environmental gradients present on a site than by time. TWINSPAN shows that samples within plots are more floristically similar to each other than samples between plots. Within the DCA diagrams, samples form a continuum, with species-rich, 100% vegetated samples from each plot clustered towards the centre of the diagram, and species-poor samples radiating outwards.

10.1.4.6.2 Mechanisms of succession

The results from sites such as Northern United and Lightmoor where the percentage of bare ground is still high, show that the pattern of succession within the plots are not even, and specific areas on each plot tend to develop before others. There was no clear pattern within the 'all-plots' data relating to time, indicating that species from the species-rich samples on each plot are more likely to colonise the rest of the plot over time rather than a series of different vegetation types developing towards a 'climax'. The results therefore support the findings of Egler (1954).

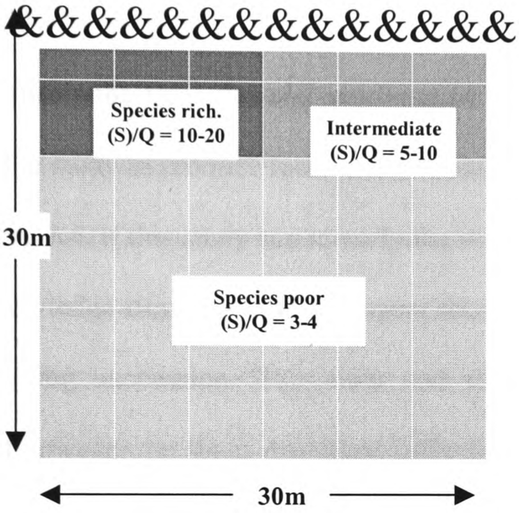


Figure 10.1: Differential patterns of mean species richness (S) of quadrats (Q) found to occur on Northern United

Figure 10.1 summarises the floristic results for Northern United (Section 9.6.1), showing the differential pattern of vegetation development caused by the presence of a mature conifer plantation at the top of the slope that may altered insolation and drainage patterns on this part of the plot. Figure 9.18 also illustrates how the activities of animals may help plants to establish on parts of the plot.

A further argument to support the findings of Egler (*op. cit.*) is that species such as *Agrostis capilaris,* the most abundant and widespread colonist overall on Northern United (8.75%) also forms part of the closed swards occurring on this site with a cover of between 10-30% (Section 9.6.2). It is also present on sites such as New Fancy A, at an overall % cover of 4%. Some of the indicator species that characterise the species-rich Northern United plots such as

Pseudoscleropodium purum, *Prunella vulgaris*, and *Vicia sativa* (Section 8.1.2) are also indicator species on the Fancy A plot (Section 8.1.5).

10.2 Recommendations for management

This section fulfils the final aim and objective of the study, by using the results gained from the study to produce recommendations for management (1.1). As explained in Figure 1.4, if this study can identify the ways in which succession is occurring, this knowledge can help land managers formulate clearer aims and objectives for managing succession. The aims and objectives of managing succession must first however, be set as discussed in Section 10.2.1. The findings of this are used to discuss these management aims in Sections 10.2.2 –10.2.4, and drawn together management prescriptions for the Forest of Dean spoil heaps. Section 10.5 also discusses site-specific management that addresses problems encountered on each plot.

10.2.1 Setting common goals for site management

Table 4.1 shows that the study plots have developed at least 3 different habitat types – woodland, grassland and heathland; differences which are confirmed by TWINSPAN analysis (Section 9.6.1). The aims of management are therefore set out in Section 10.2.1 to establish common goals for all sites. Section 10.2.1.2 examines the aims of managing succession.

10.2.1.1 Aims of site management

In order to produce management recommendations, the aims of the management should first be defined. The priorities of English Nature (1995, 1997) have therefore been used to define management aims; the key aims in the Forest of Dean area that relate to the spoil heaps (Section 4.2.3) are to:

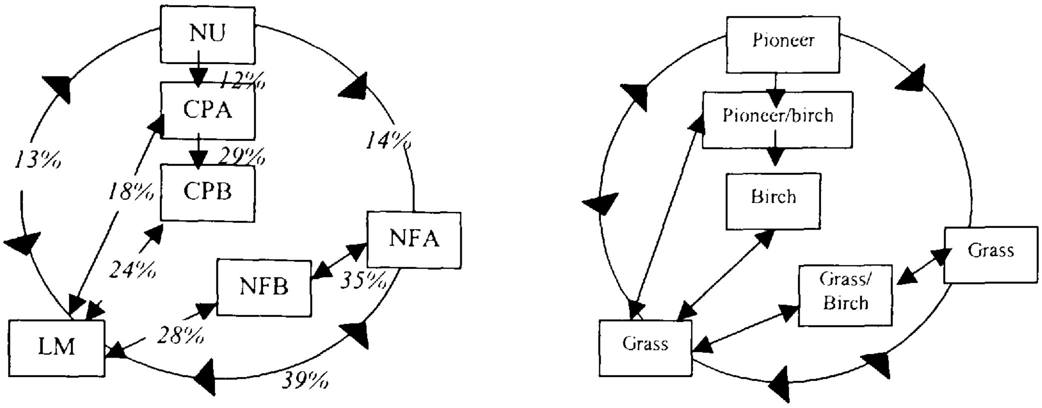
1) Prevent further loss of open habitats such as grassland and heathland
2) Seek to expand the resource where possible

Not all of the sites have developed open communities, but as these habitats are scare (English Nature, 1997), they are a priority habitat compared to woodland habitats. This does not mean that woodland sites such as Cannop should necessarily be cleared, but can help prioritise sites and actions. According to Macgurran (1988), measuring species diversity within sites can also provide a useful means of evaluating management prescriptions. A common management aim for all of the plots is therefore to improve diversity.

10.2.1.2 Aims of managing succession

The role of succession in vegetation management is explained in Section 1.4. If the management aims for an area are to be met (Section 10.2.1.1), management activities may be required to modify the rate and direction of succession.

Figure 10.2a summarises the floristic similarity results between plots produced by association analysis (Table 8.15). Arrows are drawn between sites to indicate potential successional pathways where the % similarity was above 10%. Plot names are replaced by habitat types in Figure 10.2b.



a) b)

Figure 10.2: Potential successional trends that may occur on the Forest of Dean colliery spoil heaps based on age and how high the Czekanowksi similarity coefficients are between each plot. (a) shows plot names and coefficients, used to create b) potential successional trends.

Figure 10.2 shows that management intervention in the successional process is important on younger sites such as Northern United if the management aims are to be achieved, because succession could develop towards either a woodland flora or towards open grassland habitats.

Luken (1990) argues that to manage succession, disturbance, colonisation and species performance must be controlled. In Chapter 1, Figure 1.3 explained that there may also be particular problems faced by plants trying to establish during a primary succession. Figure 10.3 summarises the answers to the questions asked in Figure 1.3. The diagram illustrates that whilst factors such as grazing regime, shade and location affect species composition, some sites may also have a problem of 'arrested succession', whereby succession is prevented from occurring or is occurring very slowly due to one or more environmental factors.

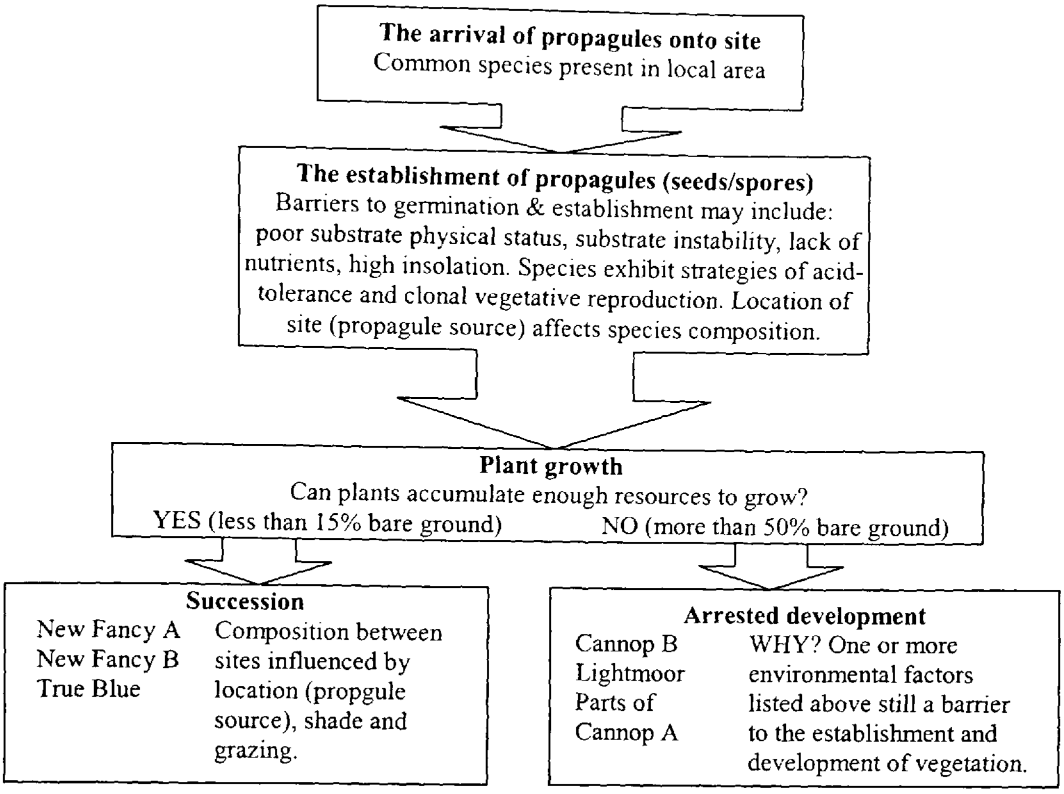


Figure 10.3: the stages involved in primary succession in the Forest of Dean, and problems faced by plants trying to establish. Adapted from Bradshaw (1993).

NB: Hawkeswell and Northern United are not listed in the diagram, as these plots have young surfaces and it is not possible to tell whether succession these plots is 'arrested' or not.

These diagrams help to illustrate the aims of managing succession in the Forest of Dean. Section 10.2.2 examines how disturbance on spoil heaps may be managed. Section 10.2.3 examines management factors that could influence successional pathways (species performance), and Section 10.2.4 examines management techniques that could be used to 'boost' vegetation development on plots where succession may be arrested.

10.2.2 Management of disturbance

Types of disturbance occurring on the Forest of Dean spoil heaps include grazing (Section 4.3); re-working of existing spoil heaps (Section 1.3.3) and amenity use (Section 4.1 and 4.2 4). Grazing is discussed in relation to species performance in Section 10.2.4, but re-working and amenity use are discussed in Sections 10.2.2.1 and 10.2.2.2.

10.2.2.1 Managing succession following the re-working of existing spoil heaps

The re-working of sites such as Hawkeswell provides an opportunity to manage the problems associated with colliery substrates before they cause problems for colonisation and succession (Figure 10.2). The deep incorporation of lime and fertilisers into fresh colliery substrates can ameliorate problems such as pyrites and high acidity (Bradshaw and Chadwick (1980).

Seeding techniques can help to 'green-over' sites very quickly to reduce its visual impact (Section 4.2.5). This may be a priority for some areas within the Forest of Dean, where tourism is important to the local economy, although may impact on diversity. Theoretically, substrate amelioration and seeding controls the initial stages of succession, and directly creates a "climax" plant community (Munshower, 1993, Parker, 1995). In reality, it is still difficult to exactly re-assemble natural plant communities because it is difficult to control the environmental and chance factors that affect plant succession (e.g. Hobbs and Norton, 1997). Studies such as Koehler (2000), have found that both plant and animal communities on restored sites are different from those left to naturally recolonise and may be less diverse. Jocheimsen (1996) argues that re-vegetation approaches should be based on natural succession, because if natural succession is allowed to occur the ecosystem will gradually develop into a self-sustaining ecosystem. For the purposes of this study, where diversity rather than quick 'greening' is a consideration, the following prescriptions are recommended:

a) Calculate the Acid Neutralising Capacity of the coal spoil to find out how much lime would be needed to ameliorate acidity.

b) Incorporate lime deep into the colliery substrate prior to re-grading the surfaces

c) Re-grade surfaces to slope factors of less that 25° to reduce erosion

d) Use hydroseeding techniques to quickly apply seed mixtures mixed with light fertiliser applications and a substrate improver such as wood-chips or compost to improve the chances of seedling establishment (DoE, 1996).

e) As diversity and nature conservation are a consideration, seed mixtures should be based as much on natural plant communities as possible.

f) Seeds could be collected from species present on older sites such as New Fancy, Cannop B or Lightmoor.

g) Control plots and monitoring should be set up to investigate the effects of these prescriptions on diversity.

10.2.2.2 Managing amenity use

Observations on the sites show that the use of spoil heaps by local people and visitors for walking and mountain-biking presents an additional stress for plant communities. This type of disturbance is particularly damaging on sites such as Cannop, and Lightmoor where substrate physical factors may be limiting plant growth such as substrate compaction or substrate surface instability. The following prescriptions are therefore recommended:

a) Promote spoil heaps that are able to tolerate amenity disturbance, and discourage amenity use of spoil heaps with arrested succession
b) Encourage people to stay to managed routes on spoil heaps rather than walking over the whole site (e.g. through fencing, interpretation, creating attractive pathways)
c) Create managed mountain-biking runs that encourage bikers to stay within specific areas
d) Create an amenity strategy for spoil heaps that would increase information available on spoil heaps to explain their value as part of the industrial landscape

10.2.3 Management of species performance

10.2.3.1 Grazing disturbance

The findings of this study and of previous studies indicate that because colliery spoil substrates tend to be nutrient poor (or nutrient deficient) grazing presents additional stress that may reduce species diversity (Section 9.4.3) rather than increase diversity. Grazing within woodland habitats also tends to reduce structural diversity because the regeneration of shrubs and trees is prevented (Fuller and Peterken, 1995). If the management aims (Section 10.2.1) are to be successful however, some regular disturbance such as grazing or mowing is likely to be needed on open habitats, or younger 'pioneer' communities, to prevent natural succession towards woodland habitats (e.g. Gimmingham, 1992, Ausden and Treweek, 1995).

One problem in the Forest of Dean is that because of ancient grazing rights, grazing cannot currently be controlled to ensure that it is set at an appropriate level for nutrient-poor spoil heap plant communities (Section 4.3.2.1). Assuming that these grazing rights continue in the future and prevent a more targeted grazing regime to be implemented, management recommendations for this site are therefore as follows:

a) Fence off woodland sites such as Cannop from grazing
b) Trial the use of semi-permanent fences on open habitats and younger sites to alleviate grazing pressure
c) Should temporary fencing be expensive, priority sites could be cut using an annual or biennial mowing regime
d) Implement a simple annual monitoring programme to record changes in species composition, % bare ground and diversity
e) Use the results of monitoring to inform management decisions, e.g. to open sites back up if grazing is needed to reduce colonisation by woodland competitors.

10.2.3.2 Differential species performance under shade

10.2.3.2 Differential species performance under shade

The results from this study (e.g. 9.2.3, 9.6.1, 9.6.5 and 9.6.8) indicate that shade affects species composition. On New Fancy A (Section 9.8), species diversity may also decrease with increasing shade cover. According to Fuller and Peterken (1995) the shading out of light by competitive species within woodland habitats places stress on plants colonising the understorey layer. Herb species that typically form the undertorey layers in shady woodland habitats are adapted to survive in such conditions. On nutrient poor colliery spoil substrates however, as discussed in Section 10.2.3.2, additional stresses may lead to decreased species-performance.

Figure 10.4: illustrating poor species-performance observed in the understorey layer of a slope on Cannop B that was densely planted n the 1960s with conifer species.

It was observed when undertaking fieldwork for example, that densely planted spoil heaps tend to have a very poorly developed herb, shrub and ground species layers, as illustrated in Figure 10.4. Recommendations are as follows:

c) Shady, woodland spoil heaps that are also grazed (e.g. Cannop) may be under particular stress. Fencing the sites from grazing, and sensitive thinning of the canopy layer may help to increase ground cover and species diversity

d) The species diversity of grass-birch habitats such as New Fancy may improve if mature trees are thinned

e) Monitoring programmes should be undertaken to investigate the effects of management programmes

10.2.4 Improving species performance on sites where plant succession may be arrested.

Poor substrate nutrient status and acidity are identified in the literature as being key growth-limiting factors on colliery spoil (Kent, 1980 and Bradshaw and Chadwick, 1980). The disturbance to naturally developed plant communities that would required to undertake deep lime incorporation (Section 10.2.2) would not be considered appropriate for a study focusing on nature conservation. The application of fertilisers and lime as topdressing in agricultural systems is common practice. Neither Crofts and Jefferson (1994) nor Gimmingham (1992) however, recommend applying fertilisers or lime to acid grasslands or heathlands. As the species of both communities are adapted to survival on nutrient poor soils, applying fertilisers or lime could totally alter the sward composition, and could reduce diversity. According to Crofts and Jefferson (*op. cit.*), the fertilisation of semi-natural grasslands tends to stimulate the growth of competitive grasses at the expense of other plants, resulting in a reduction in species richness.

a) On sites where a species-rich open plant sward has fully developed, the application of fertilisers and lime is not recommended

b) On sites where the development of a closed-sward plant community has been slow, and ‘greening’ is a primary concern, growth experiments could be undertaken.

c) Top dressings of fertilisers and lime should be extremely low: applications of 50kg/ha Nitrogen: 25kg/ha Potassium: 25kg/ha Phosphorous are recommended by DoE (1996) for low-fertility soils to reduce the risk of dominance by competitive species.

d) Small scale trials should be undertaken prior to large scale application of ameliorants to investigate whether sward growth is stimulated, and whether the effects of faster potential plant growth is positive or negative on sward diversity (DoE, *op. cit.*).

10.2.5 Management of individual plots – site-specific recommendations

10.2.5.1 Hawkeswell

On Hawkeswell, no vegetation was recorded because the site is currently being re-worked. Preliminary observations were undertaken on this site prior to re-working however, that revealed the site was almost bare despite being abandoned in 1965 (Figure 4.2). Growth experiments described in Sections 10.2.2.1, 10.2.5 and 10.4.6 could therefore be undertaken on this site without disturbing vegetation. In particular, the deep incorporation of lime may be a useful ameliorant on this site, which was found to be highly acidic. If substrate conditions can be ameliorated sufficiently to allow plants to colonise the site, natural succession would be a realistic option for this site as it is not highly visible by the public.

10.2.5.2 Northern United

As the mean pH of the plot is 4.79 (section 7.1.1), pH may be a growth limiting factor on this site in some areas, and growth experiments could be done to investigate this (Section 10.4.6). The lack of substrate and vegetation on the site means that the substrate is likely to have very little nitrogen (Section 2.3.1.4). Light topdressings of fertilisers and lime could be therefore applied to the site to try and encourage vegetation growth (Section 10.2.2.2). Re-vegetation techniques could also be trialled on this site, although as it is semi-vegetated already this may not be cost-effective or desirable.

10.2.5.3 Cannop A

If *P. aquilinum* is not removed from this plot, this invasive species may come to dominate the sward over time (Section 9.6.3). Selective herbicides could therefore be applied to affected areas to give other species a chance to re-colonise. The plot could also be fenced off from grazing to reduce disturbance (Section 10.3.2.1). Light topdressings of fertiliser on the upper slopes may encourage plant growth over the areas of substrate that have a particularly poor physical structure to help stabilise the upper slopes, but this type of prescription should be monitored to investigate the effects on species diversity.

10.2.5.4 New Fancy A

The absence of grazing may have allowed vegetation to develop a greater species-richness and species-evenness than other sites in the short- or medium-term. Shrub species however, may grow to dominate the plant community, if some form of management does not suppress potential succession of the plant community towards an increase dominance of woody species. The open nature of the habitat, valued by English Nature (Section 4.2.3), would therefore be lost.

New Fancy A has the highest species diversity of all the sites (Section 7.3.4). This plot can be used as the 'ideal' towards which succession on less diverse parts of the site such as New Fancy B should be manipulated.

Suppression of the woody species that are starting to occur regularly within the plant sward are a management priority on this site if the open nature of the site is to be maintained. Thinning or removal of shrubs and trees could be undertaken, particularly on the eastern part of the plot around Transect 2 (Section 9.6.6) to reduce the level of shade occurring on parts of the plot. This action may also reduce the number of seeds of woody-species falling within the plot and establishing.

10.2.5.5 New Fancy B

Canopy cover and grazing are different between New Fancy A and New Fancy B, and may differentially affect plant composition and diversity. Management prescriptions that manipulate these two factors should therefore be trialled on New Fancy B to ascertain whether these do have an effect on diversity, and whether diversity can be increased. For example, thinning of the birch trees could be undertaken, and the area fenced off from sheep. Any management prescriptions that are undertaken should be monitored fully however, before wide-scale application across the plot. If diversity does not improve, growth experiments such as those described in Section 10.4.6 could be undertaken on the substrates to ascertain whether factors not measured in this study such as bulk density or nutrient status is affecting the plant composition.

If management of trees and shrubs is not introduced to this plot (which as described in Section 4.2.3 lies within a predominantly grassland site valued by English Nature), woody species may continue to expand, and the grassland nature of this part of New Fancy may be lost.

10.2.5.6 Cannop B

As for Cannop A, vegetation has been particularly slow to develop on the upper slopes, probably due to the substrate surface instability. This may remain a problem for many years, as the surface is prone to erosion. Light topdressings of fertiliser may encourage plant growth on this site, and therefore help to stabilise the substrate, but may reduce diversity (Section 10.3.2.2). Fencing the plot off from sheep grazing, and thinning the canopy layer may help understorey layers to develop (Sections 10.2.3.1, 10.2.3.3).

10.2.5.7 Lightmoor

As this site still has a mean bare ground cover of over 50%, one or more environmental factors may be acting on this site that are retarding plant growth (Section 9.6.9). The factors identified in this study are potential grazing pressure, and a high insolation due to southerly aspect. However, further factors that were not measured in this study such as a high bulk density leading to compact soils, substrate nutrient status, or toxic substances (e.g. Al, Mg) could also be acting on the site (Bradshaw and Chadwick, 1980, Ayerst 1978).

Management prescriptions on this site should be aimed towards re-starting plant succession so that the plant sward and substrate can develop, through removing potential growth-limiting factors, or reducing disturbance that may add to the environmental stresses. For example, parts of the plot could be enclosed from grazing to reduce disturbance to the sward. Growth experiments may also ascertain whether nutrient status or substrate physical factors are important growth-limiting factors. Light applications of fertiliser or rotovation to alleviate compaction could then be trialled to see if they "boost" vegetation growth. However, as the site has a high current species-richness, the species diversity should be particularly monitored to ensure that management prescriptions do not negatively affect the site.

10.2.5.8 True Blue

Despite having the lowest diversity of all the vegetated sites, this site has a high nature conservation value due to its lowland heath habitat (Section 4.2.3). Few woody species were part of the sward, and it is therefore in no immediate danger of becoming invaded by shrubby species. The extremely low pH encountered on the site (Section 7.1.1) may currently be inhibiting other more competitive species. The plot should, however, be monitored regularly to ensure that succession is not developing towards grasses or shrubby species, particularly as heather is cyclical and tends to form a short-term phase in the succession of a site rather than forming a long-lived more stable community (Gimmingham, 1992).

10.3 Evaluation of the research

This section sets out to review how each of the aims and objectives of the research have been met. This has been done by returning to the original objectives (Section 1.1.2) and discussing which parts of the research have helped to achieve each one. The general aim of the research is then similarly evaluated in relation to the objectives. Areas where the research could be improved to better achieve each aim or objective are briefly described in this section, but ideas are expanded in Section 10.4.

10.3.1 Evaluation of the research in relation to the objectives

10.3.1.1 Review previous studies of plant succession on colliery spoil, and identify through this review environmental gradients likely to be present at the sites

This objective was addressed in Chapter 2, where it was found that there are many studies that have been undertaken on plant growth on colliery spoil. The literature available on succession was found to be extensive, but there was no universal theory on succession available against which applied studies could be explained and reviewed. Before reviewing the applied literature specific to colliery spoil, Chapter 2 therefore explored historical and modern viewpoints on succession to introduce the problems associated with the succession concept, and set the applied studies into context.

A series of successional trends was compiled (Table 2.2) against which succession could be measured in the Forest of Dean. This also helped to focus the literature review, as each trend was examined against previous studies to see whether they occurred in previous studies. Many studies were found that related to vegetation development on colliery spoil. These were reviewed to identify environmental variables likely to influence plant colonisation and succession in this study. Several plant growth-limiting factors such as substrate physical status, nutrient status and temperature were identified during the literature review (Section 2.3). Information could not be collected on all of these factors in the field due to constraints of time and resources. The review was therefore particularly useful as a reference point when evaluating results, particularly where factors not measured in this study were thought to influence results (e.g. Section 9.6.2).

Further quantitative environmental data would therefore have been useful so that the floristic gradients could have been compared with more environmental gradients (Section 10.4.2.1). Whilst the objective was successfully addressed for the purposes of this study, an extended data-collection regime could therefore be developed for future research (Section 10.4.2.1).

10.3.1.2 Identify and select sites within the study area to form a time-series suitable for the study of vegetation succession

This objective was fully achieved (Chapter 3), as a time-series was created from 0-100 years since-disturbance, and the selection criteria meant that environmental variables on the sites were minimised as effectively as possible. Many potential sites were found in the Forest of Dean (Appendix 1.1). The selection criteria applied to the list of sites enabled the number of sites to be reduced to a number physically capable of being sampled. The criteria also minimised environmental gradients to isolate the effects of time. Only 8 plots were found that met all of the criteria. These did form a time-series, but 2 main problems were encountered throughout the study. The number of plots available to use in statistical analyses, such as correlation analysis, was relatively low (Section 10.4.5). The spoil heaps also varied in size from c. 0.5ha to c. 600ha, which meant that the plots had different areas, and a uniform experimental design and sampling regime could not be applied (Section 10.3.1.3).

Whilst the location of the plot on each slope was carefully selected to minimise heterogeneity in drainage patterns, this could not be controlled absolutely. Some of the slopes were more uniform than others, and as discussed in

Section 9.2.1, differential vegetation development has resulted on sites such as Lightmoor and Northern United where environmental gradients vary. This did however, provide a useful insight into the mechanisms of succession on colliery spoil (Section 10.1.4.6.2).

10.3.1.3 Implement a suitable experimental design at each of the selected study sites

This objective was addressed in Chapter 5, where the experimental design is described, and in Chapters 7 and 8, where the results gained from implementing the experimental design are described.

The issue of differential area was successfully addressed by the formulation of a flexible experimental design that allowed sampling to be undertaken proportionally to area (Section 5.1.2). However, as species richness is known to increase with increasing area sampled (Section 6.2), biased species diversity results were created (Section 7.3.4.3). The potential bias of the data however, was reduced by evaluating the diversity indices and selecting those least affected by area (Sections 6.2.4, 7.3.4.3).

The experimental design is considered to be suitable for the study area. It was flexible enough to enable all of the sites selected under objective ii) to be included in the study whilst meeting the specifications outlined in Section 5.1.3, such as ensuring that samples were selected using a stratified-random sampling design (Section 5.1.3.2).

10.3.1.4 Collect floristic data from within the framework of the experimental design at each site together with environmental data such as aspect, slope factor, pH and pyrites.

This objective is addressed in Section 5.7, which outlines the techniques that were used to collect floristic data, and Chapter 8 where the processed floristic data is displayed, analysed, and interpreted.

The Braun-Blanquet visual estimation method was found to be a rapid and effective means of collecting the data. The main problem encountered during the data-collection phase was the identification of grass and moss species. These identification skills improved over the course of each plot sampled. It is therefore likely that the quadrats sampled last at each plot are likely to be more accurate in terms of species composition than those initially sampled.

Originally it was planned to collect a second vegetation data-set from the plots in the April-June period. This would have ensured that data on species that are more prevalent in spring-early summer, or only appear during this season (such as *Hyacinthoides non-scripta*), would have been collected. A secondary data-set would also have reduced the impact of potential mis-identifications of grasses and mosses.

As the Forest of Dean was closed during the Foot and Mouth epidemic until July 2002 however, only one data-set could be collected. The data-set that was collected comprised over 300 samples however, and was designed to gain a representative sample of the plant communities (Section 5.1.3.3). The objective was therefore successfully met despite the set-back. To improve the data-set in future research, more replicates would be collected (Section 10.4.2.2).

