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The implications of climate change for the conservation of beech woodlands and associated flora in the UK

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The implications of climate change for the conservation of beech woodlands and associated flora in the UK

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Preface

Our thanks to Sonia Wesche for the effort she put into this report and for allowing English Nature to publish it as part of the English Nature Research Report series.

The aim of the report is to address implications of climate change for the specific example of beech woodland and its associated vegetation assemblages. The methodology encompasses three different elements: a questionnaire to woodland experts, research into county floras and field survey. The discussion highlights the need for a dyamic attitude and an adaptive approach to nature conservation, but underlines the importance that decisions should be based on scientific research.

The report ties in with other work that English Nature leads on such as the MONARCH report.

Emma Goldberg
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Abstract

Human-induced climate change is increasingly being recognised as a threat to natural vegetation diversity. Modelling studies indicate that the range of many species will shift significantly over time as the impacts of this enduring phenomenon are registered within the natural system. This has major implications for the future conservation of natural and semi-natural habitat types in the UK and worldwide. Therefore the ideology behind current conservation practice needs to be reassessed. Contemporary priorities, based on the protected sites approach, are insufficiently flexible to address variability within an increasingly dynamic system.

This study addresses the implications of climate change for the conservation of vegetation assemblages in the UK, via the example of beech (*Fagus sylvatica*) woodland, a habitat type of significant British and European value. Results from the MONARCH project indicate probable shifts in the range of beech over the next 50 years towards northwest England and away from the southeast where current conservation efforts are focused. Such predictions may signify the need for future beech conservation beyond its current native range. This issue was addressed through: a) an expert survey of woodland conservationists, b) a study of regional vegetation pools using county floras, and c) a field survey of vegetation in southern and northern beech woods.

Results show that expert opinion favours a more flexible approach to conservation, an idea yet to be reflected in conservation policy and practice. Ecologically, the potential exists to develop similar species assemblages in northern English beech woodlands, eliciting questions about current management strategies. Findings highlight the need to reassesses the underlying conservation philosophy upon which current policy is based.

All indications point towards the need for a more dynamic, adaptive approach to conservation. Responses should be cautious and based on good science; thus, there is a need for further research at local levels to evaluate individual species responses to changing conditions.

Contents

1. Introduction

1.1 Project rationale

Ratcliffe (1977) forms the cornerstone of much nature conservation philosophy and practice in Britain over the last 25 years. Important sites have been selected, based on his criteria, to represent the range of different semi-natural habitats and sites for rare species across their natural range in Great Britain (NCC 1989). However, reliance on a static system of protected sites is proving insufficient for the following reasons:

- the survival of many species and communities depends on what is happening in the environment around them, and
- it is increasingly apparent that climate change will affect the future range and distribution of habitats and species, thus the current patterns may be untenable.

This project explores some of the issues raised by the second of these factors (climate change) using the example of beech woodland, which has been identified as a habitat type of European significance under the Habitats Directive (HAP 2002), and as being sensitive to the effects of climate change under the Modelling the Natural Resource Responses to Climate Change (MONARCH) project (Harrison *et al* 2001).

Currently, beech (*Fagus sylvatica L.*) is very common in its native southern range, but also thrives in northwestern locations (eg Cumbria, Derbyshire) where it has been planted and may regenerate naturally. In areas of southeast England currently emphasised for beech woodland conservation, the abundance and vitality of the species is likely to decline over time; conversely, parts of northwest England currently deemed beyond the native range of beech may become important for its future conservation. This raises issues in relation to:

- underlying nature conservation philosophy with respect to species at the edge of or beyond their current native range;
- policies regarding the designation of sites for particular woodland types where climate conditions are changing;
- current and future conservation practice regarding the enhancement, maintenance or removal of beech from woods in the north-west, given its potential niche under climate change scenarios.

In order to ensure the survival of beech woodland, interested parties must consider the potential need for future conservation of beech woodlands outside of their current native range, a suggestion that directly opposes generally accepted environmental ideals. In the UK, the boundaries of beech's 'native' range are somewhat blurred. If not for forest fragmentation due to human intervention, beech would probably have spread naturally from the south to other locations in the British Isles, possibly to northern England and northern Wales where it currently thrives as a plantation species. Contemporary management strategies, however, reflect the fact that beech woodlands are only valued for conservation in the southern UK. In order to address the issue of beech woodland conservation over the long term, the influence of such attitudes on consequent actions must be addressed.

In Europe and the UK, current legislation designates conservation sites according to specific floral species compositions, raising both ecological and political issues relating to the future survival of such species under shifting climatic conditions. At present there exist no guidelines to help conservationists, resource managers and government policy-makers decide on the best course of action in such a situation. European and UK conservation policies are insufficiently flexible to deal effectively with a situation in which the community structures of vegetation types currently under conservation begin to transform naturally into other types that may, in themselves, develop into diverse and interesting ecosystems that continue to warrant status as Sites of Special Scientific Interest (SSSIs).