10.3.1.5 Identify appropriate statistical methods to analyse the floristic and environmental data provided by iii) and iv)

This objective was addressed in Chapter 6, where potential methods of statistical analysis were identified and their appropriateness for use in this study evaluated. Chapters 7 and 8 also demonstrate that this objective was successfully fulfilled because the results are analysed and displayed within these chapters, and Chapter 9 demonstrates that the results gained using these methods of analysis were meaningful.

The use of a range of methods to analyse the diversity data can be considered a satisfactory approach to the problem of using data-sets of different sizes(Section 6.2.5) because it meant that important information on evenness and abundance was not lost.

However, with hindsight (and fewer time constraints) there are improvements that could be made to the programme of statistical methods, as outlined in Section 10.4.5. For example, if more environmental data had been able to be collected at the level of the quadrat, multivariate methods such as direct gradient analysis could have been used to directly examine relationships between environmental and vegetation data. Direct gradient analysis techniques can provide more information on potential relationships than correlation analysis, such as the effects of an environmental gradient on floristic composition.

10.3.1.6 Examine the results in relation to previous studies of plant succession on colliery spoil

This objective was successfully achieved through undertaking an extensive review of the literature in Chapter 2, and in Chapter 9, by evaluating the results in relation to this literature review. Fulfilment of the objective was aided by careful ordering of the chapters and sections to ensure that the literature review, methodology, results, discussion and conclusions chapters all follow similar formats.

10.3.1.7 Use the findings of the study to make management recommendations for nature conservation

This objective was fulfilled within this chapter (Section 10.2) by identifying management aims from ecological information provided in Section 4.2.3 and using the findings summarised in Section 10.1 to identify potential management actions that could be trialled on the spoil heaps. The scope and limitations of this study for producing management recommendations were defined in Figure 1.4. This research has helped to define and answer the questions that need to be asked to understand how succession is working on the coal spoil heaps. Tools that can be used to manage succession can also be suggested in this study. However, field trials and monitoring would need to be undertaken by site managers before applying the ideas over a wider area to ensure the effects on species composition and diversity are positive.

The collection of species diversity data was particularly useful within this study because it provides a tool to compare sites for nature conservation purposes. If management prescriptions are undertaken on New Fancy B for example and the effects monitored, the floristic results can be compared with the more diverse New Fancy A plot to see if they are having a positive or negative effect. However, it would be too simplistic to value sites of different habitats using only diversity criteria because it was found, for example, in this study that the site with the lowest species diversity is a heathland site, which is valuable for nature conservation because it is declining nationally and internationally. The understanding of diversity gained from using these different indices and rank-abundance diagrams justifies the use of the approach used in this study, rather than using rarefaction to standardise the results, as more information is gained about the diversity of the plots. This has helped

10.3.2 Evaluation of the research in relation to the aims

The original aims of the study were threefold (Section 1.1):

1. To collect floristic and environmental data on the Forest of Dean spoil heaps in order to examine how the environmental gradients may influence floristic composition.
2. To place the vegetation processes occurring on these spoil heaps in a wider context by relating the findings to successional theory and previous studies undertaken on colliery spoil.

3. To produce recommendations regarding the management of vegetation on colliery spoil for nature conservation.

As summarised in Table 10.2, the objectives which were designed to meet the aims have been fulfilled, and have enabled all three of the aims to be achieved. Although it was evaluated in Section 10.3.1 (viii) that diversity was only partially appropriate to evaluate the sites for nature conservation due to the differences in habitat of the site, recommendations for the management of the sites was also undertaken, in Section 10.2, based on information collected and analysed to fulfil the other aims.

Table 10.2: summary of whether the aims and objectives of the study were met (Y = yes; N = N), and whether improvements could be made

	Objective	**Aim designed to meet**	**Was objective achieved?**		
			Y	N	**Suggestions for improvement**
i)	Review previous studies of plant succession on colliery spoil, and identify environmental gradients likely to be present at the sites via literature review	**b)**	✓		Collect more site-specific data (Section 10.4.2.1)
ii)	Identify and select sites within the study area to form a time-series suitable for the study of vegetation succession	**a)**	✓		Examine real-time succession (Section 10.4.1)
iii)	Implement a suitable experimental design at each of the selected study sites	**a)**	✓		Make plots same size (Section 10.4.2.2.2)
iv)	Collect floristic data from within the framework of the experimental design at each site and environmental data such as aspect, slope factor, pH and pyrites	**a)**	✓		Collect more site-specific data (Section 10.4.2.1)
v)	Identify and use appropriate statistical methods to analyse the floristic and environmental data provided by iii) and iv)	**a)**	✓		Use direct gradient analysis (Section 10.4.5)
vi)	Link the findings of this study with the findings of previous studies	**b)**	✓		
vii)	Use the findings of the study to make management recommendations for nature conservation	**c)**	✓		

10.4. Recommendations for further research

The discussion of results in Chapter 9 and evaluation of the research in Section 10.3 have both revealed areas where the research could be improved. In the process of undertaking this research, many ideas have also been generated for further research. This section briefly outlines some of these ideas and suggestions.

10.4.1 Measuring succession

This study used the space-for-time substitution method, which has allowed inferences on plant succession have been drawn from this data. If data from the vegetation plots could be collected on an annual basis however, direct-time succession could be measured and analysed. This would provide detailed data on how the plots continue to colonise and develop. The use of permanent plots would also enable the effects of any changes in management to be monitored and evaluated.

10.4.2 Methodology

10.4.2.1 Environmental data

An extended environmental data collection and analysis programme could be undertaken as outlined in Table 10.4. This would enable detailed environmental information to be collected, particularly on factors not measured in

Table 10.4: Potential data collection programme for further research

	Parameter to be tested	Reason	Minimum sampling regime
Microclimate	Slope factor	Soil formation, soil creep, moisture regime, slope profile	Quadrat
	Aspect	Differential shading/warming may affect vegetation	Transect
	Light (lux)	Quantify shade reaching different parts of the plot	Quadrat
	Temperature	Surface temperature at key times on day (e.g. midday) in June, July, Aug	3x per transect (at same date & time on plots)
	Humidity	Whether presence/absence of vegetation affects microclimate	Quadrat
	Moisture-holding capacity	Are the plants facing drought conditions during periods of high insolation	Quadrat
Physical	Particle-size distribution	Predominance of large or small particles may limit plant growth	3x per transect (Upper, lower, middle slope)
	Bulk Density	High bulk-density = low soil pore space & water-holding capacity	3 x per transect (Upper, lower, middle slope)
	Organic matter content	A measure of soil & plant community development over time	Quadrat
Nutrient status	Nitrogen (available)	Often the main growth-limiting factor of colliery spoil.	Quadrat
	Phosphorous	Additional growth limiting factor on some colliery spoil sites	Quadrat
	Potassium	K addition found to increase plant-growth in glasshouse experiments on spoil, indicating deficiency	Quadrat
	Calcium	Can be deficient in highly acidic substrates	Subplot
Toxicities	PH	Measure of toxicity caused by pyrites, heavy metals or salts	Quadrat
	Iron pyrite (FeS_2)	Commonly present in colliery in spoil, generates sulphuric acid, causing harmful elements to come into solution.	Subplot
	Substrate neutralising capacity	With iron pyrite, gives a measure of total acid-producing potential of the substrate	Subplot
	Salinity	Commonly present in colliery in spoil	Subplot
	Sulphur	Quantifies acidity that may be caused by iron pyrites	Subplot
	Aluminium	At low acidities, Al can come into solution in toxic quantities	Subplot

Sources: Doubleday (1971); Hesse (1971); Down (1974a); Bradshaw and Chadwick (1980); Bradshaw (1997); Bridges (1997); (Williams and Chadwick, 1977).

this study such as substrate physical status (9.6.4, 9.6.8) and moisture regime (Section 9.6.9). Information on gradients such as pyrites (9.4.2) and pH would ideally be collected per quadrat and quantified, so that the effects on vegetation composition within the plot could be measured as well as between-plot effects (Section 9.2.1).

The method of pyrites analysis used in this study (Section 5.2.3.3) provided results that could be compared within the study and thus did meet the aims of the study (Section 7.1.2). The qualitative nature of the method however, meant that results could not be compared or verified with results from previous studies or with other results (Section 10.1.4.1). If further research was undertaken that needed the results to be quantitative, for example for use with direct gradient analysis (Section 10.4.5) the Dacey and Colbourne (1979) method (Section 5.2.3.1) could be used.

The assessment of plant vigour could also be made much more objective (Section 9.1.4) by creating a system of symbols for the different signs of plant health such as necrosis, that are marked next to the species on the data recording form (Table 10.3).

Table 10.3: visual effects of nutrient deficiencies which may be seen in plants

Effect	Symbol
Stunting	S
Chlorosis	C
Necrosis	N
Heat ring	H
Distortion	D
Dead	•

In order to find out if the modal pH of the spoil heaps is more neutral that that of other coalfields apart from Yorkshire, the programme outlined in Table 10.4 could be extended to other spoil heaps in different coalfields. This would enable substrate chemical data to be compared to establish the causes for this apparent difference.

10.4.2.2 Diversity

10.4.2.2.1 Grazing density

It was not possible in this study to comprehensively study the effects of grazing and grazing density due to the culling of the forest sheep during the Foot and Mouth outbreak in 2001 (Section 4.3). Further research could therefore be undertaken in conjunction with vegetation sampling regimes to quantify the effects of grazing on diversity and on floristic composition (Section 9.4.3, 9.6.5, 9.6.7). This could be undertaken using one, or a combination of the methods outlined in Table 10.4.

Table 10.4: methods of measuring the effects of grazing on species diversity and floristic composition in the Forest of Dean

Name	Parameters quantified?	Methodology	Advantages	Disadvantages
Direct count	Grazing density per plot	Count sheep grazing in the plot over a day/week	Could be combined with data collection	Time; sheep may have different weekly patterns
Radio-tracking	Grazing patterns and densities	Attach tracking devices to relevant flock/s	Enable density of sheep grazing to be measured.	Expensive due to large numbers of tracking devices
Experi-mental plots	Effects of grazing density	Set up fenced plots containing set no. of sheep	Remove grazing effects of deer and rabbits	Expensive; need to ensure sheep healthy and safe
Experi-mental plots	Effects of alternative management methods	Set up plots that are mowed on an annual or bi-annual basis	Examine possibilities for future manage-ment options	May need to sample plots over long time-frame to measure effects

10.4.2.2.2 Effects of differing area

The differing areas of the spoil heaps in the Forest of Dean, and the differing sample sizes meant that calculations involving (S), such as the diversity indices were affected by the species-area effect (Section 9.4.4). The indices used in this study were selected to minimise the species-area effect (Section 6.2). A different experimental design may however, be more appropriate for a study if the focus was on diversity. For example, the plot size used on the spoil heaps could have been reduced to the 15m x 15m area suitable for the smallest spoil heap. This type of design was not suitable for this study, as the transects used here allowed the effects of slope to be examined, but would be useful in a study where more of the aims and objectives were related to species diversity.

The effect of differing area on diversity and species composition could also be investigated by measuring the distance of a plot from the colonising

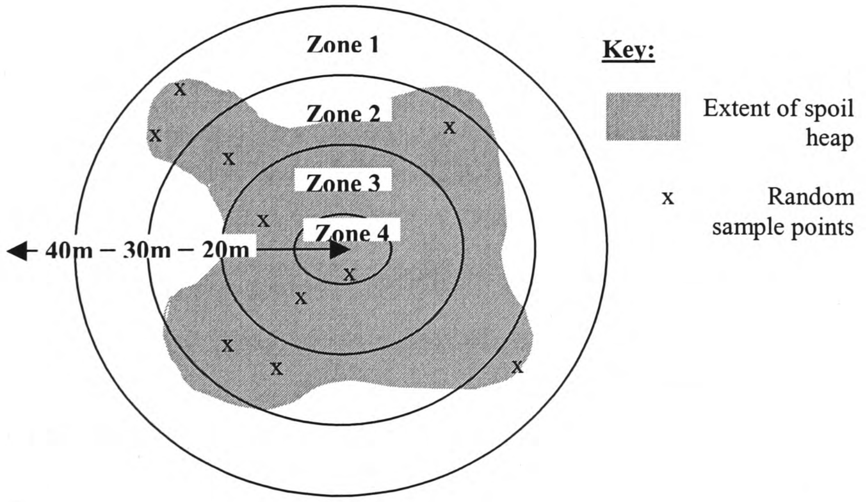


Figure 10.5: Potential experimental design for assessing the effects of area and distance from propagule source on diversity and floristic composition

propagule sources. A stratified-random experimental design could be formulated that enabled vegetation samples to be taken at different distances from the edge of the spoil heap, as suggested in Figure 10.5. Any differences in species diversity between the margins of each spoil heap or composition could therefore be quantified.

10.4.2.3 Species strategies

One of the questions asked in Section 9.5 is whether the strategies of perennial growth and vegetative reproduction found within the floristic communities colonising the spoil heaps are different to those of surrounding areas. To answer this question, the sampling design could be extended to incorporate nearby habitats. The circular stratification mechanism explained in Figure 10.5 for example, could be extended outwards from the spoil heap to incorporate sampling of surrounding plant communities. This would enable comparisons to be made between the frequency of mechanisms such as clonal growth within spoil heap plant communities, and those of surrounding areas. Further criteria may need to be used however, to select plant communities that are floristically comparable to the spoil heap communities such as other acid grassland or heathland plant communities.

If more time had been available, other sources of information on the plant species could have been used to allocate a competitive strategy category to each of the plant species that are not reviewed in Grime *et al.* (1988), and gain increased information on lateral spread and optimum pH range (Section 10.1.4.5). Detailed botanical accounts found in the *Journal of Ecology* for example, could be used to compile more information on species-strategies.

10.4.2.2 Floristic data

As noted in Section 10.3.1.4, if Foot and Mouth Disease had not prevented it, ideally further vegetation data-sets would be collected from within the same experimental design. This would ensure that data on species that are more prevalent in spring-early summer is collected, and to increase the likelihood that a representative sample of the community has been taken. This programme could also be extended over a longer time frame (Section 10.4.1) to monitor the effects of grazing control experiments (Section 10.4.2.2.1), growth experiments (10.4.6), or management prescriptions (Section 10.2) on floristic composition.

Further experiments could also be set up whereby sticky plates are used to capture the seed-rain falling on colliery spoil heaps (e.g. Huby, 1981; Werner, 1975; Urbanska and Fattorini, 2000). The composition in terms of species and abundances of those species could be compared to the actual composition of the spoil heaps to help answer several questions relating to the colonisation of the plots and the floristic development of the plant community:

i) Are the species arriving at the site present in the surrounding vegetation, or are they specialised species?

ii) What is the percentage of propagules arriving at the site that are not able to establish, and are there particular species that are unable to establish due to the environmental conditions present (e.g. Ash *et al.* 1994)

iii) Are there species occuring within the surrounding area that may be expected to occur on the spoil heaps (e.g. are known to be stress or pH tolerant) but are absent from the seed rain?

10.4.5 Statistical analysis

If more time had been available, or if the aims of the study placed more emphasis on statistical analysis, more data-runs of both TWINSPAN and DCA could have been undertaken on the data-sets. In particular, it would have been useful to examine the effects of TWINSPAN run-descriptor manipulations on the data-sets. Changing the cut levels within TWINSPAN (Section 8.1.1.2), for example, would be useful to gain a better understanding of the data-sets, and of the analysis process. Within DCA, diagrams showing axes other than I and II could have been examined to see whether further patterns within the data were present (Section 8.3.1).

If more environmental data were collected at the level of the quadrat (Section 10.4.1), multivariate techniques such as direct gradient analysis could be used to quantify the relationships between floristic composition and environmental gradients within sites as well as between sites as discussed in Section 9.1.2 (Whittaker 1967, ter Braak 1995). A further advantage over Correlation Analysis is that Direct Gradient Analysis can express how the environmental variables affect floristic composition (Kent and Coker 1992), rather than simply whether one variable increases or decreases in relation to the other.

Canonical Correspondence Analysis (CCA) is one direct ordination technique that has been used in floristic studies of derelict land that also have an extended data programme (such as that outlined in Table 10.4) by Kirkham *et al.* (1996), and Piernick *et al.* (1996). According to ter Braak (*op. cit.*), this technique is one of several Canonical Ordination techniques that have been designed to detect patterns in floristic data that can be explained by one or more environmental gradients. CCA is a canonical form of correspondence analysis, and there are also canonical forms of Principal Components Analysis (redundancy analysis). As with DCA (Section 6.3.2.2), there are advantages and disadvantages of each technique that would need to be examined in relation to the aims of the extended research and the type of data analysed.

Principal Components Analysis was also used by Smith *et al.* (1997) to determine the main sources of variance within the environmental data (e.g. which environmental variables are strongly correlated with each other) to reduce the amount of data-sets processed using CCA. This approach could be considered if data on environmental parameters such as those outlined in Table 10.4 were collected at the level of the quadrat.

10.4.6 Growth experiments

Field experiments could be undertaken to test the results of the current analyses (e.g. 9.4.2, 9.6.8), or help to determine how potentially inter-related factors identified by correlation analysis may affect plant growth (Section 9.1.2, 9.1.3). For example, to determine whether pH, nutrient status, or both are growth-limiting factors, treatments such as fertilizers and lime could be applied (Section 10.2.3.2). Treatments could also involve grazing experiments, as outlined in Table 10.4. Nutrient and fertiliser treatments could be applied within the current experimental design, using each of the subplots as treatment blocks, and applying treatments randomly to each block alongside control plots (e.g. Cochran and Cox, 1992; Davis *et al.*, 1985; Fitter and Bradshaw, 1974). As the sites may be sensitive to having large quantities of fertilisers applied (Section 10.2.3.2), low-levels of nutrients could be tested as outlined in Table 10.5. The floristic data programme (Section 10.4.2.2) would also need to be extended to quantify the effects of any treatments applied.

Table 10.5: Potential low-level application rates of experimental treatments designed to test plant response to pH and nutrient status, based on recommendations for topdressing application rates for semi-natural habitats in Croft and Jefferson (1994) and DoE (1996)

Treatment			Rate (g/m)
1	Nitrogen	Sulphate of ammonia	5
2	Phosphorus	Superphosphate	2.5
3	Potassium	Sulphate of potash	2.5
4	PH	Garden lime ($CaCo_3$)	0.3
5	NPK	Combination of treatments 1-3	5N:2.5P:2.5K
6	NPK & pH	Combination of treatments 1-4	5N:2.5P:2.5K: 0.3$CaCo_3$
7	None	Control	N/A

Glasshouse experiments could be used to replicate these experiments, using randomly-collected, bulked substrate samples from each site. These would have the advantage of being able to control external factors such as weather and vandalism. Plant response to all experiments could be measured via dry-weight biomass

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Appendix 1 Sites information

Appendix 1.1 Summary of the sites surveyed for potential inclusion within the study

The details from the sites have been compiled in standard tables for ease of comparison, listed in alphabetical order within the appendix. All grid references are taken from ordinance survey Outdoor Leisure Sheet 14 (Wye Valley & Forest of Dean). The "suitability" column is a means of ascertaining if the site is suitable for inclusion within the study, as measured by the criteria outlined in Section 3.2. Material referred to is included within the tables. Where studies were included in the Hobday report the score is given in the reference section in brackets, e.g. Hobday, (1994) (7). Where sites were included within the study and species lists are available these have been included after the relevant site table. Where sites are not included in the study, the species lists were left out as being not directly relevant to the present study.

1.1.1 Baileyhill

	Details	Suitability
Grid Reference	636073	
Location details	On outskirts of Yorkley opposite Bailey Hill	
Current site management	Open to grazing	✓
Future site management	None	✓
Approximate age of waste	Between 90-70 years old	✓
Source of waste material	Colliery spoil	✓
Topography	Small mound	✗
Aspects available	Southwest	✓
Habitat type	Grassland, some scrub on top of mound.	
Surrounding habitat	Conifer woodland to east, housing to west.	
Amenity use	On edge of village. Used for dogwalking	
Comments	Mound too small to fit 5x5 m subplot design. Mine listed by HMSO in 1910, but closed by 1935.	
References	HMSO (1911), (1936) Oldham (1998).	

1.1.2 Barnhill Coal Pit

	Details	Suitability
Grid Reference	591110	
Location details	Broadwell, Coalford. Just off B4226 Speech House Road.	
Current site management	Open. Some grazing by forest sheep.	✓
Future site management	None	✓
Approximate age of waste	c.55 years old	✓
Source of waste material	Colliery spoil, loosely tipped	✓
Topography	Gently sloping (0-10°)	✗
Aspects available	SW, S	✓
Habitat type	Bracken & gorse scrub, UI.MG1 grassland	
Surrounding habitat	Housing (W), broadleaf woodland (N,E), arable (S)	
Amenity use	Dog walking &mountain biking. RoW across site.	
Comments	Small site, c. 2.1 ha. Barnhill mine, Coleford registered as closing 1945.	
References	HMSO (1947); English Nature (1996). Species list available	

Table to show Barnhill Coal Pit species list (0.6 ha) (English Nature, 1996)

Latin name	DAFOR	Latin name	DAFOR	Latin name	DAFOR
Grasses		Cerastium fontanum	O	R. repens	R
Agrostis capilaris	F	Cirsium arvense	R	Rumex acetosa	R
Aira Praecox	R	Convolvulus arvensis	R	R. acetosella	R
Anthoxamthum odoratum	O	Crespis capillaris	O	R. Conglomeratus	R
Arrenatherum elatius	R	Digitalis purpurea	R	R. obtusifolium	R
Bromus hordaceous	R	Erica cinerea	R	Stellaria graminea	R
Cynosurus cristata	O	Euphrasia spp	R	Taraxacum spp.	R
Dactylis glomerata	R	Galium aparine	R	Teucrium scorodonia	R
Danthonia decumbens	R	G. saxatile	O	Trifolium dubium	R
Deschampsia flexuosa	R	Hieracium pilosella	R	T. pratense	O
Festuca ovina	F	Hyacinthoides non-scripta	R	T. repens	O
F. rubra	R	Hypochoeris radicata	O	Urtica diotica	R
Holcus lanatus	O	Linium catharticum	R	Vaccinium myrtillus	R
Phleum pratense	R	Lotus corniculatus	F	Veronica cham	
Poa annua	R	Luzula campestris	R	V. officinalis	
P. pratensis	O	Mentha arvensis	R	Viola riviana	
P. trivialis	O	Plantago lanceolata	F		
Trisetum flavense	R	P. major	R		
Herbs		Potentilla anserina	R		
Achillea millefolium	O	P. erecta	O	Tree/shrub	
Bellis perennis	R	P. reptans	R	Quercus spp	O
Calluna vulgaris	R	Prunella vulgaris	R	Rubus fruticosus	O
Campanula rotundifolium	R	Pteridium aquiliunum	F	Ulex europaeus	F
Carex hirta	R	Ranunculus acris	R	U. Gallii	F

1.1.3 Bixslade valley mines

	Details	Suitability
Grid Reference	599103	
Location details	Reached via track running down to Cannop Ponds on B4234	
Current site management	Open to grazing	✓
Future site management	As above	✓
Approximate age of waste	c. 120	✓
Source of waste material	Distinct spoil tips not evident	✗
Topography	Various	✗
Aspects available	None	✗
Habitat type	Mixed oak woodland	
Surrounding habitat	Mixed oak woodland	
Amenity use	Public right of way through the valley. Mining memorial for Union pit disaster present in area and used.	
Comments	A complex of tips that serviced Bixslade collieries, and Union Pit. Bixslade freemine still in operation. Colliery spoil present but not distinct spoil heap entities. Sites too disturbed.	
References	Oldham (1998), Hart (1971)	

1.1.4. Bowson House

	Details	**Suitability**
Grid Reference	649155	
Location details	Strip of grassland around a row of houses on A4151	
Current site management	Grazed	✓
Future site management	None	✓
Approximate age of waste	c. 400 according to J Harvey. Would need to be confirmed	✓
Source of waste material	Colliery spoil	✓
Topography	Small mound	✗
Aspects available	All	✓
Habitat type	Short sward acid grassland, U1c (English Nature, 1996)	
Surrounding habitat	Rank grassland (S), mixed woodland (E), housing (W)	
Amenity use	None (privately owned)	
Comments	Strip of small mounds, reputedly 400 years old.	
References	English nature (1996); Oldham (1998).	

1.1.5 Cannop

	Details	**Suitability**
Grid Reference	607123	
Location details	Vallets Wood Off B4234 (New Road)	
Current site management	Plantation/open	✓
Future site management	Possible removal	?
Approximate age of waste	40-15	✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Fan shaped mound.	✓
Aspects available	West, South-west, east	✓
Habitat type	Mixed conifer (1965) and, naturally regenerating birch-scrub	
Surrounding habitat	mature oak (S), mixed conifer (N)	

Amenity use	Several paths traverse the site. Cycle track passes close along northern and western flanks. Mountain biking use evident through erosion of some parts of slope. Part of eastern fan reworked in the 1980s.	
Comments	Serviced Cannop colliery which closed in 1960.	
References	Moore (1952); Hart (1971); Hobday (1994) (15); Oldham (1998); Forestry Commission (1999)	

Table to show the observed list of species present on Cannop in 1952 (Moore 1952)

Latin name	**Common name**	**Latin name**	**Common name**
Ajuga reptans	Bugle	*Rumex spp.*	Sorrel
Arabis spp.	Rockcress	*Senecio vulgaris*	Groundsel
Arenaria serpyllifolia	Thyme-leaved sandwort	*Teesdalia spp*	Shepherds cress
Capsella spp.	Shepherds purse	*Betula spp.*	Birch
Cerastium fontanum	Mouse-eared chickweed	*Rubus spp.*	Bramble
Cirsium arvense	Creeping thistle	*Ulex spp.*	Gorse
Digitalis purpurea	Foxglove	Nardus stricta	Matt grass
Draba spp.	Whitlowgrass	Poa spp.	Poa spp.
Epilobium montanum	Mountain willow-herb	Ceratodon	
Glechoma hederacea	Ground ivy	Dicranium	
Hypericum humifusum	Creeping St. Johns Wort	Hypnum	
Plantago	Plantain	Mnium spp.	
Pteridium aquilinum	Bracken	Polytrichum	
Ranunculus	Buttercup		

1.1.6 Castlemain

	Details	**Suitability**
Grid Reference	620083	
Location details	Churchill enclosure, west of Parkend	
Current site management	Conifer plantation	✗
Future site management	Conifer plantation	✗
Approximate age of waste	c. 40- 50	✓
Source of waste material	Colliery spoil, loosely tipped	✓
Topography	1 main conical mound with two smaller mounds attached	✓
Aspects available	None	✗
Habitat type	Corsican pine planted 1961.100% vegetated grass/herb layer	
Surrounding habitat	Conifer plantation/ mixed woodland	
Amenity use	Some footpaths pathways traversing the site.	
Comments	Serviced Parkend Royal Colliery. Company still registered with HMSO in 1945, but pines planted in 1961.	
References	HMSO (1947); Hart (1971); Hobday (1994) (7); Forestry Commission (1999)	

1.1.7 Cinderford Linear Park

	Details	**Suitability**

Grid Reference	645155 – 650129	
Location details	Park running parallel to B4227 & Cinderford industrial estate	
Current site management	Amenity parkland	✗
Future site management	Amenity parkland	✗
Approximate age of waste	20 (park created in early 1980s)	✗
Source of waste material	Various (coal spoil, washery waste, other)	✗
Topography **Aspects available**	Various All	✓ ✓
Habitat type	Amenity parkland	
Surrounding habitat	Amenity parkland	
Amenity use	High. Managed as a public park.	
Comments	Park created in former location of several collieries such as Bilson, some substrate areas of spoil remaining, but werelandscaped during restoration, and now suffer probable compaction.	
References	English Nature (1996);Visited with Dr A. Moffat (4.6.99)	

1.1.8 Crumpmeadow

	Details	Suitability
Grid Reference	640143	
Location details	Within Crumpmeadow inclosure, west of Bilson Green.	
Current site management	Conifer plantation	✗
Future site management	Conifer plantation	✗
Approximate age of waste	72	✓
Source of waste material	Colliery spoil, loosely tipped	✓
Topography	Large conical tip	✓
Aspects available	None	✗
Habitat type	Scot's Pine (planted 1974). Some areas of grassland on edges of tip to the south	
Surrounding habitat	Conifer plantation with some areas of C19 oak	
Amenity use	Cycle path runs close by to west, public footpath to east. Some tracks lead up onto the spoil heap, some mountain biking evident. Motorbike scrambling track on grassland areas.	
Comments	Serviced Crump Meadow colliery which closed in 1929	
References	Hart (1971); Hobday (1994) (15); Oldham (1998); Forestry Commission (1999)	

1.1.9 Eastern United

	Details	Suitability
Grid Reference	650110	
Location details	Above Ruspidge valley, access via track off B4226 Speech House Road.	
Current site management	Plantation	✗
Future site management	Imminent reclamation for remaining coal content	✗
Approximate age of waste	Colliery shut 1959	✓
Source of waste material	Colliery spoil, loosely tipped	✓
Topography	Tipped on eastern-facing ridge. Hard to tell extent of tip	✓
Non-planted aspects	None	✗

Habitat type	Dense conifer plantation, poor colonization of ground cover	
Surrounding habitat	Conifer/semi-natural broadleaf (bluebell wood)	
Amenity use	Limited by location away from main roads, walking or cycling trails, lack of definition and lack of vegetation, although industrial archaeological artefacts still remain on site.	
Comments	Spoil tip from Eastern United Colliery. Suspected acidity/pyrites problem.	
Previous studies	Hart (1971); Hobday (1994) (10); Oldham (1998); Forestry Commission (1999)	

1.1.10 Foxes Bridge A

	Details	**Suitability**
Grid Reference	642136	
Location details	Crabtreehill plantation, west of Cinderford. Access via cycle track.	
Current site management	Open, conifer plantation	✗
Future site management	Due to be reclaimed for clay/aggregate	✗
Approximate age of waste	71 years	✓
Source of waste material	Colliery spoil. Loosely tipped	✓
Topography	Conical mound	✓
Aspects available	None	✗
Habitat type	Conifer plantation, 100% revegatated. Herb layer of bluebell, bramble, grasses	
Surrounding habitat	Mixed broadleaf & plantation	
Amenity use	Limited due to reclamation plans	
Comments	Serviced Foxes Bridge Colliery which closed in 1930. Scot's pine planted 1940.	
Previous studies	Hart (1971); Hobday (1994) (9); Forestry Commission (1999)	

1.1.11 Foxes Bridge B

	Details	**Suitable for inclusion?**
Grid Reference	638136	
Location details	As for Foxes Bridge A	
Current site management	Open, non-dense young conifer	✓
Future site management	None	✓
Approximate age of waste	12 years.	✓
Source of waste material	Loosely tipped colliery spoil, flattened	✗
Topography	Flat	✗
Aspects available	None	✗
Habitat type	Conifer, gorse scrub, 50% bare	
Surrounding habitat	Conifer/mixed broadleaf	
Amenity use	Limited due to past re-working	
Comments	As for site A, but reclaimed for clay/aggregate, flattened. Suspected compaction	
References	Hart (1971); Hobday (1994). Visited with Dr Moffat (1999)	

1.1.12 Foxes Bridge C

	Details	Suitable for inclusion?
Grid Reference	640135	
Location details	As for Foxes Bridge A	
Current site management	Currently being re-worked	Potentially could be included as site with spoil at age 0, subject to health and safety considerations.
Future site management	Restored to Forestry	
Approximate age of waste	0. currently reworked	
Source of waste material	Loosely tipped colliery spoil	
Topography	Formerly conical	
Aspects available	None	
Habitat type	Disturbed	
Surrounding habitat	Conifer/mixed broadleaf	
Amenity use		
Comments	As for site A. Pockets of burnt shale indicate combustion.	
References	Hart (1971), Hobday (1994)	

1.1.13 Flourmill

	Details	Suitability
Grid Reference	605070	
Location details	North of Bream's Eaves to west of Bream-Parkend road	
Current site management	Conifer plantation	✗
Future site management	Conifer plantation	✗
Approximate age of waste	50+	✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Extensive non-distinct fan-shaped mound	✓
Aspects available	None	✗
Habitat type	Mainly conifer, one area of oak to north east. Understorey bramble, bracken, nettle.	
Surrounding habitat	Mixed woodland types	
Amenity use	Old tramway used as path runs across the site	
Comments	Serviced Flourmill colliery, which was listed by HMSO in 1911, but not in 1945. Tree crop not planted until 1964.	
References	HMSO (1911), (1945); Hart (1971); Hobday (1994) (15); Oldham (1998)	

1.1.14 Hawkeswell

	Details	Suitability
Grid Reference	643159	
Location details	200m south of A4136	
Current site management	Reclamation for coal	✓ (provides year '0'
Future site management	Reclamation/removal/restoration	✓
Approximate age of waste	0	✓
Source of waste material	Loosely tipped colliery spoil	✓

Topography	Formerly south facing slope	✓
Aspects available	Flattened	✓
Habitat type	Prior to reclamation site 100% bare despite mining ceasing in 1965	
Surrounding habitat	Mixed woodland types (oak and conifer)	
Amenity use	None	
Comments	Sister site to Northern United, colliery closed in 1965	
References	Oldham (1998); Forestry Commission (1999)	

1.1.15 Hayward Level (Addis Hill)

	Details	**Suitability**
Grid Reference	659158	
Location details	Hayward plantation – access via Forestry tracks	
Current site management	Open	✓
Future site management	Re-working of the mine	✗
Approximate age of waste	Dates from 1830-40	✓
Source of waste material	Clay-rich colliery spoil	✗
Topography	On sloping hill	✓
Aspects available	Southwest	✓
Habitat type	Grassland/naturally regenerating woodland mosaic	
Surrounding habitat	Conifer plantation	
Comments	Worked Addis Hill Gale. Hard to tell extent of spoil/normal soil, possibly due to small nature of site.	
References	Visited with J Harvey (date)	

1.1.16 Lightmoor

	Details	Suitability
Grid Reference	642120	
Location details	100m S. of B4226 Speech House Road (opp Dilke Hospital)	
Current site management	None/open	✓
Future site management	Possible reclamation for aggregates	✓
Approximate age of waste	60	✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Series of ridges	✓
Aspects available	Not west	✓
Habitat type	Short sward grassland 60-100% recolonised. Some areas of scrub	
Surrounding habitat	Woodland	
Amenity use	Fishing, mountain Obiking, unofficial local viewpoint, cycle trail runs to west of site	
Comments	Privately owned, but permission for use granted. Lightmoor Colliery closed in 1940.	
References	Hart (1971); Hobday (1994) (12); English Nature (1996); Oldham (1998);	

1.1.17 Mirystock Bridge

	Details	Suitability
Grid Reference	615145	
Location details	Via footpath from A 4136 Monmouth-Gloucester road	
Current site management	Coniferous plantation	✗
Future site management	As above	✓
Approximate age of waste	C 40	✓
Source of waste material	Colliery spoil loosely tipped	✓
Topography	Conical pit	✓
Aspects available	All	✓
Habitat type	Densely planted coniferous plantation	
Surrounding habitat	Mixed woodland	
Comments	Probably another part of the Waterloo mining complex	
References	See waterloo	

1.1.18 Moseley Green

	Details	Suitability
Grid Reference	633087	
Location details	Nr Parkend	
Current site management	Various (open grazed/conifer)	✓
Future site management	As above	✓
Approximate age of waste	Various	✓
Source of waste material	Colliery spoil – various types	✗
Topography	Small mounds	✗
Aspects available	None	✗
Habitat type	Various. Conifer, scrub and grassland mosaic	
Surrounding habitat	Mixed woodland, grassland patches. Some areas of U1e, CG7 & M23 grassland. Grassland sites on spoil = flat.	
Comments	Complex of mounds from various small mines, now planted with conifer. Difficult to ascertain ages and tipping methods. Spoil heaps too small for experimental design.	
References	English Nature (1996); Oldham (1998).	

1.1.19 New Fancy View

	Details	Suitability
Grid Reference	628096	
Location details	NE of Parkend, off Speech House-Parkend B-road	
Current site management	Parkland/open/forestry	✓
Future site management	As above	✓
Approximate age of waste	New Fancy Colliery closed in 1944	✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Conical mound	✓
Aspects available	South, west, north, eastern side planted	✓
Habitat type	Grassland/ birch/scrub/conifer. Grassland a mixture of NVC types CG7 and U1 (English Nature, 1996)	
Surrounding habitat	Mixed woodland	
Amenity use	Lower area managed as picnic site, high useage of viewpoint	
Comments		

References	Hart (1971); English Nature (1996); Oldham (1998);	

Table to show list of species recorded on New Fancy (English Nature, 1996)

Latin name	**DAFOR**	**Latin name**	**DAFOR**
Grasses		Hieracium pilosella	O
Agrostis capilaris	F	Hypochoeris radicata	R
Aira Praecox	O	Juncus effusus	R
Anthoxamthum odoratum	R	J. inflexus	R
Brachypodium sylvaticum	O	Leontodon saxatilis	R
Catapodium rigidum	O	Linium catharticum	O
Cynosurus cristata	R	Lotus corniculatus	O
Dactylis glomerata	R	Luzula campestris	O
Deschampsia caespitose	R	Medicago lupulina	O
Festuca rubra	F	Myostis arvensis	R
Lolium perenne	R	Plantago major	R
Poa annua	R	Potentilla erecta	R
P. pratensis	R	P. sterilis	R
Trisetum flavense	R	Prunella vulgaris	F
Vulpia bromoides	F	Pteridium aquiliunum	R
Herbs		Rosa spp.	O
Achillea millefolium	R	R. acetosella	O
Aphanes arvensis	R	Senicio jacobea	R
Arenaria serpyllifolia	F	Taraxacum spp.	R
Bellis perennis	O	Thymus praecox	F
Carex hirta	R	T. pulegioides	R
Carlina vulgaris	R	Trifolium campestre	R
Cerastium fontanum	O	T.dubium	R
Cirsium arvense	O	T. repens	O
Cirsium vulgare	O	Verbascum nigrum	O
Digitalis purpurea	R	Veronica officinalis	O
Erodium cicutarium	R	Vicia sativa	R
Filago vulgare	O	Viola riviniana	R
Fragaria vesca	O	**Trees/shrubs**	
Geranium dissectum	R	Betula spp.	R
G. molle	R	Ulex europaeus	R

1.1.20 New Fancy East

	Details	Suitability
Grid Reference	624097	
Location details	NE of Parkend, off Speech House-Parkend B-road	
Current site management	Forestry	✗
Future site management	Forestry	✗
Approximate age of waste		✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Conical mound	✓
Aspects available	None	✗
Habitat type	Conifer plantation	
Surrounding habitat	Mixed woodland	
Amenity use	None	
Comments	Sister site to New Fancy View.	
References	Hart (1971); Oldham (1998); Forestry Commission (1999)	

1.1.21 Northern United

	Details	Suitability
Grid Reference	636155	
Location details	Opposite Herbert Lodge off the A4136	
Current site management	Forestry (see Comments section)	✓
Future site management	Forestry	✓
Approximate age of waste	6 years	✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Large mound	✓
Aspects available	South, west, small areas to north and east	✓
Habitat type	Young conifer, 90% bare under-storey layer, small mound of mature conifer from 1965	
Surrounding habitat	Pasture (N), mixed woodland (S, E,W)	
Amenity use	None – not used & has derelict feel	
Comments	Tipping stopped in 1965, but site was partially reclaimed for remaining coal content, with substrate disturbance ceasing in 1996. Conifers planted, but these are widely spaced and mostly under 1m, therefore study of under-storey vegetation possible.	
References	Oldham (1998); Forestry Commission (1999)	

1.1.22 Parkend

	Details	Suitability
Grid Reference	635155	
Location details	At the back of housing in Parkend	
Current site management	Open to grazing	✓
Future site management	None	✓
Approximate age of waste	? unknown	?
Source of waste material	Colliery spoil	✓
Topography	Small mound	✓

Aspects available	None (too flat)	✗
Habitat type	Grassy bracken scrub	
Surrounding habitat	Housing (S), conifer plantation (N)	
Amenity use	Close to housing. Dogwalking, open space.	
Comments	Too flat to meet criteria. Possibly serviced Parkend Royal (see Castlemain), although many other pits also operated in area	
References		

1.1.23 Princess Royal

	Details	**Suitability**
Grid Reference	613065	
Location details	Between villages of Bream's Eaves and Whitecroft	
Current site management	Forestry/birch	✗
Future site management	Forestry/birch	✗
Approximate age of waste	39	✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Large mound	✓
Aspects available	East	✗
Habitat type	Conifer to west and south of tip, birch to east	
Surrounding habitat	Mixed woodland, domestic house and gardens to north	
Amenity use	Public footpath used passing on east side. Potential viewpoint.	
Comments	Eastern aspect not available on other tips. Birch trees also planted, not naturally regenerated.	
References	Hart (1971); Hobday (1994) (9); Oldham (1998) Forestry Commission (1999)	

1.1.24 Quidchurch Gale

	Details	**Suitability**
Grid Reference	649114	
Location details	Ridge to west of Ruspidge valley, near Staple edge	
Current site management	None	✓
Future site management	None	✓
Approximate age of waste	10 years	✓
Source of waste material	Clay-rich colliery spoil waste (freemine)	✗
Topography	Flat	✗
Aspects available	None	✗
Habitat type	Marshy-grassland	
Surrounding habitat	Mature oak woodland	
Amenity use	None. Site currently being worked.	
Comments	Freemine waste does not meet criteria	
References	Oldham (1998); Hayes (2000)	

1.1.25 Strip-and-at-it

	Details	Suitability

Grid Reference	623146	
Location details	Serridge Green, near Puzzle House	
Current site management	Forestry/open	✗
Future site management	Forestry	✗
Approximate age of waste	75	✓
Source of waste material	Loosely tipped colliery spoil	✓
Topography	Small conical mound	✓
Aspects available	None	✗
Habitat type	Conifer plantation	
Surrounding habitat	Mixed woodland	
Amenity use	None	
Comments	Small spoil heap, part of Trafalgar colliery, also closed 1925	
References	Oldham (1998); Forestry Commission (1999)	

1.1.26 Trafalgar

	Details	Suitability
Grid Reference	623142	
Location details	Within Serridge Enclosure	
Current site management	Forestry/open	✗
Future site management	Forestry	✗
Approximate age of waste	c. 77. colliery closed 1925, planted 1928	✓
Source of waste material	Colliery spoil, loosely tipped	✓
Topography	Large non-distinct mound	✓
Aspects available	None	✗
Habitat type	1993 Corsican pine plantations on southern slopes, areas of 1928 Scots pine, regenerating woodland.	
Surrounding habitat	Mixed woodland	
Amenity use	Cycle path runs below site (to south), but site only accessible via small track from north. Species-rich grassland growing on cinders at north east of site	
Comments	No direct access plus health & safety problems also to consider on site.	
References	Hart (1971); Hobday (1994) (14); Oldham (1998);	

1.1.27 True Blue

	Details	Suitability
Grid Reference	624167	
Location details	East side of village of Ruardean woodside	
Current site management	None/open	✓
Future site management	As above	✓
Approximate age of waste	100	✓
Source of waste material	Collery spoil, loosely tipped	✓
Topography	Small mound on side of hill	✓
Aspects available	West,southwest,south	✓
Habitat type	Heathland with grassland and gorse patches	
Surrounding habitat	Gardens (S, W); arable fields (N); bracken-scrub (E)	
Amenity use	Used by local people for dogwalking etc	

Comments	Serviced True Blue colliery which shut in the 1940s, but according to local memory the tip has been present for approximately 100 years.	
References	Dreghorn (1968); Oldham (1998).	

1.1.28 Waterloo

	Details	**Suitability**
Grid Reference	616145	
Location details	Via footpath from A 4136 Monmouth-Gloucester road	
Current site management	Forestry. Open.	✗
Future site management	As above	✓
Approximate age of waste	c. 40. Colliery closed 1959, Scot's pine planted 1961.	✓
Source of waste material	Colliery spoil	✓
Topography	Conical mound plus tramway ridge	✓
Aspects available	All	✓
Habitat type	Dense Scot's Pine (1961). 60% bare herb layer. Where conifer cover thin on tramway, cover 100% grasses, bramble, bluebell.	
Surrounding habitat	Mixed conifer plantations	
Amenity value	Just off main cycle route	
Comments	Spoil heaps for Waterloo (Arthur & Edward colliery)	
References	Hart (1971)Hobday (1994) (18); Oldham (1998)	

1.1.29 Woorgreen

	Details	Suitability
Grid Reference	630128	
Location details	Great Kensley Enclosure. Off Speech House Road B4226.	
Current site management	Lake/panted/open	✓
Future site management	As above	✓
Approximate age of waste	20	✓
Source of waste material	Opencast mine site	✗
Topography	Flat	✗
Aspects available	None	✗
Habitat type	Open water with grassland and mixed planted areas	
Surrounding habitat	Mixed woodland	
Amenity use	High provision of access to lake area	
Comments	Opencast site restored in 1980s to open water/grass/ woodland	
References	Addis *et al.* (1984)	

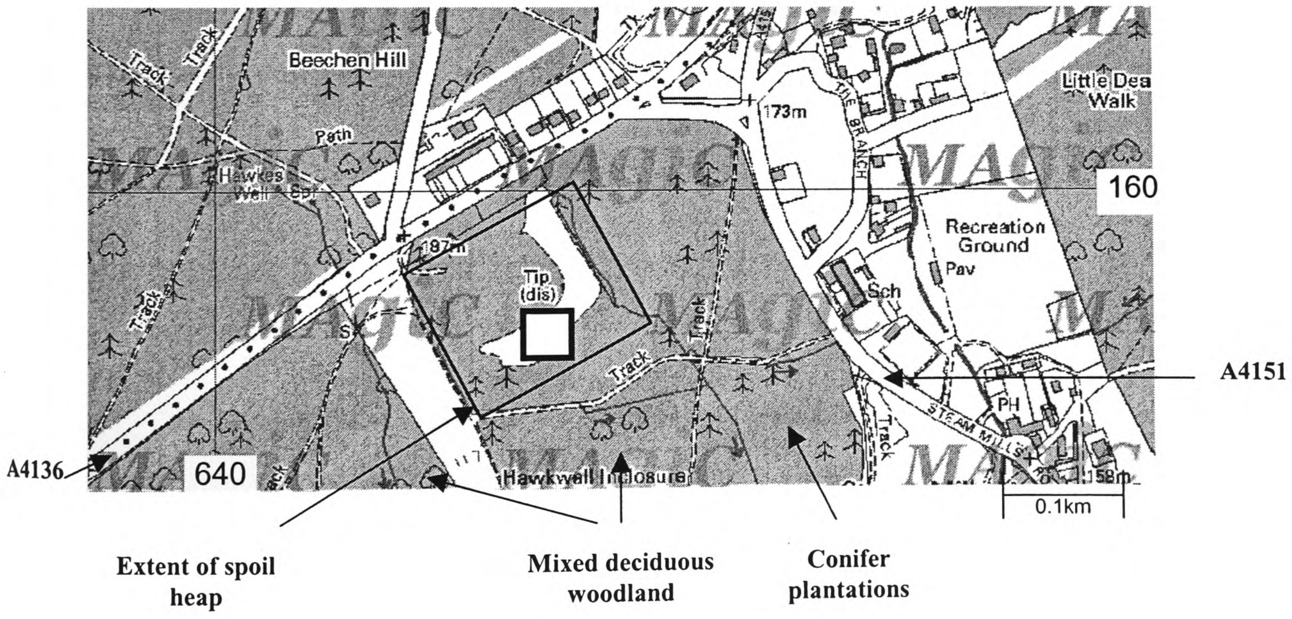
Appendix 1.2 Maps to show the location of study plots

The 1965 1:25,000 Ordnance Survey map series are used where possible to show plot locations because these give the most accurate topographical detail. These were not available for some spoil heaps, for which other mapping sources are provided. The maps are annotated to show relevant information observed from site visits. Plot locations are indicted on each site with white boxes: □ The maps are not shown at the same scale, but a scale is provided for each map, and 3 figure grid references have been overlain onto the OS gridlines to enable the precise location of the study plots to be seen. The study plots are not to scale.

Photographs have been provided in addition to the maps where these provide relevant information to the study.

1.2.1 Hawkeswell, showing location of study plot.

Source: DEFRA (Magic.gov.uk). SO6416. Original scale = 1:5,000



A4136

A4151

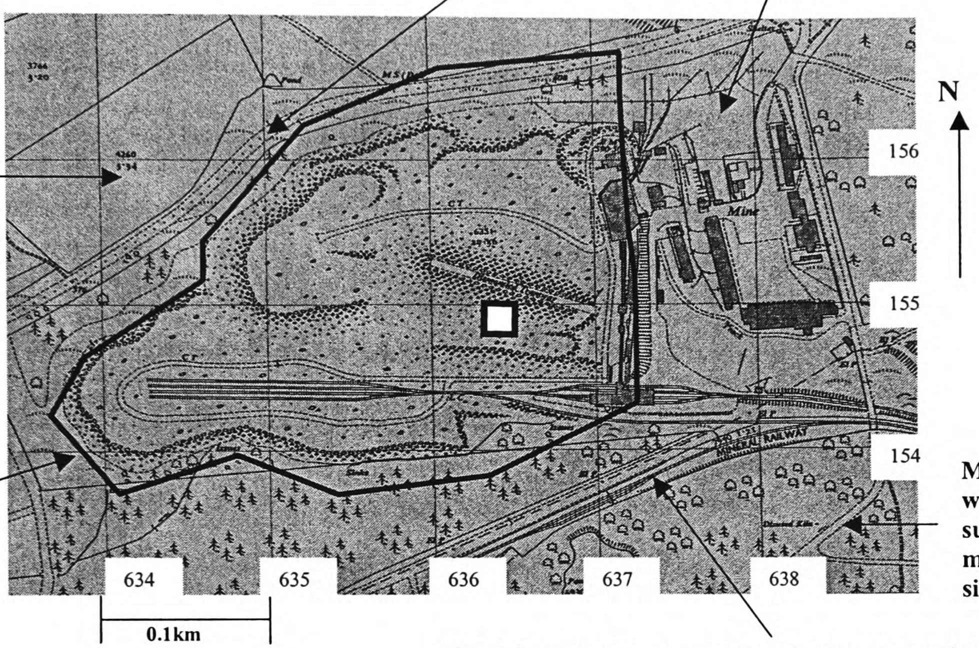
Extent of spoil heap

Mixed deciduous woodland

Conifer plantations

1.2.2 Northern United, showing location of study plot.

Source: Ordnance Survey 1961. SO6315. Original map scale = 1:25,000



The site is still hidden from the A 4316 by conifers

Derelict buildings still remain

A single, grazed, grassland enclosure lies to the north of the site

Remaining extent of coal spoil

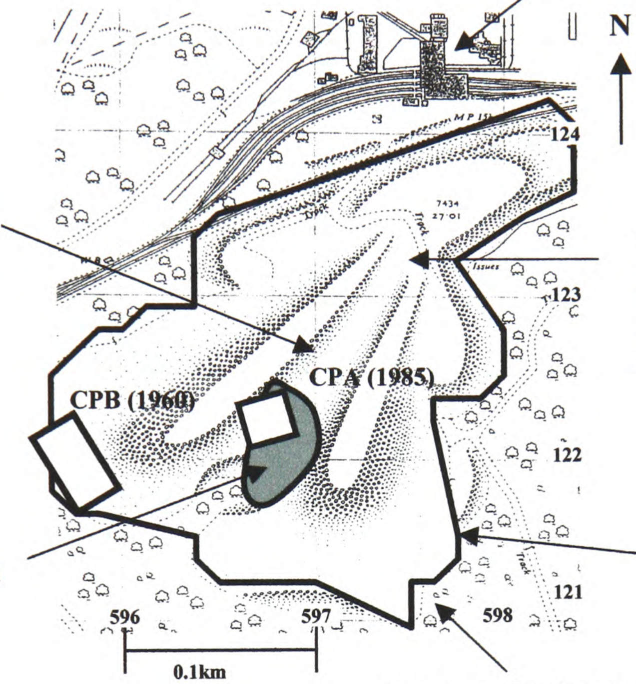
Mixed woodland surround most of the site

The old railway is now used as a pathway running past the site, but no pathways cross the site

1.2.3 Cannop colliery site showing location of study plots A and B.

Source: Ordnance Survey 1961. SO6012. Original scale = 1:25,000.

Site of the colliery buildings is now partly in local authority use, and partly used as a cycle-hire shop and cafe



Informal pathways criss-cross the site between spoil embankments, with evidence of erosion from mountain biking (see photos below).

The northern part of both fans were planted in 1960 for landscaping purposes.

Approximate extent of a trial to reclaim coal in 1985

Site boundary

Mixed woodland surrounds the site

1.2.4 Additional photographs of the Cannop colliery site

b)

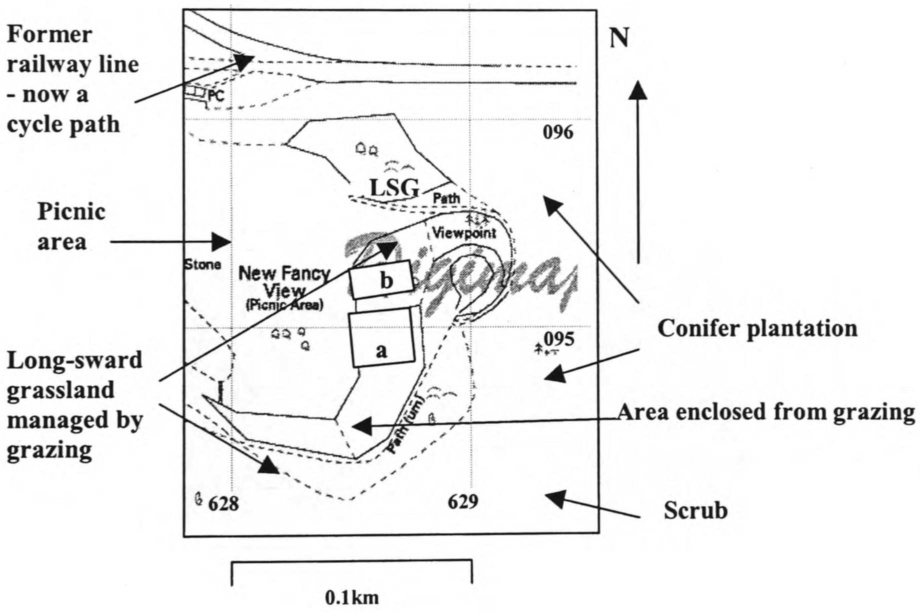
a)

Photograph a) is taken in between the two fans of the spoil heap at SO 607122 looking north. It shows the wide footpaths that traverse the lower parts of the spoil heaps – the condition of the footpaths would indicate that the site is heavily used by both walkers and cyclists, although only 4 people were encountered on the site during 4 site visits and the survey period.

Photograph b) is taken looking up a south-west slope on the western fan which had an angle of 40-45°, showing the type of erosion that was commonly observed on the steep slopes of this site. In this picture erosion has been exacerbated by a steep mountain bike 'run'.

1.2.5. New Fancy View showing the location of study plots A and B.

Source: Edina Digimap, 2001. SO6209. Original scale = 1:2500



1.2.6 Additional photographs of New Fancy View

a)

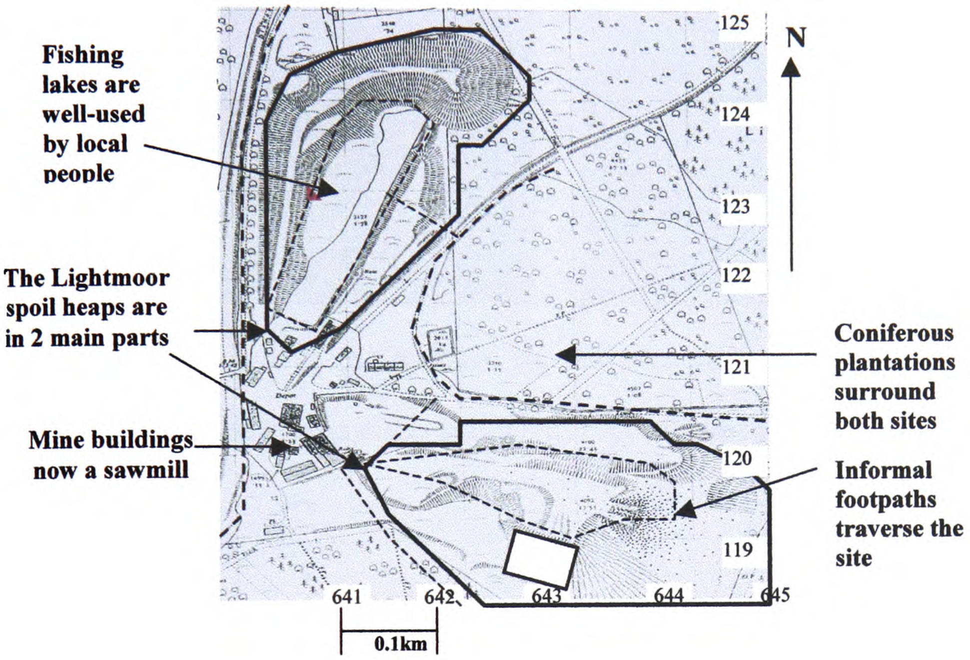
Photograph a) shows the conical tip of New Fancy View. The shot was taken from SO 628 093 looking east towards the study plots at a distance of 250m. The photograph was included because the map in Appendix 1.2.4 does not provide topographical information, and also to show habitat/landuse detail more clearly.

b)

Photograph b) is taken from the top of New Fancy View, SO629095 looking north-east, showing views across the Forest of Dean, the wide and well-used footpaths winding around the site, and the coniferous plantations that are growing on the northern and eastern slopes of the site.

1.2.7 Lightmoor, showing location of study plot

Source: Ordnance Survey 1961. SO6411-6412. Original scale = 1:25,000



Fishing lakes are well-used by local people

The Lightmoor spoil heaps are in 2 main parts

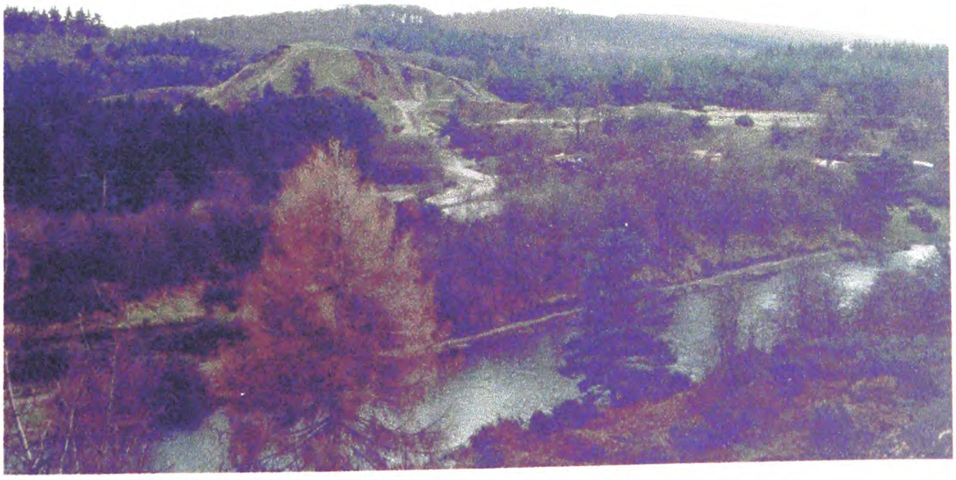
Mine buildings now a sawmill

Coniferous plantations surround both sites

Informal footpaths traverse the site

1.2.8 Additional photographs of Lightmoor

a)

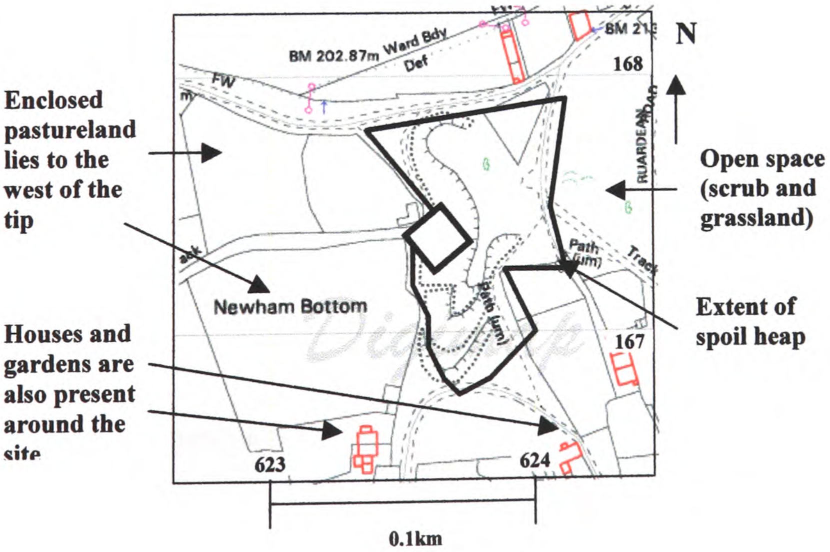


Photograph a) is a view of the southern-most Lightmoor tip taken from the top of the northern-most tip (SO642124) looking southeast. Lightmoor is the largest site included in this survey, and the largest mining site remaining in the Forest.

Photograph b) part of the southern tip has been reworked for aggregates. This photograph shows the red shales indicative of spontaneous combustion.

1.2.9 True Blue, showing location of study plot

Source: Edina Digimap 2001. SO6216. Original scale = 1:2500.



Appendix 1.3 Sources of unpublished information on the local area

This Appendix documents some of the unpublished sources of information that contributed to the site search, helped form the site selection procedure, and enabled a detailed enough knowledge of site history to be gained in order to apply the criteria. Many references are made in the text for example, to 'personal communications'. This section provides information on who the people are, and where their expertise comes from.

1.3.1 Literature search

The Gloucester Archaeology Monuments Record (Gloucester County Council, 2001) was contacted, who provided grid references for over 100 coal mining sites that could be further investigated. There is also a wide body of locally-available reports on mining by industrial archaeology enthusiasts, books and maps within local studies libraries at the Forest of Dean Heritage Centre and Cinderford Library. Oldham (1998) for example, catalogues the name, location, and (where possible) dates of working of some 310 mines over some 63 pages. Hart (1971) provides comprehensive information on the industrial archaeology of the area. The staff of both libraries were very helpful in finding old newspaper cuttings, old maps, reports, photographs, and other documents.

1.3.2 Local knowlegde

Local knowledge was a particularly valuable source of information. Governmental bodies working within the Forest of Dean such as the District

Council, County Council, and Forestry Commission were contacted early on in the study. Forestry Commission staff were able to give a lot of useful information on where to locate suitable coal wastes. Many spoil heaps of them have been planted, and the crops come under the care of 'Beat Officers'. The 'Deputy Gaveller' also administers licenses for Free-mine Gales (mining plots), and so regulates all mining activity within the Forest of Dean. The Forest of Dean Heritage Centre manager, Kate Biggs, was local to the Forest of Dean and very knowledgeable on industrial archaeology and cultural heritage Letters were also written to local industrial archaeology experts such as Dr Hart, explaining what the aims of the study were, and asking for advice in locating suitable sites.

1.3.3 Mapping information

Hobday (1994) contained maps from the 1960s OS series which identified the location of the larger mines of the 19th and 20th Centuries. The location of coal wastes from smaller mines were not as easy to locate. The grid references for the mine entrances given in Oldham (*op. cit.*), and the Gloucester Archaeology Monuments Record do not always lead to the spoil heaps used by particular mines. At Waterloo for example, spoil was taken away from the main pit head on an overhead conveyor system (Hart, 1967). One of the most effective means of finding smaller wastes looking for unusual contours near to old adits and shafts marked on the modern OS map. Coal spoil heaps in the Forest of Dean tend to have very steep, irregular-shaped contours compared to natural topographical features, which became easy to identify with experience. .These maps searches could then be followed up by site visits.

1.3.4 Site visits

Several site visits were undertaken with local and national Forestry Commission staff, including:

a) Initial tour of sites with Mr John Harvey, the Deputy Gaveller, July 1999

The role of the Deputy Gaveller is explained above (1.3.2). A tour of different types of mining wastes (e.g. opencast, fire-clay mounds, free-mine wastes, loosely tipped) was undertaken with Mr Harvey, which helped in later fieldwork to distinguish between the type of mining wastes. It was clear after this tour that selection criteria would be needed. Other information gained from Mt Harvey included:

- Landownership details
- Mining history
- Site history
- The current uses of spoil heaps for aggregates and schemes looking to re-work the heaps for remaining coal.

b) Tour of coal sites presenting growth problems for the Forestry Commission, September 1999

This tour accompanied the Beat Officer for the northern part of the Forest, Peter Kelsall, and the national Forestry Commission expert on reclaiming derelict land for tree growth based at Alice Holt, Dr Moffat (e.g. Moffat and McNeil, 1994;

Bending *et al.*, 1991; Hood and Moffat, 1995). Sites visited included Northern United, Foxes Bridge and Cinderford Linear Park. The visit was useful as for learning to spot field signs of acidity, nutrient deficiency, and compaction, as well as learning more about the history of some sites.

c) Visit to Northern United with Dr David Fourt

As Dr Moffat's predecessor, Dr Fourt was in post when Northern United was being reclaimed, and undertook a lot of work on the site including some soils analysis, which was useful for understanding the range of pH results that may be experienced on a site. Dr Fourt's personal notes were also useful for learning of site history.

Appendix 1.4 A summary of local newspaper articles found on mining in the Forest of Dean

This appendix contains the results of a search undertaken in the Cinderford Local Studies Library in 2001 for newspaper articles on coal mining within the 2 local Forest of Dean papers, the Dean Forest Mercury and The Citizen. Articles that reported factual news were not included due to sheer volume; the table below summarises articles from columnists that contain 'social comment'. The articles show the strength of feeling that local people have towards the coal mining industry in the Forest of Dean even 40 years on from the last large deep-mine closure.

Table summarizing newspaper articles from two For4st of Dean papers over 40 years from 1959-1998 that provide social comment on coal mining

Stance taken by author	Year	Newspaper and occasion	Main points of article
Grief on loss of industry	1959	Dean Forest Mercury. Closure of Waterloo Colliery. Anon.	200 men lost jobs on pit closure. Not just a sad day for those who will become unemployed, but also for retired miners who have treasured memories of Waterloo.
Grief on loss of industry	1965	The Citizen. Closure of Northern United, last deep pit. Anon.	Emotional article; Forest of Dean coal and iron have "yielded a living" for Foresters since the Roman period, with Forest men "pitting their skills against unknown dangers". Coal brought work not just to those who mined it, but to those employed in service industry and transport. The loss of the industry is a big blow to the area.
Grief on loss of industry	1965	The Citizen. Closure of Northern United, last deep pit. Anon	"seems almost incredible to those of us who have lived the greater part of our lives in the Forest….that one of the oldest coalfields in Britain should cease working"
Public hazard	1974	Dean Forest Mercury. Industrial legacy still present. R.Gregory.	Mining wastes are being afforested, buildings find new uses, but many mine shafts are still open. These present a public health risk, encourage fly-tipping, and are dangerous for children. Presses Forestry Commission to fence them off.
Influence on Culture	1976	The Citizen. Retrospective piece reminiscing on mining.	The coal industry moulded Foresters into strong, blunt, independent and hard-working people. The industry has left many scars – not only on the landscape, but on the health of the miners – now suffering from Silicosis and Pneumoconiosis
Influence on Culture	1981	The Citizen. Personal reminiscence of old	Article about the life of Ky, a freeminer since the age of 14. In spite of the hard times, he is glad he's a miner – "the comradeship was

		mining lifestyle.	wonderful; I'm a Forester and mining's in my blood".
Influence on Culture	1981	Dean Forest Mercury. Reminiscing on mining past	Now 16 years since closure of Northern United. Only a handful of freeminers now still mine, maintaining the Forest's links with the mining era. Memories of those days are now receding.
Influence on Culture	1986	Dean Forest Mercury. Cinderford's history.	Reminiscent piece. The collieries were the "lifeblood" of Cinderford, giving employment to so many men, and supporting so many thriving industries.
Continued influence on politics	1992	Dean Forest Mercury. National pit closure strategy. G. Blake.	Forest of Dean people show outrage at the John Major government decision to shut down 31 pits nationally, with 30,000 job losses. Foresters express support for the mining communities.
Cultural influence needs to be preserved.	1998	Forester. Interview with D. Bick, local industrial historian. S. Graham.	Bick laments that more should be done to preserve old industrial sites. Also need to write history of mining before it's too late, and all those involved in the mining industry have passed away and stories lost. "People visit the Forest of Dean because of it's old industries, not in spite of them".

Appendix 2

Appendix 2.1 Data recording sheet

Site name:

Date:

Time:

Grid Ref:

Quadrat no:

Quadrat co-ordinates:

21	22	23	24	25
16	17	18	19	20
11	12	13	14	15
6	7	8	9	10
1	2	3	4	5

Aspect:

% Bare ground

Surface substrate temperature:

Avg. ground layer (mm)

Avg. herb layer (cm)

Avg. shrub layer (cm)

Avg canopy layer (m)

Avg. plant vigour:

Foliage green-blue in colour		**1**
No blotches, galls, lesions, other signs of discomfort.		
Firmly rooted.		
General appearance: healthy, thriving		
Foliage mainly green-blue, some discolouration		**2**
Some blotches or other signs of discomfort		
Firmly rooted		
General appearance: healthy		
Foliage green in colour, some yellowing		**3**
Foliage blotchy, showing signs of discomfort		
Not firmly rooted, gives some resistance		
General appearance: adequately surviving		
Foliage yellowy-green in colour		**4**
Foliage showing signs of discomfort		
Unstable rooting: would be easy to pull up		
Growth may be stunted		
General appearance: surviving but not healthy		
Foliage yellowy		**5**
Foliage dying		
Barely rooted		
Stunted growth		
General appearance: Clinging onto existence		

Notes (weather conditions, seasonality, other useful observations):

Slope angle(°):

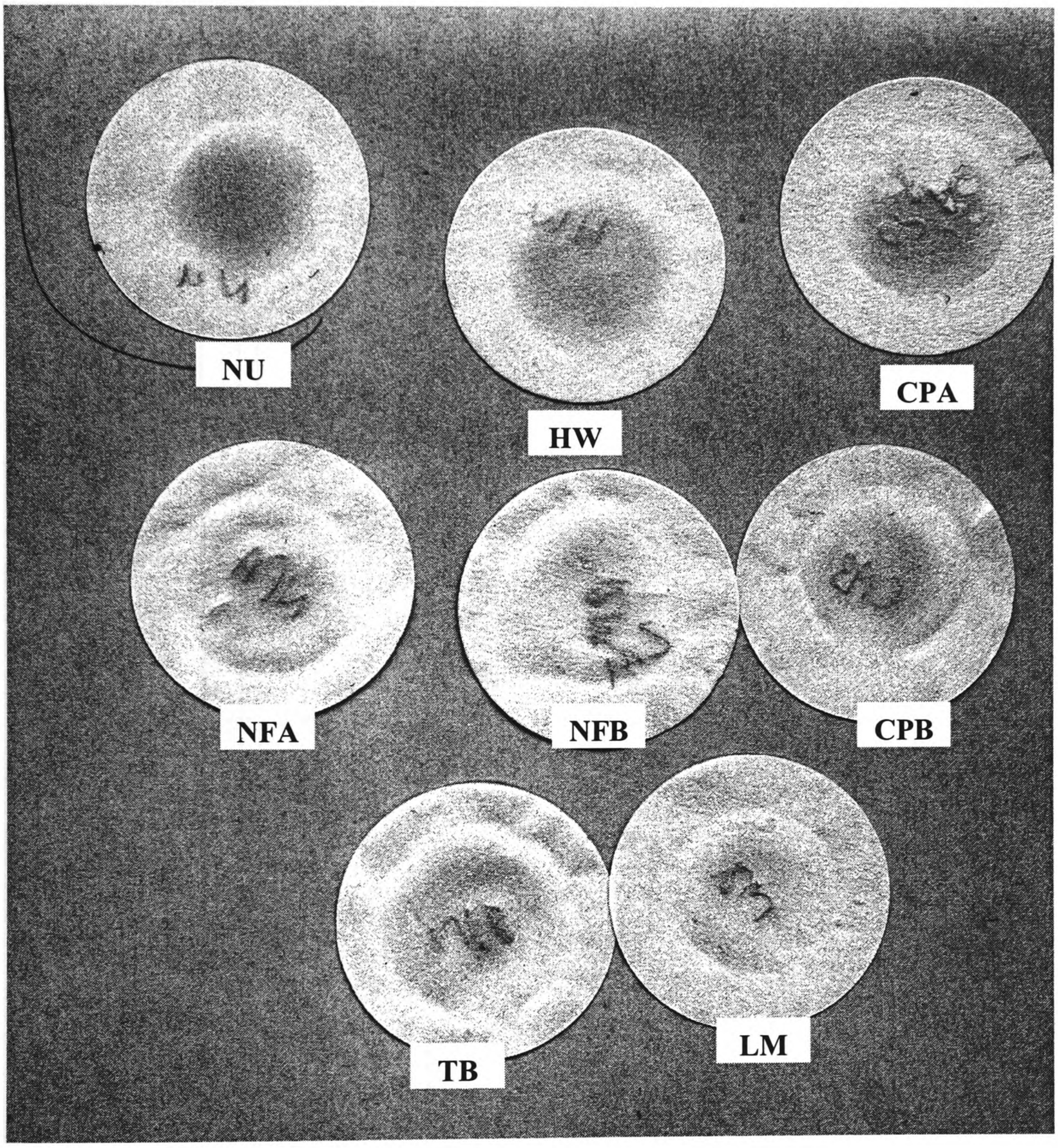
Depth of humus (cm):

Physiognamy &vigour per cell

	Vigour	Moss	Herb	Shrub
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				

Appendix 3

Appendix 3.1 Image to show the filter-papers from the pyrites analyses



Appendix 3.2: Soil depth information

a) Soil depth results by quadrat. NB: P = Plot; T = Transect

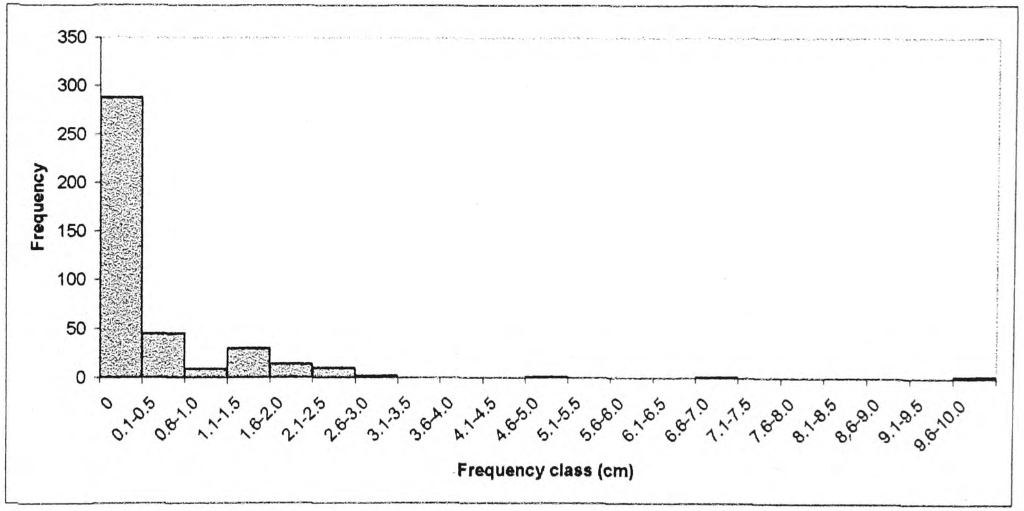
		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7				Mean	STDEV	Rank
HW	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	1
	T2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
	T3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
NU	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.02	2
	T2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0			
	T3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
CPA	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													0.06	0.17	3
	T2	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0															
NFA	T1	1.2	1.5	1.5	1.3	1.5	1.3	1.5	1.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	2.0	0.5	2.0	0.3	0.0	0.0	1.5	1.0	1.0					1.35	0.74	7
	T2	2.5	2.5	3.0	2.0	2.5	2.5	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.0	0.5	0.5	1.5	0.0	0.0	0.5	0.8	1.2	0.5	0.5							
NFB	T1	2.5	2.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.3	0.4	1.0	0.5	0.5	1.5	1.6					0.74	0.56	6
CPB	T1	0.5	5.0	0.5	0.5	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													0.18	0.73	4
	T2	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0															
	T3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0															
LM	T1	7.0	10.0	10.0	5.0	1.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0									0.58	2.08	5
	T2	0.3	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0											
	T3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0											
TB	T1	2.0	0.0	2.0	2.0	1.5	2.5	0.7	2.5	1.0	1.5	1.5	1.5																	1.63	0.77	8
	T2	2.5	2.5	2.5	2.0	1.5	1.5	1.5	3.0	1.5	1.0	1.0	0.0																			
TOTAL																														0.41	1.05	

b) Soil depth frequency classes

Frequency class	Frequency
0	288
0.1-0.5	45
0.6-1.0	9
1.1-1.5	30
1.6-2.0	14
2.1-2.5	10
2.6-3.0	2
3.1-3.5	0
3.6-4.0	0
4.1-4.5	0
4.6-5.0	1
5.1-5.5	0
5.6-6.0	0
6.1-6.5	0
6.6-7.0	1
7.1-7.5	0
7.6-8.0	0
8.1-8.5	0
8.6-9.0	0
9.1-9.5	0
9.6-10.0	2
No. samples=	404
Sample mean	0.41
ST DEV	1.05
x =	45
%	11.14

NB. x = No. samples that fall between the mean and the standard deviation

c) Graph to show soil depth frequency classes



Appendix 3.3: Plant vigour information

a) Plant vigour estimates by quadrat

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7			
HW	T1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	T2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	T3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
NU	T1	4	4	4	4	4	4	4	4	4	4	5	5	5	4	4	4	4	4	4	5	3	3	4	4	3	3	4	4
	T2	4	4	4	4	4	4	4	5	5	4	4	4	5	4	4	4	5	5	4	4	4	4	4	4	4	4	4	4
	T3	4	4	4	4	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4
CPA	T1	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5												
	T2	4	3	4	4	4	4	4	4	5	5	5	5	5	5	5	5												
NFA	T1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	4	3	3	2	2				
	T2	3	3	3	3	4	3	3	3	2	2	2	3	2	3	3	2	3	3	3	2	3	3	3	3				
NFB	T1	3	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3				
CPB	T1	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4												
	T2	2	2	3	3	4	4	4	4	5	4	5	5	4	4	4	4												
	T3	4	5	4	4	4	4	4	4	4	4	4	4	4	4	5	5												
LM	T1	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4								
	T2	2	2	3	3	4	4	4	4	5	4	5	5	5	4	4	5	4	4	4	4								
	T3	4	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4								
TB	T1	2	2	2	2	2	3	3	2	2	2	2	2																
	T2	2	2	2	2	2	2	2	2	3	2	3	3																

b) Plant vigour mode categories and assigned rank

	No. samples/category					% samples/category					Mode	Rank
	1	2	3	4	5	1	2	3	4	5		
HW	0	0	0	0	84	0	0	0	0	100	5	8
NU	0	0	5	62	17	0	0	6	74	20	4	6
CPA	0	0	1	8	23	0	0	3	25	72	5	7
NFA	0	26	20	2	0	0	54	42	4	0	2	2
NFB	0	3	21	0	0	0	13	88	0	0	3	3
CPB	0	6	6	31	5	0	13	13	65	10	4	4
LM	0	6	6	42	6	0	10	10	70	10	4	5
TB	0	19	5	0	0	0	79	21	0	0	2	1

Appendix 3.4: Slope factor (°) results by subplot and mean results per transect (T) and plot (P)

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
HW	T1																														12		
NU	T1	11	11	11	11	11	11	11	11	11	11	11	11	14	14	14	14	17	17	17	17	21	21	21	21	21	21	21	21	28	15.14		
	T2	10	10	10	10	10	10	10	10	14	14	14	14	14	14	14	14	19	19	19	19	22	22	22	22	21	21	21	21	28	15.64		
	T3	12	12	12	12	10	10	10	10	12	12	12	12	17	17	17	17	18	18	18	18	19	19	19	19	21	21	21	21	28	15.50	15.4	4.25
CPA	T1	15	15	15	15	24	24	24	24	40	40	40	40	40	40	40	40													16	29.75		
	T2	17	17	17	17	25	25	25	25	40	40	40	40	40	40	40	40													16	30.50	30.1	10.50
NFA	T1	19	19	19	19	25	25	25	25	29	29	29	29	30	30	30	30	30	30	30	30	29	29	29	29					24	27.00		
	T2	17	17	17	17	23	23	23	23	26	26	26	26	30	30	30	30	30	30	30	30	31	31	31	31					24	26.17	26.6	4.55
NFB	T1	26	26	26	26	30	30	30	30	31	31	31	31	32	32	32	32	32	32	32	32	31	31	31	31					24	30.33	30.3	2.10
CPB	T1	18	18	18	18	31	31	31	31	35	35	35	35	40	40	40	40													16	31.00		
	T2	35	35	35	35	23	23	23	23	24	24	24	24	38	38	38	38													16	30.00		
	T3	34	34	34	34	38	38	38	38	32	32	32	32	40	40	40	40													16	36.00	32.3	6.92
LM	T1	35	35	35	35	18	18	18	18	22	22	22	22	26	26	26	26	20	20	20	20									20	24.20		
	T2	19	19	19	19	24	24	24	24	35	35	35	35	30	30	30	30	26	26	26	26									20	26.80		
	T3	15	15	15	15	31	31	31	31	35	35	35	35	40	40	40	40	13	13	13	13									20	26.80	25.9	7.98
TB	T1	12	12	12	12	20	20	20	20	23	23	23	23																	12	18.17		
	T2	12	12	12	12	20	20	20	20	29	29	29	29																	12	20.17	19.2	6.33

Appendix 3.5: Canopy cover (%) results by subplot and mean results per transect (T) and plot (P)

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
NU	T1	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	14	0	0	0	0	0	0	0	28	1.66		
	T2	23	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	11	0	10	0	0	0	0	0	0	13	21	11	28	3.56		
	T3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0.00	1.74	4.77
CPA	T1	8	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0													16	1.13		
	T2	17	75	35	35	0	0	0	0	0	0	0	0	0	0	0	0													16	10.13	5.63	15.57
NFA	T1	5	75	75	20	5	0	15	50	0	10	10	0	0	0	0	0	0	0	0	0	75	0	0	0					24	14.17		
	T2	100	100	75	75	100	100	100	100	25	65	75	90	75	80	75	75	75	75	25	25	65	45	35	10					24	69.38	41.77	38.50
NFB	T1	7	20	25	15	75	75	70	50	80	75	75	70	75	80	65	65	0	0	80	75	80	0	75	70					24	54.25	54.25	30.42
CPB	T1	35	40	50	75	75	80	80	75	10	50	80	0	25	0	0	0													16	42.19		
	T2	60	40	50	95	75	20	80	80	75	40	50	85	0	45	0	35													16	51.88		
	T3	0	25	25	10	50	75	50	50	80	75	80	0	20	0	0	0													16	33.75	42.60	31.47
LM	T1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									20	0.00		
	T2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									20	0.00		
	T3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									20	0.00	0.00	0.00
TB	T1	0	0	0	0	0	0	0	0	0	0	0	0																	12	0.00		
	T2	0	0	0	0	0	0	0	0	0	0	0	0																	12	0.00	0.00	0.00

Appendix 3.6: Data on the height of the shrub, herb and ground layer species

a): Shrub height results by quadrat

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
NU	T1	0	5	0	5	0	0	0	70	0	10	50	100	55	5	40	0	60	75	10	10	70	70	50	90	120	180	110	0	28	42.32		
	T2	130	0	75	113	65	247	80	100	2	89	3	2	51	0	55	35	89	74	76	0	97	78	10	60	50	175	212	75	28	72.93		
	T3	65	65	80	100	0	25	15	60	0	75	0	50	50	25	0	0	0	80	40	5	0	70	50	110	90	25	90	70	28	44.29	53.18	51.11
CPA	T1	40	0	0	0	0	0	0	0	0	0	5	0	0	0	10	10													16	4.06		
	T2	261	27	0.4	0.4	0.6	0	0.2	0.2	5	0	5	0	0	10	5	0													16	19.70	11.88	46.28
NFA	T1	23	28	50	28	64	64	39	100	30	59	55	55	20	50	44	34	35	7.5	0	25	30	26	75	75					24	42.30		
	T2	68	21	25	25	16	14	30	15	14	20	20	20	175	34	48	30	75	18	19	34	75	75	75	75					24	42.57	42.43	30.30
NFB	T1	43	110	110	51	30	10	0	40	0	5	2	0	0	0	2	2	5	5	5	40	12	33	33	70					24	25.31	25.31	32.83
CPB	T1	0	0	0	0	0	3.5	2	20	0	40	15	15	0	0	3	15													16	7.09		
	T2	7.5	13	7.5	5	0	0	0	3	350	0	0	350	0	4	0	0													16	46.22		
	T3	5	0	0	0	200	10	0	0	10	4	4	4	1	1	2	0													16	15.06	22.79	74.86
LM	T1	40	40	80	0	35	0	10	0	10	0	10	0	10	0	0	0	0	15	0	0									20	11.50		
	T2	83	19	23	10	13	14	0	0	1	1	5	2	0	0	0	0	48	5	40	0									20	13.14		
	T3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									20	0.00	8.21	16.80
TB	T1	32	32	34	29	27	16	16	28	28	18	19	14																	12	24.36		
	T2	30	40	40	27	27	35	26	42	14	25	25	8.6																	12	28.40	26.38	8.78

b) Herb height results by quadrat

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
NU	T1	15	20	25	25	4.7	36	7.5	15	14	16	21	9.6	10	15	15	10	10	15	10	15	20	20	15	20	31	32	32	30	28	18.18		
	T2	9.3	8.4	10	10	11	7.8	18	9.1	14	16	14	15	28	25	15	14	20	17	15	15	16	19	13	11	26	28	31	31	28	16.64		
	T3	23	5.1	8.5	5	20	8.5	0	30	3	7.5	17	8.5	21	14	9.5	16	20	11	15	16	14	16	27	5	27	14	27	29	28	14.93	16.58	7.94
CPA	T1	17	0	31	25	0	0	74	46	0	10	5	5	0	0	0	0													16	13.34		
	T2	6.9	6.4	8.4	8.4	5.8	4.8	3.7	4.2	10	0	15	5	5	5	5	0													16	5.85	9.59	15.50
NFA	T1	40	28	29	37	40	50	42	50	38	30	28	28	12	24	22	30	9.2	21	18	12	19	8.8	12	12					24	26.69		
	T2	19	27	15	15	12	28	18	23	31	30	21	30	60	32	36	50	25	28	15	14	25	28	15	14					24	25.34	26.02	11.94
NFB	T1	29	40	20	27	19	25	25	30	25	25	30	30	25	25	25	25	26	21	30	25	18	18	22	30					24	25.61	25.61	4.91
CPB	T1	3.5	1.6	2.6	1.2	5.4	2.3	2.1	5	2.1	8.8	4.5	4.7	2.2	2.6	3.9	7.7													16	3.77		
	T2	6.2	8.9	5	3	2	3	6.4	2.2	0	2	4	3	0	2	10	10													16	4.23		
	T3	2.6	3	5.7	3	6.7	4.5	4.5	8	9.7	6	7	4.9	2.2	2.5	2	0													16	4.52	4.17	2.65
LM	T1	29	27	35	32	16	15	13	8.1	4.5	7.4	5.1	4.9	5.3	3.8	6	3.9	5	6	3	5									20	11.75		
	T2	29	6.6	8.6	10	8.8	8.4	11	9.8	3.8	8.4	3.3	5.4	6.4	7.8	4.9	4	13	9.6	8.5	8									20	8.75		
	T3	8.9	2.3	3.5	11	4.3	2.4	2.9	6	5.3	3.5	3.6	2.6	8.5	8.7	7.8	9.6	9.1	5.7	5.5	7.5									20	5.91	8.81	7.27
TB	T1	15	15	15	15	15	10	10	15	10	10	10	5																	12	12.05		
	T2	17	25	20	20	15	15	15	25	7.9	10	10	5.6																	12	15.42	13.74	5.21

c) Ground-layer height results by quadrat

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
NU	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	1.0	0.5	0.3	0.2	28	0.50		
	T2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.0	0.0	0.2	28	0.23		
	T3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.37	0.15
CPA	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0																
	T2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0													16	0.35	0.35	0.09
NFA	T1	7.4	5.7	6.8	4.2	2.0	3.0	5.7	10.0	4.0	5.0	4.0	4.0	1.4	3.1	3.6	1.7	1.1	2.5	1.3	1.4	0.3	0.5	0.6	0.6					24	3.33		
	T2	2.5	1.9	2.7	2.7	0.6	1.8	1.8	2.4	1.0	2.4	3.0	1.2	1.2	0.5	0.3	0.3	2.5	0.2	0.3	0.2	2.5	0.2	0.3	0.2					24	1.36	2.35	2.14
NFB	T1	1.2	0.0	0.5	0.5	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.7	1.0	1.0	1.5	1.5	3.0	1.0	1.0	1.5	1.3	1.5	1.0	1.0					24	1.03	0.99	0.58
CPB	T1	0.7	0.5	0.8	0.5	0.3	0.3	0.3	1.0	0.8	0.0	1.0	1.0	0.0	0.0	0.0	0.2													16	0.61		
	T2	0.6	0.4	1.0	1.0	0.3	1.0	0.2	1.0	0.0	5.0	0.5	1.3	0.0	1.0	0.0	0.3													16	1.05		
	T3	0.3	0.3	0.2	0.3	1.0	0.3	0.1	0.3	1.0	0.3	1.0	1.0	0.0	0.5	0.0	0.0													16	0.51	0.57	0.76
LM	T1	1.0	5.0	1.0	0.5	0.3	0.5	0.5	0.3	0.3	0.3	0.7	0.7	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3									20	0.66		
	T2	3.8	1.7	0.3	4.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.0	0.0	6.3	0.3	0.2	0.2									20	1.10		
	T3	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.0	0.0	0.3	0.3	0.0	0.3	0.3	0.2	0.2	0.3	0.2									20	0.28	0.68	1.18
TB	T1	5.1	5.0	0.5	0.5	3.9	0.2	1.0	2.0	0.5	0.4	4.0	3.0																	12	2.17		
	T2	5.4	3.0	4.0	5.2	1.0	1.0	1.0	5.0	0.9	0.5	0.5	0.5																	12	2.33	2.25	1.93

Appendix 3.7: Data on the % cover of the shrub, herb and ground layer species

a) % shrub cover by quadrat

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
NU	T1	0	0	10	10	0.1	0	0.3	0	0.3	0.1	0.1	0.2	4.4	1.3	5.3	3.2	2	13	0.3	4.5	14	8.7	4.3	4.6	1.9	2.3	0.2	8.8	28	3.55	4.09	4.64
	T2	23	0	4.9	11	4.2	8	2	4.4	0	4.7	0.2	0.9	2.3	0.8	2.8	1.4	11	6.1	10	1.4	5.7	5.8	0.4	3.1	3.3	13	21	11	28	5.79		
	T3	5	13	5.3	2.2	0	0.8	1	2	0	3.8	0.4	2.3	3.6	1.2	0.1	0	1.2	2.8	1.4	3.3	0.4	2.6	3.8	5.6	4.7	2.1	4.7	8.5	28	2.93		
CPA	T1	8	0	0	0.2	0	0	0	0	0	10	2	2	0	0	5	5													16	2.01	1.71	3.71
	T2	17	3	0.3	0.3	0.4	0	0.1	0.2	0.2	0	0.4	0	0	0.4	0.2	0													16	1.41		
NFA	T1	5.4	35	1.2	3.7	15	14	6.4	2.4	3.1	3.4	1.5	4.4	0.7	5.7	1.4	2.7	1.6	0	1	1	0.6	2.2	4.9	4.9					24	5.09	13.79	17.77
	T2	4.9	8.9	3.6	3.6	11	18	4.9	6.9	24	7.5	4.6	9.4	50	12	7.5	5.1	64	18	49	57	33	26	56	55					24	22.49		
NFB	T1	54	90	60	48	1.6	0.7	0.1	5.5	0	0.2	0.7	0.4	48	13	11	1.8	3.4	4.6	0.8	2.8	1.2	2.4	5.6	5.3					24	15.05	15.05	24.91
CPB	T1	0.2	0	0.2	8.1	0.5	0.9	0.3	8.2	0	0.6	4.6	4.6	0	0	0.2	0.6													16	1.82	1.92	3.67
	T2	4.4	4.8	0.5	0.2	0	0	0	0.2	16	0	0	12	0	0.2	0	0													16	2.40		
	T3	0.2	0	0	0	4.1	12	0	0	0.1	0.3	0.2	0.2	3	2	2	0													16	1.54		
LM	T1	0.5	3.1	0.6	1	0.8	9	1.8	0.8	0.6	0	0	0	0.3	0	0	0	0	4	0	0									20	1.13	1.26	3.45
	T2	21	1.7	4.6	3.5	0.8	2.4	0	0	0	0.1	0	0	0	0	0	0	14	0.1	4	0									20	2.60		
	T3	0	0	0	0	0.4	0.1	0	0	0	0	0	0	0	0	0.2	0.1	0	0	0	0									20	0.04		
TB	T1	89	82	83	61	84	32	24	52	73	66	75	46																	12	63.99	70.34	23.41
	T2	73	98	88	69	95	93	88	85	45	90	82	14																	12	76.69		

b): % Herb cover by quadrat

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
NU	T1	2	9.4	6.2	21	2.9	6.3	3.3	12	10	0.6	4.1	7.4	16	1.6	3.2	3.9	12	14	3.8	25	53	24	55	22	78	47	22	45	28	18.25	14.16	15.38
	T2	12	3	12	2.1	3.5	5.8	9.1	3.3	16	12	6.3	32	18	17	12	5.4	3.3	16	8.4	14	20	39	22	15	74	27	17	11	28	15.57		
	T3	8.9	0.7	4.2	1.6	0.5	0.3	0	0.3	0	0.7	0.4	0.3	3.3	8.9	9.2	8.8	5.7	18	11	9.1	17	15	26	9.5	15	31	15	22	28	8.66		
CPA	T1	8.9	0	12	16	0	0	35	28	0	0	5	0	0	0	0	0													16	6.51	15.41	23.42
	T2	68	94	42	43	35	27	39	41	0.2	0	0	0.2	0.4	0.2	0.4	0													16	24.30		
NFA	T1	48	62	41	59	90	94	71	49	87	65	82	84	77	74	71	67	68	42	65	30	83	72	75	75					24	67.96	54.42	20.59
	T2	60	57	35	36	26	30	30	32	54	43	43	47	51	57	52	68	9	29	51	46	49	19	25	31					24	40.88		
NFB	T1	43	17	4.3	52	56	41	77	80	71	77	76	80	27	54	53	48	56	58	54	71	57	54	61	91					24	56.54	56.54	20.54
CPB	T1	63	38	44	34	36	29	29	32	30	60	43	47	9.9	4.2	4.4	4.1													16	31.75	15.77	16.57
	T2	13	22	14	8.2	11	22	14	18	0	0.2	1.6	8.5	0	0.9	0.4	1.4													16	8.51		
	T3	2.2	4.3	2.1	3.3	14	24	1.9	2	11	11	2.9	6.2	7	16	5	0													16	7.06		
LM	T1	99	124	108	124	68	90	81	66	54	58	43	40	57	39	56	40	48	47	53	46									20	67.12	54.87	26.21
	T2	104	112	81	88	88	56	53	56	42	69	23	28	49	65	30	23	43	63	57	45									20	58.88		
	T3	19	11	17	45	30	18	29	21	32	35	35	52	57	62	53	51	55	44	54	52									20	38.62		
TB	T1	6.6	7.1	6	12	8.6	52	43	35	5.8	3.5	5.4	12																	12	16.50	13.02	13.33
	T2	10	2.4	2.7	9.1	2.4	1.6	8.3	3.9	26	14	14	20																	12	9.54		

c): % ground-layer cover by quadrat

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7					Mean/T	Mean/SP	STDEV/SP
NU	T1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	14	6.6	0	16	6	18	0.6	28	2.36	0.93	3.20
	T2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	3.2	0	0	7.5	0	0	0.5	28	0.41		
	T3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0.2	0.1	0.2	0.1	28	0.03		
CPA	T1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0													16	0.00	0.04	0.21
	T2	1.2	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0													16	0.09		
NFA	T1	74	15	79	53	32	27	45	62	33	58	42	26	18	40	48	39	47	46	3.4	8.3	30	32	35	35					24	38.64	38.02	20.47
	T2	46	43	72	71	48	51	66	66	42	61	57	36	2.3	23	10	8	46	15	43	43	17	7.5	3.9	19					24	37.40		
NFB	T1	25	0	21	5	29	15	18	11	25	24	23	32	55	40	53	55	54	46	42	54	54	55	35	23					24	33.05	33.05	17.38
CPB	T1	44	43	42	40	2.5	1.5	2.1	18	4.8	0.2	8.1	0.2	0	0	0	0.1													16	12.87	7.14	13.64
	T2	15	13	28	48	8.3	1.7	5	1.5	0	0.3	0.2	1.6	0	0.3	0	0.6													16	7.74		
	T3	0.8	0.6	4.6	0.1	2.3	1	0.1	0.1	0.5	0.8	0.4	0.7	0	1	0	0													16	0.81		
LM	T1	29	7	25	7.3	22	13	12	7.3	1	2.5	6.5	4.6	2.9	0.4	1.1	0.4	0.4	0.5	2.8	0									20	7.27	3.70	6.24
	T2	18	12	6.1	3.2	3.1	2.8	1.4	3.9	0.3	0.1	0.4	1.2	2.3	0.3	0	0	2.3	0	2	1.2									20	3.03		
	T3	0	0.2	1.1	0.2	0.6	0.3	0.1	0.2	0.8	0.1	0.6	7.5	0.2	0.2	0.5	1.2	0.7	0.5	0.6	0.7									20	0.81		
TB	T1	20	28	28	51	18	28	6.2	12	12	5.4	6.3	14																	12	19.02	18.20	12.13
	T2	27	13	24	43	15	9.1	15	29	17	6.1	10	0.2																	12	17.37		

Appendix 3.8: Bare ground information

a) Bare ground cover (%) results by quadrat

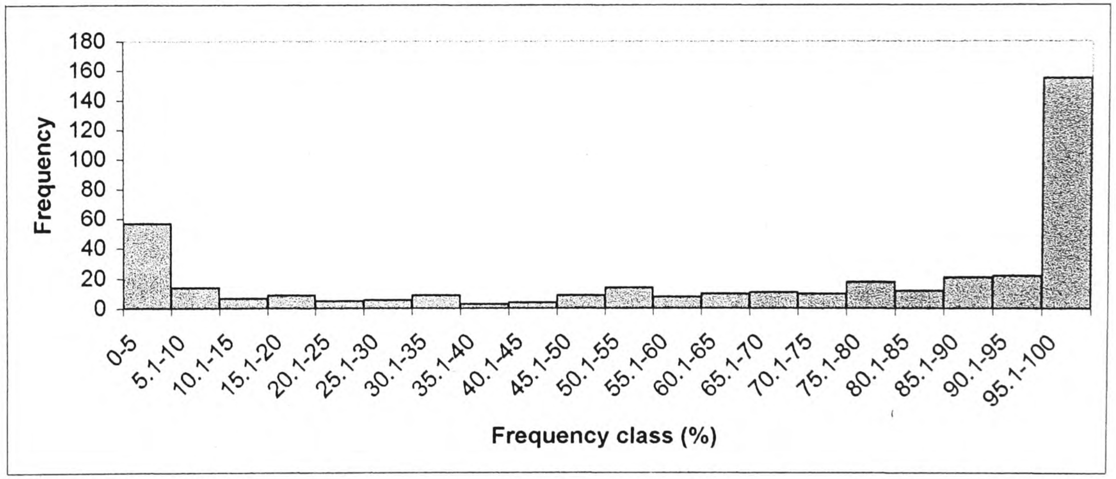
	Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7				n	Mean/T	Mean/SP	STDEV/SP
HW T1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	28	100		
HW T2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	28	100		
HW T3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	28	100	100	0
NU T1	98.9	93.5	96	86.9	97.5	95.1	96.9	89.8	92.8	99.3	96.6	94.6	89.6	97.4	97.2	96.3	88.5	85.9	96.1	75.8	49.2	83.3	55	81.3	28.4	29.6	63.2	40.4	28	81.97		
T2	91.1	99.2	93.2	78.7	97.3	95.5	93.8	97.6	87	95.2	95	75.9	87.5	83.3	88.6	96	96.2	83.6	91.4	86.6	81.8	67.8	78.6	84.4	43.1	77.6	85.8	85	28	86.31		
T3	95.8	99.4	98.1	99.6	99.5	99.7	100	99.6	100	99.4	99.8	99.7	97.3	92.1	91.3	94.2	95	81.3	90.5	93.2	84.3	84.1	76.8	90.5	79.8	52.4	79.8	64.9	28	90.63	86.30	15.90
CPA T1	99.2	100	99.4	99.1	100	100	90	90	100	95	94	99	100	100	99	99													16	97.74		
T2	33.7	36.2	61	59.6	72.9	78.8	70	68.1	99.8	100	100	99.8	99.6	100	99.6	100													16	79.93	88.83	18.84
NFA T1	0	1	0.8	0	0.4	0	0.2	0	0	0	0	0	1.8	0	0	0.4	4.4	0.6	54.4	78.7	0	10.2	0	0					24	6.37		
T2	1.2	0	0	0	17	0	1	1	1	0	0.2	8.6	30	18.8	35.4	30.4	0	63.3	7.2	7.2	15.4	47.2	15.2	17.4					24	13.23	9.80	18.21
NFB T1	0.2	0	57.2	8.6	21.4	13.7	11.3	12.4	13.6	13.8	21.7	8.08	5.4	9	5.4	4	0.4	6.6	3.1	1.3	0.8	3	10.4	0					24	9.64	9.64	11.94
CPB T1	21	29.8	26.6	40.6	69.5	75.2	75.4	61.3	75.1	68	68	74.9	96.3	97.6	97.4	96.1													16	67.06		
T2	74.4	72.8	59.8	49	86.3	79.5	85.3	85.5	99	99.8	98.8	87.8	100	99.1	99.9	98.9													16	85.99		
T3	94.7	97	94.8	97.8	86.7	78.4	98.6	98.3	93.3	96.2	98.5	97	91.7	82.3	94.3	100													16	93.72	82.26	20.61
LM T1	1.8	0	0	1.6	22.4	5	18.4	33.2	51.3	50.4	57.3	61.6	50	69.6	52.6	67.8	60	62.6	57.1	60.5									20	39.16		
T2	2.2	17.2	30.2	22	32.4	54.9	55	53.6	65.2	39.8	81.4	75.5	54.5	44.2	72.4	77.2	49.8	48.2	50.9	65.4									20	49.60		
T3	86.5	93.2	88.6	68.6	73.7	85	73.6	83.8	78.8	71.6	70.4	53.8	47.8	45.4	55.1	54.2	49.8	62.7	50.8	54.4									20	67.40	52.05	23.91
TB T1	0	0	6.8	0	0.76	4.6	30.7	7.4	28.4	31	25.6	45																	12	15.03		
T2	0	0	2	0	0	6.2	3	17.4	34.6	8.32	16.7	71.8																	12	13.33	14.18	18.35
																													404		65.86	37.85

b) Frequency of samples within 20 bare ground cover classes

Frequency class (%)	Frequency
0-5	57
5.1-10	14
10.1-15	7
15.1-20	9
20.1-25	5
25.1-30	6
30.1-35	9
35.1-40	3
40.1-45	4
45.1-50	9
50.1-55	14
55.1-60	8
60.1-65	10
65.1-70	11
70.1-75	10
75.1-80	18
80.1-85	12
85.1-90	21
90.1-95	22
95.1-100	155
n	404
Sample mean	56.89
Standard deviation	37.71
x=	31
%	9.69

NB x = No. samples that fall between the mean and the standard deviation

C) Graph to show frequency distribution classes for % bare ground



Appendix 3.9: Biomass index information

a) shrub biomass by quadrat (% shrub cover * mean shrub height)

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7			
NU	T1	0	0	0	50	0	0	0	0	0	1.2	5	23	242	6.25	212	0	120	943.5	2.5	44.5	973.1	609.7	217	413.1	225.6	417.6	26.4	0
	T2	2969	0	369	1197	273.7	1976	180	441	0.02	416.5	0.54	1.76	115.3	0	154	49	973.5	451.1	766.4	0	552	456.5	3.83	185.6	164.5	2324	4474	812.3
	T3	325.2	852.8	420	220	0	20	15	120.6	0	285	0	116	180	30	0	0	0	224	57.6	16.66	0	184.8	190	614.2	424.8	53	424.8	596.4
CPA	T1	320	0	0	0	0	0	0	0	0	0	10	0	0	0	50	50												
	T2	4439	81.81	0.128	0.128	0.24	0	0.024	0.04	1	0	2	0	0	4	1	0												
NFA	T1	120.6	969.9	62	102.3	956.6	915.5	245.3	244	93.6	199.1	83.6	242	14.4	286	62.01	91.12	57.4	0.3	0	25	16.8	58.8	366	366				
	T2	332.1	188.7	91.19	91.19	176	257.7	146.4	104	327.4	149.6	93.73	191.4	8782	387.3	362.5	153.6	4793	329.4	960.4	1911	2460	1924	4185	4140				
NFB	T1	2332	9900	6622	2462	48	6.842	0	219.2	0	0.8	1.417	0	0	0	21.2	3.6	17.2	22.8	3.8	113.7	13.54	76.7	182.7	371.7				
CPB	T1	0	0	0	0	0	3.22	0.64	164	0	24	69.6	69	0	0	0.6	9												
	T2	33	60	3.9	1	0	0	0	0.6	5600	0	0	4200	0	0.8	0	0												
	T3	1	0	0	0	824	124	0	0	1.2	1.28	0.8	0.8	3	2	4	0												
LM	T1	20.8	124.8	36	0	26.6	0	18.4	0	5.6	0	0.4	0	2.8	0	0	0	0	60	0	0								
	T2	1696	32.68	103.5	35.32	10.11	33.04	0	0	0.04	0.08	0	0	0	0	0	0	674.5	0.4	160	0								
	T3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								
TB	T1	2807	2591	2792	1756	2294	510	397.9	1435	2069	1208	1414	648.8																
	T2	2196	3912	3520	1902	2603	3232	2316	3595	641.8	2240	2053	117.5																

b) herb biomass by quadrat (% herb cover * mean herb height)

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7			
NU	T1	29.85	188.8	155.8	528	13.34	229.1	24.68	180	142.5	9.48	83.43	71.13	155.4	24.3	48.3	38.5	120.4	217.4	38.4	369	1060	487.4	822.3	449.5	2440	1497	719.4	1340
	T2	112.3	25	119.1	21.44	36.33	45.08	163.4	29.87	222	194.6	88.67	463.6	501.6	415.5	178.2	76.6	67.6	279.2	123.5	204.6	318.6	753.8	287.9	162.4	1962	764	510	352.7
	T3	206.6	3.665	35.28	7.735	10	2.72	0	9.3	0.06	4.875	6.92	2.38	70.04	119.5	87.31	143.9	114	201.3	166.6	147.2	234.2	250.3	692.7	47.58	388.4	448.6	388.4	648
CPA	T1	153.4	0	374.5	390.8	0	0	2592	1272	0	0	25	0	0	0	0	0												
	T2	468.3	600	348.2	355.6	203.9	129.3	142.2	171.9	2	0	0.18	1	2.06	1	2.06	0												
NFA	T1	1910	1734	1189	2220	3604	4690	2972	2427	3352	1924	2345	2385	922.4	1750	1546	1986	627.3	878.1	1191	342.2	1571	637.9	929.2	929.2				
	T2	1130	1539	520.4	536.3	310.4	844.7	536.4	731.4	1669	1273	903.6	1395	3089	1810	1881	3382	225	795.9	758.9	644.4	1230	521.9	376.5	433.8				
NFB	T1	1256	680	85.6	1384	1070	1030	1936	2386	1768	1921	2290	2414	667	1350	1315	1210	1456	1187	1619	1764	1003	983.7	1339	2734				
CPB	T1	221.8	61.44	114.2	42.29	196.1	67.56	59.82	160.3	63.94	527	196	218.1	21.82	11.12	17.15	31.68												
	T2	78.42	195.3	71	24.72	22.05	67.44	90.49	39.8	0	0.48	6.24	25.44	0	1.864	4.12	14.36												
	T3	5.755	12.85	11.76	10.02	95.7	108.5	8.714	16	107.7	64.46	20.04	30.18	15.4	40	10	0												
LM	T1	2872	3386	3760	4028	1077	1311	1069	536.2	241.6	430.4	220.5	198.8	300.1	145.4	331.1	155.6	242	284.9	158.4	230.3								
	T2	2971	746.6	696.9	892	781.8	466.4	583	551.2	161	577.5	76.67	149.3	313.4	507.9	149.8	91.12	566.6	608.1	485.6	357.2								
	T3	170	26.17	59.18	480.3	127.9	42.68	84.13	128	169.7	120.4	128.7	134.1	484.9	534.4	413.8	490	506.2	249.2	296	388.5								
TB	T1	96.94	106.8	90	184.2	129	523.2	433.2	520.8	58.4	35.2	54	61																
	T2	175	61	54.4	178.7	35.4	24.6	123.8	98	205.9	140	136	113.3																

c) Moss biomass by quadrat (% moss cover * mean moss height)

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7			
NU	T1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.02	6.785	0	0	15.72	3.02	5.256	0.112
	T2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.648	0	0	2.244	0	0	0.1
	T3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0												
CPA	T1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0												
	T2	0.6	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0	0												
NFA	T1	546.1	84.14	536.7	221.1	63.68	79.68	259.5	616.4	133.8	294.3	170.6	106.5	26.18	123.6	171.4	67.27	53.9	112.5	4.352	11.23	8.856	14.45	22.3	22.3				
	T2	117.1	81.22	193.3	192.2	28.07	91.22	120.7	158.1	40.55	144.9	169	43.44	2.691	11.6	3	2.4	115	3.024	12.95	8.592	43.5	1.5	1.176	3.73				
NFB	T1	30	0	10.4	2.5	29.69	14.84	9.125	5.6	12.36	12	11.38	22.45	54.6	39.84	79.86	82.08	159	46.4	42.28	80.27	70.2	83.16	34.8	22.5				
CPB	T1	31.36	20.2	31.87	19.96	0.756	0.444	0.636	17.8	3.744	0	8.12	0.24	0	0	0	0.016												
	T2	9.326	5.158	28.16	48.32	2.496	1.68	1	1.48	0	1.6	0.08	2.028	0	0.32	0	0.18												
	T3	0.252	0.192	0.92	0.036	2.28	0.288	0.008	0.024	0.48	0.24	0.4	0.72	0	0.5	0	0												
LM	T1	28.6	35	24.76	3.66	6.72	6.26	6.22	2.196	0.3	0.744	4.752	3.192	0.576	0.112	0.216	0.08	0.117	0.15	0.846	0								
	T2	68.04	21.08	1.824	12.96	0.936	0.852	0.42	1.164	0.088	0.024	0.108	0.348	0.684	0.064	0	0	14.66	0	0.4	0.24								
	T3	0	0.06	0.324	0.072	0.18	0.084	0.024	0.06	0.24	0	0	2.244	0.06	0	0.156	0.348	0.102	0.069	0.168	0.161								
TB	T1	102.6	139.2	14	25.4	67.94	5.52	6.2	24	6.22	2.16	25.28	41.76																
	T2	144.7	38.16	94.4	222.6	15.44	9.12	14.92	147	15.58	3.06	5.1	0.1																

Appendix 3.9 continued: Biomass index information

d) Biomass index (Moss biomass + herb biomass + shub biomass)

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7			
NU	T1	30	189	156	578	13	229	25	180	142	11	88	94	397	31	260	39	240	1161	41	414	2036	1104	1039	863	2682	1917	751	1340
	T2	3081	25	488	1218	310	2021	323	471	222	611	89	465	617	415	332	126	1041	730	890	205	871	1211	292	348	2129	3088	4984	1165
	T3	532	856	455	228	10	23	15	130	0	290	7	118	250	149	87	144	114	425	224	164	234	435	883	662	813	502	813	1244
CPA	T1	473	0	374	391	0	0	2592	1272	0	0	35	0	0	0	50	50												
	T2	4908	682	348	356	204	129	142	172	3	0	2	1	2	5	3	0												
NFA	T1	2576	2788	1788	2544	4624	5685	3477	3287	3579	2418	2599	2734	963	2160	1779	2145	739	991	1195	378	1596	711	1317	1317				
	T2	1579	1809	805	820	514	1194	804	994	2037	1568	1166	1630	11873	2209	2247	3538	5133	1128	1732	2564	3734	2447	4563	4577				
NFB	T1	3618	10580	6718	3848	1147	1052	1945	2610	1780	1934	2303	2436	722	1390	1416	1296	1632	1256	1665	1958	1087	1144	1556	3128				
CPB	T1	253	82	146	62	197	71	61	342	68	551	274	287	22	11	18	41												
	T2	121	260	103	74	25	69	91	42	5600	2	6	4227	0	3	4	15												
	T3	7	13	13	10	922	233	9	16	109	66	21	32	18	43	14	0												
LM	T1	2922	3546	3821	4032	1111	1317	1094	538	247	431	226	202	303	146	331	156	242	345	159	230								
	T2	4735	800	802	940	793	500	583	552	161	578	77	150	314	508	150	91	1256	608	646	357								
	T3	170	26	60	480	128	43	84	128	170	120	129	136	485	534	414	490	506	249	296	389								
TB	T1	3007	2837	2896	1966	2491	1039	837	1980	2133	1246	1493	752																
	T2	2516	4011	3669	2303	2654	3265	2455	3840	863	2383	2194	231																

e) Frequency distribution of biomass index within 14 classes, and mode class of each site

	0-499	500-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499	3500-3999	4000-4499	4500-4999	5000-5499	5499-5999	6000+	SUM	Mode	% within mode	Rank
HW	84	0	0	0	0	0	0	0	0	0	0	0	0	84	0-499	100	1
NU	52	15	9	1	3	1	2	0	1	0	0	0	0	84	0-499	62	3
CPA	28	1	1	0	0	1	0	0	0	1	0	0	0	32	0-499	88	4
NFA	1	9	6	8	7	6	2	3	0	3	1	1	1	48	500-999	19	6
NFB	0	1	8	7	2	1	1	2	0	0	0	0	2	24	1000-1499	33	7
CPB	45	1	0	0	0	0	0	0	1	0	0	1	0	48	0-499	94	2
LM	37	15	3	0	0	1	0	2	1	1	0	0	0	60	500-999	25	5
TB	1	3	3	2	6	4	2	2	1	0	0	0	0	24	2000-2499	25	8

Appendix 6.19. Shannon Diversity (H') and evenness [illegible] indices calculations for New Fancy B, Cannop B, Lightmoor, True Blue

	Northern United					Cannop A					New Fancy A				
(S)	54.0000			20.0000		28.0000					72.0000				
Inverse (S)	3.9890			2.9957		3.2581					4.2767				
H'= -SUM Pl ln Pl	2.2272					2.3522					3.0313				
E=H'/lnS	-0.5583					-0.7219					-0.7088				
	nl	pl	lN pl	pl ln pl	pl(ln pl)2	nl	pl	lN pl	pl ln pl	pl(ln pl)2	nl	pl	lN pl	pl ln pl	pl(ln pl)2
SUM	19.1842	1.0000	-343.8484	-2.2272	7.4346	17.1634	1.0000	-121.4824	-2.3522	6.4937	108.3028	1.0022	-447.8965	-3.0313	10.5431
Spp. Rank	nl	pl	lN pl	pl ln pl	pl(ln pl)2	nl	pl	lN pl	pl ln pl	pl(ln pl)2	nl	pl	lN pl	pl ln pl	pl(ln pl)2
1	8.7453	0.4559	-0.7856	-0.3581	0.2813	4.1879	0.2440	-1.4106	-0.3442	0.4856	16.5518	0.1532	-1.8762	-0.2874	0.5392
2	2.0917	0.1090	-2.2161	-0.2416	0.5355	3.0963	0.1804	-1.7128	-0.3090	0.5291	14.1057	0.1305	-2.0361	-0.2658	0.5412
3	1.7028	0.0888	-2.4219	-0.2149	0.5206	1.8200	0.1060	-2.2439	-0.2379	0.5339	12.3109	0.1139	-2.1722	-0.2475	0.5376
4	0.9223	0.0481	-3.0350	-0.1459	0.4428	1.5533	0.0905	-2.4024	-0.2174	0.5223	7.8391	0.0725	-2.6236	-0.1903	0.4993
5	0.6528	0.0340	-3.3806	-0.1150	0.3889	1.3288	0.0774	-2.5585	-0.1981	0.5068	7.3363	0.0679	-2.6899	-0.1826	0.4912
6	0.5687	0.0296	-3.5185	-0.1043	0.3670	1.2688	0.0739	-2.6047	-0.1926	0.5015	6.3609	0.0589	-2.8325	-0.1667	0.4723
7	0.5539	0.0289	-3.5448	-0.1024	0.3628	1.0075	0.0587	-2.8353	-0.1664	0.4719	4.4248	0.0409	-3.1955	-0.1308	0.4181
8	0.5496	0.0287	-3.5526	-0.1016	0.3616	0.7038	0.0410	-3.1941	-0.1310	0.4183	4.2695	0.0395	-3.2312	-0.1277	0.4125
9	0.4731	0.0247	-3.7025	-0.0913	0.3381	0.5225	0.0304	-3.4919	-0.1063	0.3712	3.8621	0.0357	-3.3315	-0.1191	0.3967
10	0.3771	0.0197	-3.9292	-0.0772	0.3035	0.4725	0.0275	-3.5925	-0.0989	0.3553	3.0475	0.0282	-3.5684	-0.1006	0.3591
11	0.3589	0.0187	-3.9789	-0.0744	0.2961	0.2529	0.0147	-4.2176	-0.0621	0.2621	2.6273	0.0243	-3.7166	-0.0904	0.3359
12	0.2310	0.0120	-4.4196	-0.0532	0.2352	0.2013	0.0117	-4.4460	-0.0521	0.2318	2.5801	0.0238	-3.7349	-0.0892	0.3331
13	0.2235	0.0116	-4.4526	-0.0519	0.2309	0.1583	0.0091	-4.6891	-0.0428	0.2010	2.1441	0.0198	-3.9200	-0.0778	0.3049
14	0.1801	0.0094	-4.6681	-0.0438	0.2046	0.1475	0.0086	-4.7567	-0.0409	0.1944	1.9964	0.0185	-3.9914	-0.0737	0.2943
15	0.1510	0.0079	-4.8449	-0.0381	0.1847	0.0838	0.0049	-5.3227	-0.0260	0.1382	1.8566	0.0172	-4.0640	-0.0698	0.2838
16	0.1410	0.0074	-4.9127	-0.0361	0.1774	0.0800	0.0047	-5.3885	-0.0250	0.1343	1.5507	0.0143	-4.2440	-0.0609	0.2585
17	0.1264	0.0066	-5.0227	-0.0331	0.1662	0.0724	0.0042	-5.4687	-0.0231	0.1261	1.3843	0.0128	-4.3721	-0.0552	0.2413
18	0.1190	0.0062	-5.0823	-0.0315	0.1603	0.0375	0.0022	-6.1262	-0.0134	0.0820	1.1966	0.0111	-4.5032	-0.0499	0.2246
19	0.1190	0.0062	-5.0825	-0.0315	0.1603	0.0350	0.0020	-6.1952	-0.0126	0.0783	1.0827	0.0100	-4.6032	-0.0461	0.2123
20	0.1139	0.0059	-5.1263	-0.0304	0.1561	0.0333	0.0019	-6.2465	-0.0121	0.0758	1.0084	0.0093	-4.6764	-0.0436	0.2037
21	0.0952	0.0050	-5.3055	-0.0263	0.1397	0.0313	0.0018	-6.3065	-0.0115	0.0725	0.9745	0.0090	-4.7085	-0.0425	0.1999
22	0.0827	0.0043	-5.4462	-0.0235	0.1279	0.0238	0.0014	-6.5829	-0.0091	0.0600	0.9227	0.0085	-4.7631	-0.0407	0.1937
23	0.0740	0.0039	-5.5584	-0.0214	0.1191	0.0225	0.0013	-6.6370	-0.0087	0.0577	0.8698	0.0080	-4.8222	-0.0388	0.1872
24	0.0607	0.0032	-5.7557	-0.0182	0.1048	0.0125	0.0007	-7.2248	-0.0053	0.0380	0.8255	0.0076	-4.8745	-0.0372	0.1815
25	0.0596	0.0031	-5.7743	-0.0179	0.1036	0.0063	0.0004	-7.9179	-0.0029	0.0228	0.7955	0.0074	-4.9116	-0.0362	0.1776
26	0.0433	0.0023	-6.0929	-0.0138	0.0839	0.0063	0.0004	-7.9179	-0.0029	0.0228	0.7264	0.0067	-5.0024	-0.0336	0.1682
27	0.0414	0.0022	-6.1379	-0.0133	0.0814						0.6800	0.0063	-5.0684	-0.0319	0.1616
28	0.0382	0.0020	-6.2180	-0.0124	0.0771						0.4564	0.0042	-5.4672	-0.0231	0.1262
29	0.0378	0.0020	-6.2280	-0.0123	0.0765						0.4319	0.0040	-5.5224	-0.0221	0.1219
30	0.0335	0.0017	-6.3510	-0.0111	0.0704						0.2991	0.0028	-5.8897	-0.0163	0.0960
31	0.0310	0.0016	-6.4294	-0.0104	0.0667						0.2645	0.0024	-6.0125	-0.0147	0.0885
32	0.0270	0.0014	-6.5678	-0.0092	0.0606						0.2636	0.0024	-6.0159	-0.0147	0.0883
33	0.0248	0.0013	-6.6525	-0.0086	0.0571						0.2091	0.0019	-6.2477	-0.0121	0.0755
34	0.0190	0.0010	-6.9149	-0.0069	0.0475						0.2027	0.0019	-6.2786	-0.0118	0.0740
35	0.0168	0.0009	-7.0399	-0.0062	0.0434						0.1873	0.0017	-6.3579	-0.0110	0.0701
36	0.0167	0.0009	-7.0484	-0.0061	0.0432						0.1864	0.0017	-6.3628	-0.0110	0.0698
37	0.0163	0.0009	-7.0686	-0.0060	0.0425						0.1861	0.0017	-6.3640	-0.0110	0.0696
38	0.0147	0.0008	-7.1730	-0.0055	0.0395						0.1827	0.0017	-6.3825	-0.0108	0.0689
39	0.0130	0.0007	-7.2987	-0.0049	0.0360						0.1718	0.0016	-6.4440	-0.0102	0.0660
40	0.0071	0.0004	-7.8957	-0.0029	0.0232						0.1682	0.0016	-6.4654	-0.0101	0.0651
41	0.0067	0.0003	-7.9647	-0.0028	0.0220						0.1655	0.0015	-6.4818	-0.0099	0.0643
42	0.0067	0.0003	-7.9647	-0.0028	0.0220						0.1594	0.0015	-6.5193	-0.0096	0.0627
43	0.0062	0.0003	-8.0388	-0.0026	0.0209						0.1500	0.0014	-6.5798	-0.0091	0.0601
44	0.0024	0.0001	-8.9943	-0.0011	0.0100						0.1491	0.0014	-6.5859	-0.0091	0.0598
45	0.0021	0.0001	-9.0997	-0.0010	0.0092						0.1464	0.0014	-6.6044	-0.0089	0.0591
46	0.0014	0.0001	-9.5052	-0.0007	0.0067						0.1455	0.0013	-6.6108	-0.0089	0.0588
47	0.0014	0.0001	-9.5052	-0.0007	0.0067						0.1209	0.0011	-6.7954	-0.0076	0.0517
48	0.0010	0.0000	-9.9106	-0.0005	0.0049						0.1118	0.0010	-6.8738	-0.0071	0.0489
49	0.0010	0.0000	-9.9106	-0.0005	0.0049						0.1082	0.0010	-6.9067	-0.0069	0.0478
50	0.0005	0.0000	-10.6038	-0.0003	0.0028						0.1012	0.0009	-6.9735	-0.0065	0.0455
51	0.0005	0.0000	-10.6038	-0.0003	0.0028						0.0664	0.0006	-7.3953	-0.0045	0.0336
52	0.0002	0.0000	-11.2969	-0.0001	0.0016						0.0636	0.0006	-7.4373	-0.0044	0.0326
53	0.0001	0.0000	-11.8078	-0.0001	0.0010						0.0293	0.0003	-8.2123	-0.0022	0.0183
54	0.0001	0.0000	-11.8078	-0.0001	0.0010						0.0275	0.0003	-8.2763	-0.0021	0.0174
55											0.0273	0.0003	-8.2846	-0.0021	0.0173
56											0.0264	0.0002	-8.3185	-0.0020	0.0169
57											0.0245	0.0002	-8.3899	-0.0019	0.0160
58											0.0227	0.0002	-8.4669	-0.0018	0.0151
59											0.0200	0.0002	-8.5947	-0.0016	0.0137
60											0.0182	0.0002	-8.6900	-0.0015	0.0127
61											0.0145	0.0001	-8.9132	-0.0012	0.0107
62											0.0136	0.0001	-8.9777	-0.0011	0.0102
63											0.0109	0.0001	-9.2009	-0.0009	0.0085
64											0.0109	0.0001	-9.2009	-0.0009	0.0085
65											0.0100	0.0001	-9.2879	-0.0009	0.0080
66											0.0082	0.0001	-9.4886	-0.0007	0.0068
67											0.0082	0.0001	-9.4886	-0.0007	0.0068
68											0.0082	0.0001	-9.4886	-0.0007	0.0068
69											0.0057	0.0001	-9.8532	-0.0005	0.0051
70											0.0055	0.0001	-9.8940	-0.0005	0.0049
71											0.0045	0.0000	-10.0763	-0.0004	0.0043
72											0.0009	0.0000	-11.6858	-0.0001	0.0011

Appendix 3.10: Shannon Diversity (H') and evenness (pi ln pi) indices calculations for New Fancy B, Cannop B, Lightmoor, True Blue

New Fancy B				
59.0000				
4.0775				
2.1221				
-0.5204				
ni	pi	lN pi	pi ln pi	pi(ln pi)2
104.6170	1.0000	-389.5629	-2.1221	6.5206
ni	pi	lN pi	pi ln pi	pi(ln pi)2
37.1988	0.3558	-1.0340	-0.3677	0.3802
24.3231	0.2325	-1.4589	-0.3392	0.4948
11.1333	0.1064	-2.2404	-0.2384	0.5341
9.8202	0.0939	-2.3659	-0.2221	0.5254
3.4888	0.0333	-3.4013	-0.1134	0.3856
2.7913	0.0267	-3.6238	-0.0967	0.3504
2.6750	0.0256	-3.6664	-0.0937	0.3437
1.9088	0.0182	-4.0036	-0.0731	0.2926
1.4419	0.0138	-4.2844	-0.0590	0.2530
1.1762	0.0112	-4.4880	-0.0505	0.2265
1.0822	0.0103	-4.5713	-0.0473	0.2162
0.9786	0.0094	-4.6720	-0.0437	0.2042
0.8243	0.0079	-4.8435	-0.0382	0.1848
0.6346	0.0061	-5.1051	-0.0310	0.1561
0.5038	0.0048	-5.3360	-0.0257	0.1371
0.4804	0.0046	-5.3834	-0.0247	0.1331
0.4409	0.0042	-5.4692	-0.0230	0.1261
0.3979	0.0038	-5.5718	-0.0212	0.1181
0.2750	0.0026	-5.9413	-0.0156	0.0928
0.2326	0.0022	-6.1092	-0.0136	0.0829
0.2258	0.0022	-6.1383	-0.0133	0.0813
0.2125	0.0020	-6.1991	-0.0126	0.0781
0.2030	0.0019	-6.2450	-0.0121	0.0757
0.2000	0.0019	-6.2597	-0.0120	0.0749
0.1902	0.0018	-6.3099	-0.0115	0.0724
0.1822	0.0017	-6.3530	-0.0111	0.0703
0.1546	0.0015	-6.5173	-0.0096	0.0628
0.1474	0.0014	-6.5649	-0.0092	0.0607
0.1088	0.0010	-6.8703	-0.0071	0.0490
0.1033	0.0010	-6.9201	-0.0068	0.0473
0.1017	0.0010	-6.9364	-0.0067	0.0468
0.0913	0.0009	-7.0445	-0.0061	0.0433
0.0886	0.0008	-7.0734	-0.0060	0.0424
0.0867	0.0008	-7.0960	-0.0059	0.0417
0.0810	0.0008	-7.1634	-0.0055	0.0397
0.0667	0.0006	-7.3564	-0.0047	0.0345
0.0583	0.0006	-7.4919	-0.0042	0.0313
0.0533	0.0005	-7.5815	-0.0039	0.0293
0.0417	0.0004	-7.8284	-0.0031	0.0244
0.0417	0.0004	-7.8284	-0.0031	0.0244
0.0417	0.0004	-7.8284	-0.0031	0.0244
0.0383	0.0004	-7.9117	-0.0029	0.0229
0.0359	0.0003	-7.9769	-0.0027	0.0218
0.0330	0.0003	-8.0618	-0.0025	0.0205
0.0319	0.0003	-8.0941	-0.0025	0.0200
0.0300	0.0003	-8.1569	-0.0023	0.0191
0.0263	0.0003	-8.2904	-0.0021	0.0172
0.0238	0.0002	-8.3905	-0.0019	0.0160
0.0172	0.0002	-8.7119	-0.0014	0.0125
0.0167	0.0002	-8.7447	-0.0014	0.0122
0.0167	0.0002	-8.7447	-0.0014	0.0122
0.0150	0.0001	-8.8500	-0.0013	0.0112
0.0117	0.0001	-9.1013	-0.0010	0.0092
0.0083	0.0001	-9.4378	-0.0008	0.0071
0.0083	0.0001	-9.4378	-0.0008	0.0071
0.0058	0.0001	-9.7945	-0.0005	0.0053
0.0052	0.0000	-9.9078	-0.0005	0.0049
0.0050	0.0000	-9.9466	-0.0005	0.0047
0.0021	0.0000	-10.8241	-0.0002	0.0023

Cannop B				
65.0000				
4.1744				
2.8916				
-0.6927				
ni	pi	lN pi	pi ln pi	pi(ln pi)2
26.2700	1.0000	-375.8202	-2.8916	10.2641
ni	pi	lN pi	pi ln pi	pi(ln pi)2
7.2452	0.2758	-1.2881	-0.3553	0.4576
2.3309	0.0887	-2.4222	-0.2149	0.5205
2.1609	0.0823	-2.4979	-0.2055	0.5132
2.0445	0.0778	-2.5533	-0.1987	0.5074
1.7265	0.0658	-2.7212	-0.1790	0.4872
1.3295	0.0506	-2.9837	-0.1510	0.4505
0.9699	0.0369	-3.2990	-0.1218	0.4018
0.7656	0.0291	-3.5355	-0.1030	0.3643
0.7147	0.0272	-3.6044	-0.0981	0.3534
0.6336	0.0241	-3.7247	-0.0898	0.3346
0.4836	0.0184	-3.9948	-0.0735	0.2938
0.4455	0.0170	-4.0771	-0.0691	0.2819
0.4073	0.0155	-4.1667	-0.0646	0.2692
0.3900	0.0148	-4.2100	-0.0625	0.2631
0.3127	0.0119	-4.4309	-0.0527	0.2337
0.2900	0.0110	-4.5063	-0.0497	0.2242
0.2864	0.0109	-4.5189	-0.0493	0.2226
0.2633	0.0100	-4.6028	-0.0461	0.2124
0.2618	0.0100	-4.6085	-0.0459	0.2117
0.2618	0.0100	-4.6085	-0.0459	0.2117
0.2564	0.0098	-4.6296	-0.0452	0.2092
0.2360	0.0090	-4.7124	-0.0423	0.1995
0.2209	0.0084	-4.7784	-0.0402	0.1920
0.1973	0.0075	-4.8916	-0.0367	0.1797
0.1882	0.0072	-4.9388	-0.0354	0.1747
0.1755	0.0067	-5.0088	-0.0335	0.1676
0.1473	0.0056	-5.1839	-0.0291	0.1507
0.1455	0.0055	-5.1963	-0.0288	0.1495
0.1282	0.0049	-5.3227	-0.0260	0.1382
0.0973	0.0037	-5.5987	-0.0207	0.1161
0.0827	0.0031	-5.7606	-0.0181	0.1045
0.0818	0.0031	-5.7717	-0.0180	0.1038
0.0800	0.0030	-5.7942	-0.0176	0.1022
0.0790	0.0030	-5.8067	-0.0175	0.1014
0.0782	0.0030	-5.8171	-0.0173	0.1007
0.0700	0.0027	-5.9277	-0.0158	0.0936
0.0636	0.0024	-6.0230	-0.0146	0.0879
0.0618	0.0024	-6.0520	-0.0142	0.0862
0.0591	0.0022	-6.0971	-0.0137	0.0836
0.0545	0.0021	-6.1771	-0.0128	0.0792
0.0455	0.0017	-6.3585	-0.0110	0.0700
0.0436	0.0017	-6.4003	-0.0106	0.0680
0.0400	0.0015	-6.4873	-0.0099	0.0641
0.0373	0.0014	-6.5579	-0.0093	0.0610
0.0336	0.0013	-6.6606	-0.0085	0.0568
0.0336	0.0013	-6.6606	-0.0085	0.0568
0.0264	0.0010	-6.9042	-0.0069	0.0478
0.0205	0.0008	-7.1535	-0.0056	0.0400
0.0182	0.0007	-7.2758	-0.0050	0.0368
0.0182	0.0007	-7.2758	-0.0050	0.0368
0.0173	0.0007	-7.3271	-0.0048	0.0353
0.0164	0.0006	-7.3811	-0.0046	0.0339
0.0139	0.0005	-7.5436	-0.0040	0.0301
0.0136	0.0005	-7.5634	-0.0039	0.0297
0.0136	0.0005	-7.5634	-0.0039	0.0297
0.0109	0.0004	-7.7866	-0.0032	0.0252
0.0091	0.0003	-7.9689	-0.0028	0.0220
0.0073	0.0003	-8.1921	-0.0023	0.0186
0.0045	0.0002	-8.6621	-0.0015	0.0130
0.0045	0.0002	-8.6621	-0.0015	0.0130
0.0036	0.0001	-8.8852	-0.0012	0.0109
0.0036	0.0001	-8.8852	-0.0012	0.0109
0.0027	0.0001	-9.1729	-0.0010	0.0087
0.0027	0.0001	-9.1729	-0.0010	0.0087
0.0003	0.0000	-11.4755	-0.0001	0.0014

Lightmoor				
76.0000				
4.3307				
2.7521				
-0.6356				
ni	pi	lN pi	pi ln pi	pi(ln pi)2
58.0941	1.0000	-506.5515	-2.7521	9.3649
ni	pi	lN pi	pi ln pi	pi(ln pi)2
13.7353	0.2364	-1.4421	-0.3410	0.4917
7.9645	0.1371	-1.9871	-0.2724	0.5413
7.6147	0.1311	-2.0320	-0.2663	0.5412
4.8747	0.0839	-2.4780	-0.2079	0.5153
3.8128	0.0656	-2.7237	-0.1788	0.4869
2.4105	0.0415	-3.1822	-0.1320	0.4202
2.2849	0.0393	-3.2358	-0.1273	0.4118
1.5860	0.0273	-3.6008	-0.0983	0.3540
1.4873	0.0256	-3.6651	-0.0938	0.3439
1.3359	0.0230	-3.7725	-0.0867	0.3273
1.2776	0.0220	-3.8171	-0.0839	0.3204
0.8949	0.0154	-4.1731	-0.0643	0.2683
0.8482	0.0146	-4.2267	-0.0617	0.2608
0.7088	0.0122	-4.4062	-0.0538	0.2369
0.6938	0.0119	-4.4276	-0.0529	0.2341
0.5570	0.0096	-4.6473	-0.0446	0.2071
0.5093	0.0088	-4.7367	-0.0415	0.1967
0.4360	0.0075	-4.8922	-0.0367	0.1796
0.4287	0.0074	-4.9091	-0.0362	0.1778
0.3751	0.0065	-5.0427	-0.0326	0.1642
0.3627	0.0062	-5.0763	-0.0317	0.1609
0.3339	0.0057	-5.1591	-0.0296	0.1530
0.2949	0.0051	-5.2833	-0.0268	0.1417
0.2763	0.0048	-5.3482	-0.0254	0.1361
0.2458	0.0042	-5.4652	-0.0231	0.1264
0.2153	0.0037	-5.5978	-0.0207	0.1161
0.1987	0.0034	-5.6782	-0.0194	0.1103
0.1933	0.0033	-5.7056	-0.0190	0.1083
0.1692	0.0029	-5.8389	-0.0170	0.0993
0.1600	0.0028	-5.8946	-0.0162	0.0957
0.1450	0.0025	-5.9931	-0.0150	0.0896
0.1198	0.0021	-6.1837	-0.0128	0.0789
0.1180	0.0020	-6.1991	-0.0126	0.0781
0.1167	0.0020	-6.2105	-0.0125	0.0775
0.1000	0.0017	-6.3646	-0.0110	0.0697
0.0993	0.0017	-6.3713	-0.0109	0.0694
0.0930	0.0016	-6.4372	-0.0103	0.0663
0.0928	0.0016	-6.4390	-0.0103	0.0663
0.0927	0.0016	-6.4408	-0.0103	0.0662
0.0880	0.0015	-6.4925	-0.0098	0.0639
0.0680	0.0012	-6.7503	-0.0079	0.0533
0.0635	0.0011	-6.8188	-0.0075	0.0508
0.0573	0.0010	-6.9209	-0.0068	0.0473
0.0553	0.0010	-6.9564	-0.0066	0.0461
0.0540	0.0009	-6.9808	-0.0065	0.0453
0.0502	0.0009	-7.0538	-0.0061	0.0430
0.0473	0.0008	-7.1126	-0.0058	0.0412
0.0393	0.0007	-7.2977	-0.0049	0.0361
0.0387	0.0007	-7.3148	-0.0049	0.0356
0.0383	0.0007	-7.3235	-0.0048	0.0354
0.0343	0.0006	-7.4337	-0.0044	0.0327
0.0327	0.0006	-7.4835	-0.0042	0.0315
0.0200	0.0003	-7.9741	-0.0027	0.0219
0.0200	0.0003	-7.9741	-0.0027	0.0219
0.0167	0.0003	-8.1564	-0.0023	0.0191
0.0133	0.0002	-8.3796	-0.0019	0.0161
0.0120	0.0002	-8.4849	-0.0018	0.0149
0.0120	0.0002	-8.4849	-0.0018	0.0149
0.0113	0.0002	-8.5421	-0.0017	0.0142
0.0073	0.0001	-8.9774	-0.0011	0.0102
0.0067	0.0001	-9.0727	-0.0010	0.0094
0.0067	0.0001	-9.0727	-0.0010	0.0094
0.0067	0.0001	-9.0727	-0.0010	0.0094
0.0053	0.0001	-9.2958	-0.0009	0.0079
0.0047	0.0001	-9.4294	-0.0008	0.0071
0.0047	0.0001	-9.4294	-0.0008	0.0071
0.0030	0.0001	-9.8712	-0.0005	0.0050
0.0027	0.0000	-9.9890	-0.0005	0.0046
0.0023	0.0000	-10.1225	-0.0004	0.0041
0.0020	0.0000	-10.2767	-0.0004	0.0036
0.0020	0.0000	-10.2767	-0.0004	0.0036
0.0013	0.0000	-10.6821	-0.0002	0.0026
0.0013	0.0000	-10.6821	-0.0002	0.0026
0.0012	0.0000	-10.8157	-0.0002	0.0023
0.0004	0.0000	-11.8861	-0.0001	0.0010
0.0002	0.0000	-12.5793	0.0000	0.0005

True Blue				
32.0000				
3.4657				
1.1100				
-0.3203				
ni	pi	lN pi	pi ln pi	pi(ln pi)2
101.5586	0.3077	-194.5802	-1.1100	4.3089
ni	pi	lN pi	pi ln pi	pi(ln pi)2
70.3100	0.6923	-0.3677	-0.2546	0.0936
6.3300	0.0623	-2.7753	-0.1730	0.4801
4.9917	0.0492	-3.0129	-0.1481	0.4462
4.7683	0.0470	-3.0586	-0.1436	0.4392
3.3217	0.0327	-3.4202	-0.1119	0.3826
3.0117	0.0297	-3.5181	-0.1043	0.3670
1.5600	0.0154	-4.1760	-0.0641	0.2679
1.4483	0.0143	-4.2502	-0.0606	0.2576
1.2500	0.0123	-4.3975	-0.0541	0.2380
1.1083	0.0109	-4.5178	-0.0493	0.2227
0.6171	0.0061	-5.1034	-0.0310	0.1582
0.4917	0.0048	-5.3306	-0.0258	0.1376
0.4367	0.0043	-5.4492	-0.0234	0.1277
0.2933	0.0029	-5.8471	-0.0169	0.0987
0.2900	0.0029	-5.8585	-0.0167	0.0980
0.2683	0.0026	-5.9362	-0.0157	0.0931
0.2000	0.0020	-6.2301	-0.0123	0.0764
0.1917	0.0019	-6.2726	-0.0118	0.0743
0.1667	0.0016	-6.4124	-0.0105	0.0675
0.1300	0.0013	-6.6609	-0.0085	0.0566
0.1250	0.0012	-6.7001	-0.0082	0.0553
0.0417	0.0004	-7.7967	-0.0032	0.0250
0.0383	0.0004	-7.8821	-0.0030	0.0234
0.0350	0.0003	-7.9730	-0.0027	0.0219
0.0333	0.0003	-8.0218	-0.0026	0.0211
0.0333	0.0003	-8.0218	-0.0026	0.0211
0.0267	0.0003	-8.2450	-0.0022	0.0178
0.0133	0.0001	-8.9361	-0.0012	0.0105
0.0083	0.0001	-9.4061	-0.0008	0.0073
0.0083	0.0001	-9.4061	-0.0008	0.0073
0.0067	0.0001	-9.6313	-0.0006	0.0061
0.0033	0.0000	-10.3244	-0.0003	0.0035

Appendix 3.11 (cont): Simpson 1/D calculations for Northern United, Cannop A and New Fancy A

	Northern United					Cannop A					New Fancy A				
N	19.18					17.16					108.30				
N(N-1)	348.85					277.42					11621.19				
D	*0.19*					*0.08*					*0.07*				
1/D	5.16					13.06					14.95				
	ni	ni-1	(ni(ni-1))	N(N-1)	(ni(ni-1))/N(N-1)	ni	ni-1	(ni(ni-1))	N(N-1)	(ni(ni-1))/N(N-1)	ni	ni-1	(ni(ni-1))	N(N-1)	(ni(ni-1))/N(N-1)
	8.75	7.75	67.74	348.85	0.19	4.19	3.19	13.35	277.42	0.05	16.55	15.55	257.41	11621.19	0.02
	2.09	1.09	2.28	348.85	0.01	3.10	2.10	6.49	277.42	0.02	14.11	13.11	184.87	11622.19	0.02
	1.70	0.70	1.20	348.85	0.00	1.82	0.82	1.49	277.42	0.01	12.31	11.31	139.25	11623.19	0.01
	0.92	-0.08	-0.07	348.85	0.00	1.55	0.55	0.86	277.42	0.00	7.84	6.84	53.61	11624.19	0.00
	0.65	-0.35	-0.23	348.85	0.00	1.33	0.33	0.44	277.42	0.00	7.34	6.34	46.48	11625.19	0.00
	0.57	-0.43	-0.25	348.85	0.00	1.27	0.27	0.34	277.42	0.00	6.36	5.36	34.10	11626.19	0.00
	0.55	-0.45	-0.25	348.85	0.00	1.01	0.01	0.01	277.42	0.00	4.42	3.42	15.15	11627.19	0.00
	0.55	-0.45	-0.25	348.85	0.00	0.70	-0.30	-0.21	277.42	0.00	4.27	3.27	13.96	11628.19	0.00
	0.47	-0.53	-0.25	348.85	0.00	0.52	-0.48	-0.25	277.42	0.00	3.86	2.86	11.05	11629.19	0.00
	0.38	-0.62	-0.23	348.85	0.00	0.47	-0.53	-0.25	277.42	0.00	3.05	2.05	6.24	11630.19	0.00
	0.36	-0.64	-0.23	348.85	0.00	0.25	-0.75	-0.19	277.42	0.00	2.63	1.63	4.28	11631.19	0.00
	0.23	-0.77	-0.18	348.85	0.00	0.20	-0.80	-0.16	277.42	0.00	2.58	1.58	4.08	11632.19	0.00
	0.22	*-0.78*	*-0.17*	*348.85*	*0.00*	*0.16*	*-0.84*	*-0.13*	*277.42*	0.00	2.14	1.14	2.45	11633.19	0.00
	0.18	-0.82	-0.15	348.85	0.00	0.15	-0.85	-0.13	277.42	0.00	2.00	1.00	1.99	11634.19	0.00
	0.15	-0.85	-0.13	348.85	0.00	0.08	-0.92	-0.08	277.42	0.00	1.86	0.86	1.59	11635.19	0.00
	0.14	-0.86	-0.12	348.85	0.00	0.08	-0.92	-0.07	277.42	0.00	1.55	0.55	0.85	11636.19	0.00
	0.13	-0.87	-0.11	348.85	0.00	0.07	-0.93	-0.07	277.42	0.00	1.36	0.36	0.50	11637.19	0.00
	0.12	-0.88	-0.10	348.85	0.00	0.04	-0.96	-0.04	277.42	0.00	1.20	0.20	0.24	11638.19	0.00
	0.12	-0.88	-0.10	348.85	0.00	0.04	-0.97	-0.03	277.42	0.00	1.08	0.08	0.09	11639.19	0.00
	0.11	-0.89	-0.10	348.85	0.00	0.03	-0.97	-0.03	277.42	0.00	1.01	0.01	0.01	11640.19	0.00
	0.10	-0.90	-0.09	348.85	0.00	0.03	-0.97	-0.03	277.42	0.00	0.97	-0.03	-0.02	11641.19	0.00
	0.08	-0.92	-0.08	348.85	0.00	0.02	-0.98	-0.02	277.42	0.00	0.92	-0.08	-0.07	11642.19	0.00
	0.07	-0.93	-0.07	348.85	0.00	0.02	-0.98	-0.02	277.42	0.00	0.87	-0.13	-0.11	11643.19	0.00
	0.06	-0.94	-0.06	348.85	0.00	0.01	-0.99	-0.01	277.42	0.00	0.83	-0.17	-0.14	11644.19	0.00
	0.06	-0.94	-0.06	348.85	0.00	0.01	-0.99	-0.01	277.42	0.00	0.80	-0.20	-0.16	11645.19	0.00
	0.04	-0.96	-0.04	348.85	0.00	0.01	-0.99	-0.01	277.42	0.00	0.73	-0.27	-0.20	11646.19	0.00
	0.04	-0.96	-0.04	348.85	0.00						0.68	-0.32	-0.22	11647.19	0.00
	0.04	*-0.96*	*-0.04*	*348.85*	*0.00*						*0.46*	*-0.54*	*-0.25*	*11648.19*	*0.00*
	0.04	-0.96	-0.04	348.85	0.00						0.43	-0.57	-0.25	11649.19	0.00
	0.03	-0.97	-0.03	348.85	0.00						0.30	-0.70	-0.21	11650.19	0.00
	0.03	-0.97	-0.03	348.85	0.00						0.26	-0.74	-0.19	11651.19	0.00
	0.03	-0.97	-0.03	348.85	0.00						0.26	-0.74	-0.19	11652.19	0.00
	0.02	-0.98	-0.02	348.85	0.00						0.21	-0.79	-0.17	11653.19	0.00
	0.02	-0.98	-0.02	348.85	0.00						0.20	-0.80	-0.16	11654.19	0.00
	0.02	-0.98	-0.02	348.85	0.00						0.19	-0.81	-0.15	11655.19	0.00
	0.02	-0.98	-0.02	348.85	0.00						0.19	-0.81	-0.15	11656.19	0.00
	0.02	-0.98	-0.02	348.85	0.00						0.19	-0.81	-0.15	11657.19	0.00
	0.01	-0.99	-0.01	348.85	0.00						0.18	-0.82	-0.15	11658.19	0.00
	0.01	-0.99	-0.01	348.85	0.00						0.17	-0.83	-0.14	11659.19	0.00
	0.01	-0.99	-0.01	348.85	0.00						0.17	-0.83	-0.14	11660.19	0.00
	0.01	-0.99	-0.01	348.85	0.00						0.17	-0.83	-0.14	11661.19	0.00
	0.01	-0.99	-0.01	348.85	0.00						0.16	-0.84	-0.13	11662.19	0.00
	0.01	*-0.99*	*-0.01*	*348.85*	*0.00*						*0.15*	*-0.85*	*-0.13*	*11663.19*	*0.00*
	0.00	-1.00	0.00	348.85	0.00						0.15	-0.85	-0.13	11664.19	0.00
	0.00	-1.00	0.00	348.65	0.00						0.15	-0.85	-0.12	11665.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.15	-0.85	-0.12	11666.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.12	-0.88	-0.11	11667.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.11	-0.89	-0.10	11668.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.11	-0.89	-0.10	11669.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.10	-0.90	-0.09	11670.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.07	-0.93	-0.06	11671.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.06	-0.94	-0.06	11672.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.03	-0.97	-0.03	11673.19	0.00
	0.00	-1.00	0.00	348.85	0.00						0.03	-0.97	-0.03	11674.19	0.00
											0.03	-0.97	-0.03	11675.19	0.00
											0.03	-0.97	-0.03	11676.19	0.00
											0.02	-0.98	-0.02	11677.19	0.00
											0.02	-0.98	-0.02	11678.19	0.00
											0.02	-0.98	-0.02	11679.19	0.00
											0.02	-0.98	-0.02	11680.19	0.00
											0.01	-0.99	-0.01	11681.19	0.00
											0.01	-0.99	-0.01	11682.19	0.00
											0.01	-0.99	-0.01	11683.19	0.00
											0.01	-0.99	-0.01	11684.19	0.00
											0.01	-0.99	-0.01	11685.19	0.00
											0.01	*-0.99*	*-0.01*	*11686.19*	*0.00*
											0.01	-0.99	-0.01	11687.19	0.00
											0.01	-0.99	-0.01	11688.19	0.00
											0.01	-0.99	-0.01	11689.19	0.00
											0.01	-0.99	-0.01	11690.19	0.00
											0.00	-1.00	0.00	11691.19	0.00
											0.00	-1.00	0.00	11692.19	0.00

Appendix 3.11 (cont): Simpson 1/D calculations for New Fancy B, Cannop B, Lightmoor and True Blue

New Fancy B

104.62
10840.10
0.20
5.09

nl	nl-1	(nl(nl-1))	N(N-1)	(nl(nl-1))/N(N-1)
37.20	36.20	1346.55	10840.10	0.12
24.32	23.32	567.29	10841.10	0.05
11.13	10.13	112.82	10842.10	0.01
9.82	8.82	86.62	10843.10	0.01
3.49	2.49	8.67	10844.10	0.00
2.79	1.79	5.00	10845.10	0.00
2.68	1.68	4.48	10846.10	0.00
1.91	0.91	1.73	10847.10	0.00
1.44	0.44	0.64	10848.10	0.00
1.18	0.18	0.21	10849.10	0.00
1.08	0.08	0.09	10850.10	0.00
0.98	-0.02	-0.02	10851.10	0.00
0.82	-0.18	-0.14	10852.10	0.00
0.63	-0.37	-0.23	10853.10	0.00
0.50	-0.50	-0.25	10854.10	0.00
0.48	-0.52	-0.25	10855.10	0.00
0.44	-0.56	-0.25	10856.10	0.00
0.40	-0.60	-0.24	10857.10	0.00
0.28	-0.73	-0.20	10858.10	0.00
0.23	-0.77	-0.18	10859.10	0.00
0.23	-0.77	-0.17	10860.10	0.00
0.21	-0.79	-0.17	10861.10	0.00
0.20	-0.80	-0.16	10862.10	0.00
0.20	-0.80	-0.16	10863.10	0.00
0.19	-0.81	-0.15	10864.10	0.00
0.18	-0.82	-0.15	10865.10	0.00
0.15	-0.85	-0.13	10866.10	0.00
0.15	-0.85	-0.13	10867.10	0.00
0.11	-0.89	-0.10	10868.10	0.00
0.10	-0.90	-0.09	10869.10	0.00
0.10	-0.90	-0.09	10870.10	0.00
0.09	-0.91	-0.08	10871.10	0.00
0.09	-0.91	-0.08	10872.10	0.00
0.09	-0.91	-0.08	10873.10	0.00
0.08	-0.92	-0.07	10874.10	0.00
0.07	-0.93	-0.06	10875.10	0.00
0.06	-0.94	-0.05	10876.10	0.00
0.05	-0.95	-0.05	10877.10	0.00
0.04	-0.96	-0.04	10878.10	0.00
0.04	-0.96	-0.04	10879.10	0.00
0.04	-0.96	-0.04	10880.10	0.00
0.04	-0.96	-0.04	10881.10	0.00
0.04	-0.96	-0.03	10882.10	0.00
0.03	-0.97	-0.03	10883.10	0.00
0.03	-0.97	-0.03	10884.10	0.00
0.03	-0.97	-0.03	10885.10	0.00
0.03	-0.97	-0.03	10886.10	0.00
0.02	-0.98	-0.02	10887.10	0.00
0.02	-0.98	-0.02	10888.10	0.00
0.02	-0.98	-0.02	10889.10	0.00
0.02	-0.98	-0.02	10890.10	0.00
0.02	-0.99	-0.01	10891.10	0.00
0.01	-0.99	-0.01	10892.10	0.00
0.01	-0.99	-0.01	10893.10	0.00
0.01	-0.99	-0.01	10894.10	0.00
0.01	-0.99	-0.01	10895.10	0.00
0.01	-0.99	-0.01	10896.10	0.00
0.01	-1.00	0.00	10897.10	0.00
0.00	-1.00	0.00	10898.10	0.00

Cannop B

26.27
663.84
0.08
13.04

nl	nl-1	(nl(nl-1))	N(N-1)	(nl(nl-1))/N(N-1)
7.25	6.25	45.25	663.84	0.07
2.33	1.33	3.10	664.84	0.00
2.16	1.16	2.51	665.84	0.00
2.04	1.04	2.14	666.84	0.00
1.73	0.73	1.26	667.84	0.00
1.33	0.33	0.44	668.84	0.00
0.97	-0.03	-0.03	669.84	0.00
0.77	-0.23	-0.18	670.84	0.00
0.71	-0.29	-0.20	671.84	0.00
0.63	-0.37	-0.23	672.84	0.00
0.48	-0.52	-0.25	673.84	0.00
0.45	-0.55	-0.25	674.84	0.00
0.41	-0.59	-0.24	675.84	0.00
0.39	-0.61	-0.24	676.84	0.00
0.31	-0.69	-0.21	677.84	0.00
0.29	-0.71	-0.21	678.84	0.00
0.29	-0.71	-0.20	679.84	0.00
0.26	-0.74	-0.19	680.84	0.00
0.26	-0.74	-0.19	681.84	0.00
0.26	-0.74	-0.19	682.84	0.00
0.26	-0.74	-0.19	683.84	0.00
0.24	-0.76	-0.18	684.84	0.00
0.22	-0.78	-0.17	685.84	0.00
0.20	-0.80	-0.16	686.84	0.00
0.19	-0.81	-0.15	687.84	0.00
0.18	-0.82	-0.14	688.84	0.00
0.15	-0.85	-0.13	689.84	0.00
0.15	-0.85	-0.12	690.84	0.00
0.13	-0.87	-0.11	691.84	0.00
0.10	-0.90	-0.09	692.84	0.00
0.08	-0.92	-0.08	693.84	0.00
0.08	-0.92	-0.08	694.84	0.00
0.08	-0.92	-0.07	695.84	0.00
0.08	-0.92	-0.07	696.84	0.00
0.08	-0.92	-0.07	697.84	0.00
0.07	-0.93	-0.07	698.84	0.00
0.06	-0.94	-0.06	699.84	0.00
0.06	-0.94	-0.06	700.84	0.00
0.06	-0.94	-0.06	701.84	0.00
0.05	-0.95	-0.05	702.84	0.00
0.05	-0.95	-0.04	703.84	0.00
0.04	-0.96	-0.04	704.84	0.00
0.04	-0.96	-0.04	705.84	0.00
0.04	-0.96	-0.04	706.84	0.00
0.03	-0.97	-0.03	707.84	0.00
0.03	-0.97	-0.03	708.84	0.00
0.03	-0.97	-0.03	709.84	0.00
0.02	-0.98	-0.02	710.84	0.00
0.02	-0.98	-0.02	711.84	0.00
0.02	-0.98	-0.02	712.84	0.00
0.02	-0.98	-0.02	713.84	0.00
0.02	-0.98	-0.02	714.84	0.00
0.01	-0.99	-0.01	715.84	0.00
0.01	-0.99	-0.01	716.84	0.00
0.01	-0.99	-0.01	717.84	0.00
0.01	-0.99	-0.01	718.84	0.00
0.01	-0.99	-0.01	719.84	0.00
0.01	-0.99	-0.01	720.84	0.00
0.00	-1.00	0.00	721.84	0.00
0.00	-1.00	0.00	722.84	0.00
0.00	-1.00	0.00	723.84	0.00
0.00	-1.00	0.00	724.84	0.00
0.00	-1.00	0.00	725.84	0.00
0.00	-1.00	0.00	726.84	0.00
0.00	-1.00	0.00	727.84	0.00

Lightmoor

58.09
3316.47
0.10
10.49

nl	nl-1	(nl(nl-1))	N(N-1)	(nl(nl-1))/N(N-1)
13.74	12.74	174.92	3316.47	0.05
7.96	6.96	55.47	3317.47	0.02
7.61	6.61	50.37	3318.47	0.02
4.87	3.87	18.89	3319.47	0.01
3.81	2.81	10.72	3320.47	0.00
2.41	1.41	3.40	3321.47	0.00
2.28	1.28	2.94	3322.47	0.00
1.59	0.59	0.93	3323.47	0.00
1.49	0.49	0.72	3324.47	0.00
1.34	0.34	0.45	3325.47	0.00
1.28	0.28	0.35	3326.47	0.00
0.89	-0.11	-0.09	3327.47	0.00
0.85	-0.15	-0.13	3328.47	0.00
0.71	-0.29	-0.21	3329.47	0.00
0.69	-0.31	-0.21	3330.47	0.00
0.56	-0.44	-0.25	3331.47	0.00
0.51	-0.49	-0.25	3332.47	0.00
0.44	-0.56	-0.25	3333.47	0.00
0.43	-0.57	-0.24	3334.47	0.00
0.38	-0.62	-0.23	3335.47	0.00
0.36	-0.64	-0.23	3336.47	0.00
0.33	-0.67	-0.22	3337.47	0.00
0.29	-0.71	-0.21	3338.47	0.00
0.28	-0.72	-0.20	3339.47	0.00
0.25	-0.75	-0.19	3340.47	0.00
0.22	-0.78	-0.17	3341.47	0.00
0.20	-0.80	-0.16	3342.47	0.00
0.19	-0.81	-0.16	3343.47	0.00
0.17	-0.83	-0.14	3344.47	0.00
0.16	-0.84	-0.13	3345.47	0.00
0.15	-0.86	-0.12	3346.47	0.00
0.12	-0.88	-0.11	3347.47	0.00
0.12	-0.88	-0.10	3348.47	0.00
0.12	-0.88	-0.10	3349.47	0.00
0.10	-0.90	-0.09	3350.47	0.00
0.10	-0.90	-0.09	3351.47	0.00
0.09	-0.91	-0.08	3352.47	0.00
0.09	-0.91	-0.08	3353.47	0.00
0.09	-0.91	-0.08	3354.47	0.00
0.09	-0.91	-0.08	3355.47	0.00
0.07	-0.93	-0.06	3356.47	0.00
0.06	-0.94	-0.06	3357.47	0.00
0.06	-0.94	-0.05	3358.47	0.00
0.06	-0.94	-0.05	3359.47	0.00
0.05	-0.95	-0.05	3360.47	0.00
0.05	-0.95	-0.05	3361.47	0.00
0.05	-0.95	-0.05	3362.47	0.00
0.04	-0.96	-0.04	3363.47	0.00
0.04	-0.96	-0.04	3364.47	0.00
0.04	-0.96	-0.04	3365.47	0.00
0.03	-0.97	-0.03	3366.47	0.00
0.03	-0.97	-0.03	3367.47	0.00
0.02	-0.98	-0.02	3368.47	0.00
0.02	-0.98	-0.02	3369.47	0.00
0.02	-0.98	-0.02	3370.47	0.00
0.01	-0.99	-0.01	3371.47	0.00
0.01	-0.99	-0.01	3372.47	0.00
0.01	-0.99	-0.01	3373.47	0.00
0.01	-0.99	-0.01	3374.47	0.00
0.01	-0.99	-0.01	3375.47	0.00
0.01	-0.99	-0.01	3376.47	0.00
0.01	-0.99	-0.01	3377.47	0.00
0.01	-0.99	-0.01	3378.47	0.00
0.01	-0.99	-0.01	3379.47	0.00
0.00	-1.00	0.00	3380.47	0.00
0.00	-1.00	0.00	3381.47	0.00
0.00	-1.00	0.00	3382.47	0.00
0.00	-1.00	0.00	3383.47	0.00
0.00	-1.00	0.00	3384.47	0.00
0.00	-1.00	0.00	3385.47	0.00
0.00	-1.00	0.00	3386.47	0.00
0.00	-1.00	0.00	3387.47	0.00
0.00	-1.00	0.00	3388.47	0.00
0.00	-1.00	0.00	3389.47	0.00
0.00	-1.00	0.00	3390.47	0.00
0.00	-1.00	0.00	3391.47	0.00

True Blue

101.56
10212.62
0.49
2.06

nl	nl-1	(nl(nl-1))	N(N-1)	(nl(nl-1))/N(N-1)
70.31	69.31	4873.19	10212.62	0.48
6.33	5.33	33.74	10213.62	0.00
4.99	3.99	19.93	10214.62	0.00
4.77	3.77	17.97	10215.62	0.00
3.32	2.32	7.71	10216.62	0.00
3.01	2.01	6.06	10217.62	0.00
1.56	0.56	0.87	10218.62	0.00
1.46	0.45	0.65	10219.62	0.00
1.25	0.25	0.31	10220.62	0.00
1.11	0.11	0.12	10221.62	0.00
0.62	-0.38	-0.24	10222.62	0.00
0.49	-0.51	-0.25	10223.62	0.00
0.44	-0.56	-0.25	10224.62	0.00
0.29	-0.71	-0.21	10225.62	0.00
0.29	-0.71	-0.21	10226.62	0.00
0.27	-0.73	-0.20	10227.62	0.00
0.20	-0.80	-0.16	10228.62	0.00
0.19	-0.81	-0.15	10229.62	0.00
0.17	-0.83	-0.14	10230.62	0.00
0.13	-0.87	-0.11	10231.62	0.00
0.13	-0.88	-0.11	10232.62	0.00
0.04	-0.96	-0.04	10233.62	0.00
0.04	-0.96	-0.04	10234.62	0.00
0.04	-0.97	-0.03	10235.62	0.00
0.03	-0.97	-0.03	10236.62	0.00
0.03	-0.97	-0.03	10237.62	0.00
0.03	-0.97	-0.03	10238.62	0.00
0.01	-0.99	-0.01	10239.62	0.00
0.01	-0.99	-0.01	10240.62	0.00
0.01	-0.99	-0.01	10241.62	0.00
0.01	-0.99	-0.01	10242.62	0.00
0.00	-1.00	0.00	10243.62	0.00

Appendix 3.12: Species-richness indices gained from units of constant size

a) Number of species per quadrat (1m x 1.5m)

		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7				n	Mean/T	Mean/SP	STDEV/SP
NU	T1	2	3	3	5	3	1	3	4	7	2	4	6	6	4	4	4	5	8	2	4	16	10	18	8	24	28	16	19	28	7.82		
	T2	4	3	6	5	4	3	4	4	5	4	3	4	6	4	4	4	4	9	8	5	12	14	7	7	22	10	7	7	28	6.39		
	T3	5	4	5	3	1	2	1	2	1	3	2	4	4	4	7	3	6	5	7	6	6	11	17	14	8	12	8	7	28	5.64	6.62	5.30
CPA	T1	3	0	4	4	0	0	2	6	0	1	2	1	0	0	1	1													16	1.56		
	T2	15	13	13	13	8	8	10	11	2	0	2	1	3	2	3	0													16	6.50	4.03	4.69
NFA	T1	23	24	22	19	28	26	27	21	24	24	22	20	20	23	24	17	18	15	25	26	28	30	23	23					24	23.00		
	T2	21	23	19	18	19	19	15	17	16	14	16	17	8	17	14	14	9	17	18	15	18	11	12	17					24	16.00	19.50	5.01
NFB	T1	21	7	9	19	20	12	12	15	14	17	15	11	24	25	20	16	17	29	18	18	22	25	25	13					24	17.67	17.67	5.61
CPB	T1	25	29	32	28	19	15	16	24	11	11	14	11	8	10	11	6													16	16.88		
	T2	22	29	23	15	21	11	13	11	1	3	3	8	0	5	2	5													16	10.75		
	T3	11	12	8	8	17	19	7	8	11	8	12	11	5	8	4	0													16	9.31	12.31	8.09
LM	T1	30	27	20	30	29	27	28	25	18	19	19	19	22	19	22	18	29	23	27	21									20	23.60		
	T2	29	30	30	33	26	25	21	17	16	18	13	15	13	15	11	14	15	15	16	14									20	19.30		
	T3	18	16	15	18	13	16	12	14	17	13	19	18	19	21	19	15	18	18	15	13									20	16.35	19.75	5.70
TB	T1	11	14	11	9	7	15	10	11	10	4	9	7																	12	9.83		
	T2	11	7	8	9	14	10	13	11	10	11	10	5																	12	9.92	9.88	2.69
																														320		12.7	8.2

b) Mean number of species per subunit (20x30cm)

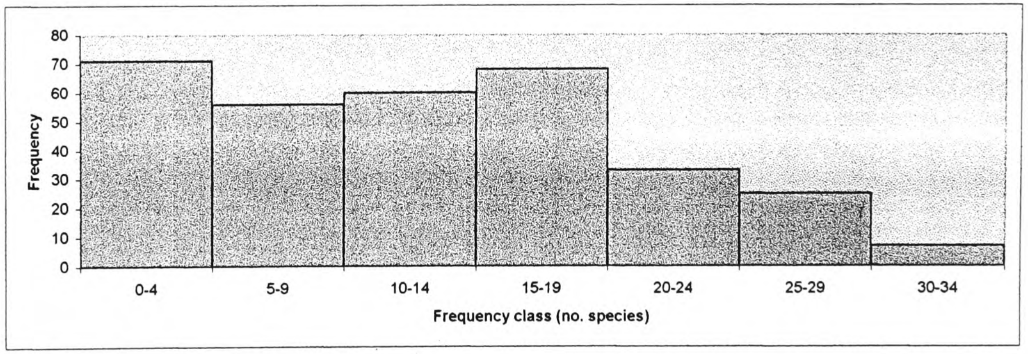
		Subplot1				Subplot 2				Subplot 3				Subplot 4				Subplot 5				Subplot 6				Subplot 7				n	Mean/T	Mean/SU	STDEV/SP
NU	T1	0.84	1.24	0.56	0.88	1.2	0.4	0.36	0.64	1.24	1.04	0.24	0.56	1.52	1.04	1.16	1	1.4	2.08	0.48	1.44	5.24	3.32	6.2	1.96	7.16	6.96	3.28	8.52	28	2.14		
	T2	0.98	0.25	1.06	0.65	0.93	0.41	0.16	0.47	1.12	0.96	0.6	1.12	1.56	1.28	0.92	0.8	1.04	2.44	2.16	1.24	2.44	4.52	1.6	2.28	5.54	2.12	2.04	1.32	28	1.50		
	T3	0.92	0.48	0.76	0.24	0.08	0.16	0.04	0.2	0.04	0.28	0.2	0.24	1.08	1.16	1.36	1.56	1.44	4.8	2.68	2.16	1.52	2.2	2.96	2.6	1.96	1.8	1.96	1.8	28	1.31	1.65	1.60
CPA	T1	0.28	0	0.4	0.52	0	0	0.4	0.04	0	0.04	0.04	0.09	0	0	0.04	0.08													16	0.12		
	T2	4.64	4.84	3.48	3.6	2.84	2.84	2.8	2.76	0.08	0	0.08	0.04	0.16	0.08	0.16	0													16	1.76	0.94	1.53
NFA	T1	7.8	6.88	6.76	5.6	6.92	7.04	6.16	5.88	6.68	7.44	7	6.44	7.48	7	7.44	5.4	6.12	5.8	6.92	6.36	9.24	8.56	8.12	8.12					24	6.97		
	T2	6.4	5.92	5.04	4.8	4.52	4.48	5.12	5.4	6.44	5.08	5.04	5.08	2.32	5.36	3.96	3.96	3.04	4.2	5.04	4.8	3.25	4.85	3.36	4.25					24	4.65	5.81	1.52
NFB	T1	4.76	1.89	1.72	4.6	4.28	2.4	2.52	3.48	3.8	3.84	2.24	2.52	5	5.44	4.08	3.24	5	6.44	4.52	4.92	6.2	6.48	6.92	3.63					24	4.16	4.16	1.50
CPB	T1	7.12	9.12	8.68	8.4	3.52	3.16	3.24	5.84	2.32	2.16	2.84	1.96	1.88	1.12	1.12	0.8													16	3.96		
	T2	5.04	5.72	5.12	3.6	4.84	3.16	3.36	2.52	0.16	0.2	0.4	1.4	0	0.48	0.12	0.68													16	2.30		
	T3	1.44	1.88	1.52	1.36	3.52	2.84	0.8	0.84	2.52	1.32	1.2	1.68	0.16	1.1	0.2	0													16	1.40	2.55	2.35
LM	T1	7.92	8.08	7.84	7.44	6.56	7.36	6.4	6.2	4.96	5.08	5.28	5.24	5.16	5.88	5.24	5.32	5.89	5.03	4.98	5.46									20	6.07		
	T2	8.64	9.04	7.08	7.68	7.12	5.96	4.92	5.12	4.04	4.46	4.08	4.4	4.6	4.29	4.85	4.01	4.12	5	5.24	4.76									20	5.47		
	T3	3.44	3.12	4.4	4.6	3.36	3.56	3.16	3.32	4.4	3.96	4.16	5.32	5.44	5.02	5.2	4.8	2.4	4.88	5.38	4.32									20	4.20	5.25	1.43
TB	T1	2.4	2.44	1.88	1.88	2.84	3.28	1.96	1.76	2.68	2.12	2.24	2.92																	12	2.37		
	T2	3.12	2.32	2.8	3.48	2.76	2.24	3.72	2.64	3.64	2.92	2.44	1.64																	12	2.81	2.58	0.59
																														320		3.27	2.39

c) Distribution of species per quadrat data in 7 frequency classes

No spp/quadrat	Frequency
0-4	71
5-9	56
10-14	60
15-19	68
20-24	33
25-29	25
30-34	7
n=	320
Sample mean	#####
St dev	8.23
x=	#####
%	#####

NB: x = No. samples that fall between the sample mean and the standard deviation

d) Frequency distribution graph for speciesper quadrat data



Appendix 3.13: data matrix to show species strategies data for species found on all sites

	Life-span			Life-form								Reproduction					Special features			Lateral spread					Strategy										pH					tolerance range				Hydrology					
GRASSES	AN	BI	PER	M	Chh	H	Hp	Hs	Hr	Gr	Th	V	S	W	Bs	Bl	Tap	Clon	Leg	1	2	3	4	5	C	S	R	CSR	CS	SC	RS	CR	SR	W	3	4	5	6	7	a	b	c	d	1	2	3	4	5	6
Agrostis capilans	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0				1		0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0						
Agrostis gigantea	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0					1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0						
Agrostis stolonifera	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0					1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1	1	1
Aira carophylla	1	0	0	0	0	0	0	0	0	0	1	?	?	?	?	?	0	0	0	1					0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0						
A. praecox	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1					0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Anthoxanthum odoratum	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0		1				0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0	0
Arrhenatherum elatius	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	1	0	0				1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	0
Brachypodium sylvaticum	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0			1			0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Bromus hordeaceous	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0					1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Carex hirta	0	0	1	0	0	1	0	0	0	0	0	?	?	?	?	?	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1						
Carex nigra	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0				1		0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0
Cynosurus cristata	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0		1				0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	1	0	0	0
Deschampsia caespitosa	0	0	1	0	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0				1		0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	1	1	0	0
Deschampsia flexuosa	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0				1		0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	1	0	0	0
Dactylis glomerata	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0			1			0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	0
Festuca ovina	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0			1			0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Festuca rubra	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0				1		0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0						
Holcus lanatus	0	0	1	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0			1			0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	1	1	0	0
Juncus effusus	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0				1		1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	1	1	0	1
luzula sylvestris	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0				1		0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0
Lolium perenne	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0			1			0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	1	0	1	0
Poa annua	1	0	1	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1					0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	0
Poa pratensis	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	1	1	0			1			0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	1
Vulpia bromoides	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1					0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1						
Tree/shrub >1.5m																																																	
Acer campestre	0	0	1	1	0	0	0	0	0	0	0					0								1						1									1			1							
Alnus glutinosa	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1					1						1							1					1							
Alnus cordata	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1																									
Betula pubescens	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0					1						1					1						1								
Crataegus monogyne	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0					1						1									1				1	0					
Ilex aquifolium	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1						1					1								1						
Larix decidua	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1																									
Pinus nigra var maritime	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1																									
Prunus spinosa	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1						1								1				1							
Quercus sp.	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0					1						1						1					1								
Salix cinerea	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0					1	1													1			1								
Sambucus nigra	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0					1	1												1						1						
Ulex europeeus	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1					1						1							1				1								
	Life-span			Life-form								Reproduction					Special features			Lateral spread					Strategy										pH					tolerance range				Hydrology					
Herb	AN	BI	PER	M	Chh	H	Hp	Hs	Hr	Gr	Th	V	S	W	Bs	Bl	Tap	Clon	Leg	1	2	3	4	5	C	S	R	CSR	CS	SC	RS	CR	SR	W	3	4	5	6	7	a	b	c	d	1	2	3	4	5	6
Bellis perennis	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0			1					1												1			1		0	1	1	0	0	0
Calluna vulgaris	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0				1					0		1					1					1				0	1	1	0	0	0
Cerastium holosteoides	0	0	1	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0		1				0			1									1					1		1	1	1	0	0	0
Chamerion angustifolium	0	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	1	1	0					1	1											1							1	1	1	1	0	0	0
Cirsium arvense	0	0	1	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	0					1	1		0										1					1		0	0	1	0	1	0
Crepis capillaris	1	0	0	0	0	0	0	0	0		1	0	0	1	1	0	0	0	0	1							1												1		1			0	0	0	0	0	0
Digitalis purpurea	0	0	1	0	0	0	0	0	1			1	0	0	1	0	1	0	0		1							1								1						1		1	0	0	0	0	0
Epilobium hirsutum	0	0	1	0	0	0	1	0				1	0	1	1	0	1	1	0					1				1											1		1			1	1	1	1	1	0
Epilobium montanum	0	0	1	0	0	0	1	0				0	0	1	1	0	0	0	0		1							1											1			1		0	0	1	0	0	0
Epilobium tetragonum	0	0	1	0	0	0	1	0													1							1										1				1							
Epilobium palustre	0	0	1	0	0	0	1	0				0	0	1	1	0					1							1										1		1		0							
Euphorbia platyphyllos	0	0	1	0	0	0		0				0				0																																	
Euphrasia nemorosa	1	0	0	0	0	0		0			1	0	1	0	0	0	0	0	0	1						1													1		1			0	0	0	0	0	0
Fragaria vesca	0	0	1	0	0	0		0	1			1	0	0	1	0	1	1	0				1					1											1	1				0	0	0	0	0	0
F. sterilis	0	0	1	0	0	0		1				1	1	0	0	0	0	1	0			1				1											1					1		0	0	0	0	0	0
Galium saxatile	0	0	1	0	0	0	1					1	1	0	1	0	1	1	0				1			1									1						1			1	1	1	0	0	0
Geranium molle	1	0	0	0	0	0					1	0	0	0	1	0	0	0	0	1							1												1		1			0	0	0	0	0	0
Geranium robertinum	0	1	0	0	0	0		1				0	0	0	0	0	0	0	0	1							1												1		1			1	1	1	0	0	0
Geum urbanum	0	0	1	0	0	0		1				0	0	0	0	0	0	0	0		1							1									1					1		0	0	0	0	0	0
Hedera helix	0	0	1	1	0	0						1	0	0	0	0	0	1	0					1						1									1				1	0	1	0	0	0	0
Heracleum sphondylium	0	0	1		0	0		1				0	0	0	0	0	1	0	0		1											1					1					1		1	1	1	0	0	0
Hypochoeris radicata	0	0	1		0	0			1			1	0	1	0	0	1	1	0		1							1											1				1	0	0	0	0	0	0
Leontodon autumnalis	0	0	1		0	0			1			0	0	1	1	0	0	0	0		1							1										1				1		0	1	0	0	0	0
Linium catharticum	0	1	0		0	0					0	0	0	1	0	0	0	0	0	1													1						1	1				0	0	0	0	0	0
Lotus corniculatus	0	0	1		0	0	1					0	1	0	1	0	0	0	1		1					1													1			1		0	0	0	0	0	0
lotus pendunculus	0	0	1		0	0	1					0	1	0	1	0	0	0	1							1													0										
Malva neglecta	0	0	1		0	0	0				1		0			0							1									1						1			1								
Medicago lupulina	1	0	0		0	0	0				1	0	0	0	1	0	1	0	1	1						1													1	1				0	0	0	0	0	0
Melilotus altissima	0	1	0		0	0	0									0	0	0	1																														
Mentha arvensis	0	0	1		0	1	0									0							1									1						1				1							
Myostis arvensis	1	0	0		0		0				1	0	1	0	1	0	0	0	0	1											1							1			1			0	0	0	0	0	0
Pilosella officinarum	0	0	1		0		0		1		0	1	0	1	0	0	0	0	0				1			1													1			1		0	0	0	0	0	0
Plantago lanceolata	0	0	1		0		0		1		0	1	0	0	1	0	1	0	0		1							1											1			1		1	1	1	0	0	0
Plantago major	0	0	1		0		0		1		0	0	0	0	1	0	0	0	0		1						1												1		1			0	1	1	0	0	0
Potentilla reptans	0	0	1		0	1	0		0		0	1	0	0	0	0	0	1	0					1								1						1				1							
Prunella vulgaris	0	0	1		0		0	1	0		0	1	0	0	1	0	0	1	0		1							1									1			1				1	1	1	0	0	0
Pteridium aquilinum	0	0	1		0		0		0	1	0	1	0	1	1	0	0	1	0					1	1										1						1			1	1	1	0	0	0

Appendix 3.13: data matrix to show species strategies data for species found on all sites

Pyrola minor	0	0	1		0		0		0	0	0					0	0	1	0																														
Rosa canina	0	0	1	1	0		0		0	0	0					0								1						1									1			1							
Rubus fruticosus	0	0	1	1	0		0		0	0	0	1	0	0	1	0	0	1	0					1						1						1					1			1	1	1	0	0	0
Rumex acetosella	0	0	1	0	0		0	1	0	0	0	1	0	0	1	0	1	0	0				1					1								1	0					1		0	0	0	0	0	0
Sagina procumbens	0	0	1	0	0		0	1	0	0	0	1	0	0	1	0	0	0	0		1						1										1					1		1	1	1	0	0	0
Senecio jacobaea	0	1	0	0	0		0	1	0	0	0	1	0	1	1	0	1	0	0	1							1												1	1				0	0	1	0	0	0
Senecio vulgaris	1	0	0	0	0	0	0	0	0	0	1					0	0	0	0	1							1					0							1	1				0	0	0	0	0	0
Sonchus arvensis	0	0	1	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0				1				0					1							1			1							
Taraxacum officinale	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0	1	0	0		1						1												1		1			1	1	1	0	0	0
Teucrium scorodonia	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0			1						1						1										0	0	0	0	0	0
Thymus polytrichus	0	0	1	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0				1			1													1			1		0	0	0	0	0	0
Trifolium pratense	0	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	1			1						1									1					1		0	1	0	0	0	0
Trifolium repens	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1				1					1									1					1		1	1	1	0	0	0
Tussilago farfara	0	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0					1								1							1		1			1	1	1	0	0	0
Veronica officinalis	0	0	1	0	1	0	0	0	0	0	0					0						1				1											1						1						
Vicia sativa	1	0	0	0	0	0	0	0	0	0	1					0	0	0	1	1							1											1					1						
Viola riviniana	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0		1					1											1						1	1	0	1	0	0	0
Acer campestre	0	0	1	1	0	0	0	0	0	0	0					0								1						1									1			1							
Alnus glutinosa	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1					1						1							1					1							
Alnus cordata	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1																									
Betula pubescens	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0					1						1					1						1								
Crataegus monogyna	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0					1						1									1				1	0					
Ilex aquifolium	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1						1					1								1						
Larix decidua	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1																									
Pinus nigra var maritima	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1																									
Prunus spinosa	0	0	1	1	0	0	0	0	0	0	0					0	0	0	0					1						1								1				1							
Quercus sp	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0					1						1						1					1								
Salix cinerea	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0					1	1													1			1								
Sambucus nigra	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0					1	1												1						1						
Ulex europaeus	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1					1						1							1				1								
COUNTIF > 0	12	4	89	29	4	7	15	20	8	4	13	44	27	21	41	0	18	28	11	18	20	13	20	41	10	14	12	22	0	23	1	8	4	2	11	10	29	19	35	10	24	44	14	30	37	36	7	6	5

	Site	No. Vasc. Spp.	Life-span			Life-form								Reproduction					Special features			Lateral spread				
			Annu:	Bienn	Peren	P	Ch	H	Hp	Hs	Hr	G	Th	V	S	W	Bs	Bj	Tap	Clon	Leg	1	2	3	4	5
			Frequency of occurrence per plot																							
	Northern United	47	4	2	42	11	2	4	9	10	3	3	4	24	8	13	20	0	10	18	5	7	11	4	11	19
	Cannop A	25	1	0	24	3	1	1	5	8	1	4	2	15	6	7	11	0	6	11	0	2	7	4	7	10
	New Fancy A	58	6	3	50	11	2	4	8	16	7	2	6	32	16	13	25	0	12	20	7	8	14	11	10	19
	New Fancy B	45	4	2	39	9	1	3	7	15	4	1	4	27	13	9	21	0	8	15	3	7	11	10	9	13
	Cannop B	38	3	1	35	4	1	2	9	13	3	2	4	26	11	9	20	0	10	15	0	5	10	8	10	10
	Lightmoor	62	8	2	52	7	3	5	13	15	8	2	8	32	18	12	30	0	14	18	7	10	17	11	13	15
	True Blue	18	2	1	16	2	2	0	3	7	1	0	2	12	8	2	9	0	4	8	0	4	3	4	8	4
			% of all species present per plot																							
By Age																										
6	Northern United	47	8.51	4.26	89.36	23.40	4.26	8.51	19.15	21.28	6.38	6.38	8.51	51.06	17.02	27.66	42.55	0.00	21.28	38.30	10.64	14.89	23.40	8.51	23.40	40.43
16	Cannop A	25	4.00	0.00	96.00	12.00	4.00	4.00	20.00	32.00	4.00	16.00	8.00	60.00	24.00	28.00	44.00	0.00	24.00	44.00	0.00	8.00	28.00	16.00	28.00	40.00
36	New Fancy A	58	10.34	5.17	86.21	18.97	3.45	6.90	13.79	27.59	12.07	3.45	10.34	55.17	27.59	22.41	43.10	0.00	20.69	34.48	12.07	13.79	24.14	18.97	17.24	32.76
36	New Fancy B	45	8.89	4.44	86.67	20.00	2.22	6.67	15.56	33.33	8.89	2.22	8.89	60.00	28.89	20.00	46.67	0.00	17.78	33.33	6.67	15.56	24.44	22.22	20.00	28.89
41	Cannop B	38	7.89	2.63	92.11	10.53	2.63	5.26	23.68	34.21	7.89	5.26	10.53	68.42	28.95	23.68	52.63	0.00	26.32	39.47	0.00	13.16	26.32	21.05	26.32	26.32
60	Lightmoor	62	12.90	3.23	83.87	11.29	4.84	8.06	20.97	24.19	12.90	3.23	12.90	51.61	29.03	19.35	48.39	0.00	22.58	29.03	11.29	16.13	27.42	17.74	20.97	24.19
100	True Blue	18	11.11	5.56	88.89	11.11	11.11	0.00	16.67	38.89	5.56	0.00	11.11	66.67	44.44	11.11	50.00	0.00	22.22	44.44	0.00	22.22	16.67	22.22	44.44	22.22
Mean			9.09	3.61	89.01	15.33	4.64	5.63	18.55	30.21	8.24	5.22	10.04	58.99	28.56	21.75	46.76	0.00	22.12	37.58	5.81	14.82	24.34	18.10	25.77	30.69
STDEV			2.83	1.89	4.05	5.3	2.99	2.93	3.41	6.15	3.31	5.18	1.71	6.85	8.24	5.78	3.79	0	2.68	5.67	5.69	4.23	3.8	4.83	9.02	7.33
Mean + stdev			11.92	5.50	93.06	20.63	7.64	8.56	21.96	36.37	11.55	10.40	11.75	65.84	36.80	27.52	50.56	0.00	24.80	43.25	11.50	19.05	28.14	22.93	34.79	38.01
mean-stdev			6.27	1.72	84.97	10.03	1.65	2.70	15.13	24.06	4.94	0.04	8.33	52.14	20.32	15.97	42.97	0.00	19.45	31.91	0.12	10.59	20.54	13.27	16.74	23.36
% within 1stdev			71.43	71.43	71.43	85.71	85.71	85.71	71.43	71	57	71	71	43	14	57	71	0	71	57	43	71	86	86	86	57
			% of all species present per plot																							
By pH																										
3.02	True Blue	18	11.11	5.56	88.89	11.11	11.11	0.00	16.67	38.89	5.56	0.00	11.11	66.67	44.44	11.11	50.00	0.00	22.22	44.44	0.00	22.22	16.67	22.22	44.44	22.22
4.6	Northern United	47	8.51	4.26	89.36	23.40	4.26	8.51	19.15	21.28	6.38	6.38	8.51	51.06	17.02	27.66	42.55	0.00	21.28	38.30	10.64	14.89	23.40	8.51	23.40	40.43
4.79	Cannop B	38	7.89	2.63	92.11	10.53	2.63	5.26	23.68	34.21	7.89	5.26	10.53	68.42	28.95	23.68	52.63	0.00	26.32	39.47	0.00	13.16	26.32	21.05	26.32	26.32
5	Lightmoor	62	12.90	3.23	83.87	11.29	4.84	8.06	20.97	24.19	12.90	3.23	12.90	51.61	29.03	19.35	48.39	0.00	22.58	29.03	11.29	16.13	27.42	17.74	20.97	24.19
5.73	New Fancy A	58	10.34	5.17	86.21	18.97	3.45	6.90	13.79	27.59	12.07	3.45	10.34	55.17	27.59	22.41	43.10	0.00	20.69	34.48	12.07	13.79	24.14	18.97	17.24	32.76
5.93	Cannop A	25	4.00	0.00	96.00	12.00	4.00	4.00	20.00	32.00	4.00	16.00	8.00	60.00	24.00	28.00	44.00	0.00	24.00	44.00	0.00	8.00	28.00	16.00	28.00	40.00
6.38	New Fancy B	45	8.89	4.44	86.67	20.00	2.22	6.67	15.56	33.33	8.89	2.22	8.89	60.00	28.89	20.00	46.67	0.00	17.78	33.33	6.67	15.56	24.44	22.22	20.00	28.89

		No. Vasc.	Lateral spread					Strategy									pH						tolerance range			
	Site	Spp.	1	2	3	4	5	C	S	R	CSR	CS	SC	RS	CR	SR	W	3	4	5	6	7	a	b	c	d
			Frequency of occurrence per plot																							
	Northern United	47	7	11	4	11	19	6	4	4	16	0	7	0	5	2	0	3	6	15	7	18	6	10	22	6
	Cannop A	25	2	7	4	7	10	4	2	2	8	0	6	0	3	0	1	5	5	7	5	7	3	10	8	3
	New Fancy A	58	8	14	11	10	19	3	9	7	18	0	11	1	6	1	1	4	8	15	10	23	6	11	30	8
	New Fancy B	45	7	11	10	9	13	1	3	6	15	0	11	0	4	4	2	5	5	12	6	19	5	7	23	7
	Cannop B	38	5	10	8	10	10	3	9	4	11	0	7	0	3	1	2	5	7	12	4	13	4	11	16	5

	Lightmoor	62	10	17	11	13	15	5	11	9	19	0	9	0	4	4	2	4	7	19	8	25	6	13	31	8
	True Blue	18	4	3	4	8	4	0	4	1	7	0	4	0	1	1	1	4	5	3	1	9	3	3	10	1
			% of all species present per plot																							
By Age																										
6	Northern United	47	14.89	23.40	8.51	23.40	40.43	12.77	8.51	8.51	34.04	0.00	14.89	0.00	10.64	4.26	0.00	6.38	12.77	31.91	14.89	38.30	12.77	21.28	46.81	12.77
16	Cannop A	25	8.00	28.00	16.00	28.00	40.00	16.00	8.00	8.00	32.00	0.00	24.00	0.00	12.00	0.00	4.00	20.00	20.00	28.00	20.00	28.00	12.00	40.00	32.00	12.00
36	New Fancy A	58	13.79	24.14	18.97	17.24	32.76	5.17	15.52	12.07	31.03	0.00	18.97	1.72	10.34	1.72	1.72	6.90	13.79	25.86	17.24	39.66	10.34	18.97	51.72	13.79
36	New Fancy B	45	15.56	24.44	22.22	20.00	28.89	2.22	6.67	13.33	33.33	0.00	24.44	0.00	8.89	8.89	4.44	11.11	11.11	26.67	13.33	42.22	11.11	15.56	51.11	15.56
41	Cannop B	38	13.16	26.32	21.05	26.32	26.32	7.89	23.68	10.53	28.95	0.00	18.42	0.00	7.89	2.63	5.26	13.16	18.42	31.58	10.53	34.21	10.53	28.95	42.11	13.16
60	Lightmoor	62	16.13	27.42	17.74	20.97	24.19	8.06	17.74	14.52	30.65	0.00	14.52	0.00	6.45	6.45	3.23	6.45	11.29	30.65	12.90	40.32	9.68	20.97	50.00	12.90
100	True Blue	18	22.22	16.67	22.22	44.44	22.22	0.00	22.22	5.56	38.89	0.00	22.22	0.00	5.56	5.56	5.56	22.22	27.78	16.67	5.56	50.00	16.67	16.67	55.56	5.56
			% of all species present per plot																							
By pH																										
3.02	True Blue	18	22.22	16.67	22.22	44.44	22.22	0.00	22.22	5.56	38.89	0.00	22.22	0.00	5.56	5.56	5.56	22.22	27.78	16.67	5.56	50.00	16.67	16.67	55.56	5.56
4.6	Northern United	47	14.89	23.40	8.51	23.40	40.43	12.77	8.51	8.51	34.04	0.00	14.89	0.00	10.64	4.26	0.00	6.38	12.77	31.91	14.89	38.30	12.77	21.28	46.81	12.77
4.79	Cannop B	38	13.16	26.32	21.05	26.32	26.32	7.89	23.68	10.53	28.95	0.00	18.42	0.00	7.89	2.63	5.26	13.16	18.42	31.58	10.53	34.21	10.53	28.95	42.11	13.16
5	Lightmoor	62	16.13	27.42	17.74	20.97	24.19	8.06	17.74	14.52	30.65	0.00	14.52	0.00	6.45	6.45	3.23	6.45	11.29	30.65	12.90	40.32	9.68	20.97	50.00	12.90
5.73	New Fancy A	58	13.79	24.14	18.97	17.24	32.76	5.17	15.52	12.07	31.03	0.00	18.97	1.72	10.34	1.72	1.72	6.90	13.79	25.86	17.24	39.66	10.34	18.97	51.72	13.79
5.93	Cannop A	25	8.00	28.00	16.00	28.00	40.00	16.00	8.00	8.00	32.00	0.00	24.00	0.00	12.00	0.00	4.00	20.00	20.00	28.00	20.00	28.00	12.00	40.00	32.00	12.00
6.38	New Fancy B	45	15.56	24.44	22.22	20.00	28.89	2.22	6.67	13.33	33.33	0.00	24.44	0.00	8.89	8.89	4.44	11.11	11.11	26.67	13.33	42.22	11.11	15.56	51.11	15.56

Appendix 4: List of species found in the Forest of Dean, and codes used in the dendrograms for indicator species

	CODE	Species name – flowering plants		CODE	Species name – grasses
Flowering plants	**BlP**	*Bellis perennis*	Grasses, rushes and sedges	**Ae**	*Arrhenatherum elatius*
	Cv	*Calluna vulgaris*		**Bs**	*Brachypodium sylvaticum*
	Ch	*Cerastium holosteoides*		**CxD**	*Carex demissa*
	Cha	*Chamarion angustifolium*		**CxO**	*Carex ovalis*
	Ca	*Cirsium arvense*		**CxH**	*Carex Hirta*
	CrC	*Crepis capillaris*		**CxN**	*Carex nigra*
	EpH	*Epilobium hirsutum*		**Cc**	*Cynosurus cristata*
	EpM	*Epilobium montanum*		**Dg**	*Dactylis glomerata*
	EpP	*Epilobium palustre*		**Dd**	*Danthonia decumbens*
	EpT	*Epilob tetragonum*		**Gl**	*Deschampsia cespitosa*
	EPl	*Euphorbia platyphyllos*		**Df**	*Deschampsia flexuosa*
	En	*Euphrasia nemorosa*		**Fr**	*Festuca rubra*
	Fv	*Fragaria vesca*		**Fo**	*Festuca ovina*
	Gs	*Galium saxatile*		**Hl**	*Holcus lanatus*
	Gr	*Geranium robertianum*		**Je**	*Juncus effuses*
	Gm	*G. molle*		**Lp**	*Lolium perenne*
	Gu	*Geum urbanum*		**PoA**	*Poa annua*
	Hs	*Heracleum sphondylium*		**Pt**	*Poa trivialis*
	Hr	*Hypochoeris radicata*		**Luz**	*Luzula sylvestrix*
	Ia	*Ilex aquifolium*		**Vb**	*Vulpia bromoides*
	La	*Leontodon autumnalis*	Trees and shrubs	**Acer**	*Acer campestre*
	LiC	*Linium catharticum*		**Ag**	*Alnus glutinosa*
	Lc	*Lotus corniculatus*		**AlT**	*Alnus cordata*
	Mn	*Malva neglecta*		**Bp**	*Betula pubescens*
	Ml	*Medicago lupulina*		**Cm**	*Crataegus monogyna*
	Ma	*Meliotus altissima*		**Ld**	*Larix deciduas*
	MeA	*Mentha arvensis*		**Ps**	*Pinus sylvestris*
	MyA	*Myostis arvensis*		**PSp**	*Prunus spinosa*
	Po	*Pilosella officinarum*		**Salix**	*Salix cinerea*
	Pm	*Plantago major*		**Sn**	*Sambucus nigra*
	Pl	*P. lanceolata*		**Ue**	*Ulex europaeus*
	Pr	*Potentilla reptans*	Bryophytes	**Au**	*Atrichum undulatum*
	Pv	*Prunella vulgaris*		**Br**	*Brachythecium rutabulum*
	Pa	*Pteridium aquilinum*		**Ccu**	*Calliergon cuspidatum*
	PyM	*Pyrola minor*		**Cp**	*Campylopus paradoxus*
	Rc	*Rosa canina*		**Cg**	*Cladonia glauca*
	Rf	*Rubus fruticosus*		**Dh**	*Dicranella heteromalla*
	Ra	*Rumex acetosella*		**Ds**	*Dicranium scoparium*
	Sp	*Sagina procumbens*		**Ep**	*Eurhynchium praelongum*
	Sv	*Senecio vulgaris*		**Es**	*E. striatum*
	Sa	*Sonchus arvensis*		**Esw**	*E. swartzii*
	To	*Taraxacum officinale*		**Hspl**	*Hylocomium splendens*
	Ts	*Teucrium scorodonia*		**Hc**	*Hypnum cupressiforme*
	Tp	*Thymus polytrichus*		**Hm**	*H. mammillatum*
	TriP	*Trifolium pratense*		**Lr**	*Lepidozia reptans*
	TriR	*Trifolium repens*		**Lg**	*Leucobryum Glaucum*
	Tf	*Tussilago farfara*		**Lh**	*Lophocolea heteromallea*
	Vo	*Veronica officinalis*		**Pp**	*Pseudoscleropodium purum*
	Vs	*Vicia sativa*		**Pc**	*Peltina canina*
	Vr	*Viola riviana*		**PAc**	*Pleuridium acuminatum*
	Ac	*Agrostis capillaris*		**PlS**	*Pleurozium schreberi*
	As	*Agrostis stolonifera*		**Pog**	*Pogonatum aloides*
	AirC	*Aira caryophyllea*		**Pf**	*P. formosum (woodland)*
	Ap	*Aira praecox*		**Rs**	*Rhytidiadelphus squarrosus*
	Ao	*Anthoxanthum odoratum*		**Tt**	*Thuidium tamariscium*