These concerns bring about the specific question of beech conservation in this instance, where a shift in range will definitely occur (although its magnitude is unclear). Beech is expected to have increasing difficulty surviving in areas of the southeast where some of the key protected sites occur. This issue relates directly to the problem now faced by conservation managers in the north, many of who are interested in removing beech where, through natural regeneration from plantation sources, it is invading and changing the composition of existing woodlands (eg beech invasion of oak woodlands in the Lake District and ash woodlands in the Peak District) (Kirby 2001a). This practice must be reassessed in light of the potential need for beech woodland conservation in the north to ensure the long-term survival of associated species.

The debate concerning these issues applies much more widely within the UK with respect to other species and habitats, but also in relation to climate change impacts on flora elsewhere.

1.2 Research aim

The overall research aim is to gain a better understanding of beech woodland ecology under changing climatic conditions, and to assess the need for related changes in policy to deal effectively with declining vitality of floral communities currently under conservation designation. To this end, the following questions will be addressed:

- Do beech forests in southeast England have similar community structures to planted forests in the northwest? Can similar species be conserved in northern beech woodlands as those found in the south?
- What are the probable implications of climate change on beech range in the UK and how should these considerations be incorporated into national conservation policy to ensure the continuity of beech woodland communities?

This study is focused on the potential effects of climate change. The impact of other pressures on beech woodland, such as land use, fragmentation, effects of pollution, development and urbanization, are recognised but not considered further. The study evaluates climate change impacts on floral diversity conservation only. Impacts on other types of diversity, including fungi, invertebrates and animals, are recognised but not dealt with here.

1.3 Objectives

This research aims to meet the following objectives:

- to determine whether similar typical and rare species of beech woodland vegetation exist in northern counties to those in woods currently under conservation in southern England. Thus, based on climate change predictions, the potential for developing similar beech woodland community structures in northern locations will be addressed;
- to evaluate whether current UK floral conservation policy reflects the current understanding and attitudes of experts in the field, and whether it incorporates mechanisms to deal with predicted shifts in environmental conditions that will affect community structure in areas of conservation interest (especially in the southeast). Elements and methods for improving policy development processes and site-level practices may be identified;
- to provide a basic methodological approach that may be used and extended in future research and policy development in comparable situations relating to species and habitat conservation in the face of climate change.

1.4 Methodology

In order to address the above questions, the research was carried out in three stages. A survey of experts in the field of woodland conservation was undertaken in order to provide a context for this work. As interest in this issue is relatively recent, and research on specific habitat issues with relation to climate change is limited, current conservation policy does not necessarily reflect the opinions of those who are working on the cutting edge of research in this field. Thus, such a survey helps to put the broader conservation context in perspective and to elicit the topics deemed important for the future of beech woodland conservation in particular.

The regional occurrence of beech woodland associated species was then explored using two methods: (a) a survey of existing species identified in county flora books, and (b) vegetation sampling in beech woods in both the south and the north of England. The former draws a broader picture of the geographical spread of the types of species traditionally associated with beech communities. The latter provides concrete evidence to help characterise the floral assemblages associated with beech woodland both within and beyond its native range.

1.5 Study scope and limitations

This project aims to cover a range of issues relating to UK biodiversity conservation under climate change conditions. This is a huge area with many associated variables, even when limited to the example of one habitat type. Thus, the issues herein are covered in limited depth. This is not a flaw of the project itself, but rather a reflection of the lack of previous work in the area of habitat responses to climate change.

Conservation policy plays out at many levels, from international treaty commitments all the way down to site-level management practice. This study addresses a small corner of this greater picture by focusing specifically on beech woodland habitat. It attempts to provide ecological evidence against which to question the philosophical underpinnings upon which current conservation policy and practice are based, and to provide a foundation against which future conservation research and decision-making can be evaluated.

The short timeframe of this project placed limitations on the scope of research work possible. It restricted the depth of study of opinions and attitudes towards conservation under climate change scenarios; this was limited to a handful of experts. It also restricted the possible extent of the beech woodland vegetation field survey (see Section 6.1 for further discussion on limitations).

1.6 Report structure

The body of this report is structured into five parts, each comprising a chapter. Chapter 2 provides a brief review of existing literature on the implications of climate change for nature conservation in Britain and the significance of beech woodland as an important habitat type for conservation. Chapter 3 investigates the attitudes towards beech woodland conservation by means of an 'expert' consultation. Chapter 4 explores, through the use of county floras, how the regional species pool in the north of England compares to that in the south. In Chapter 5 the results from a limited field survey of beech woods in the Chilterns and Cumbria are analysed to illustrate the types of vegetation found in beech woods within and beyond their native range. Chapter 6 provides a final discussion of the issues in the broader conservation context, a summary of main findings, recommendations for further research, and final conclusions.

2. Literature review

2.1 Introduction

This review of current literature outlines the impacts of climate change on flora in the UK and potential implications for relevant conservation policy. Section 2.2 addresses the current state of climate change research as it relates to the conservation of floral biodiversity. Section 2.3 focuses on climate change impacts on beech woodlands as an example of the wider issue. The current status of beech woodland conservation in the UK and the results of the MONARCH vegetation modelling study are explored.

2.2 Climate change and modelling

2.2.1 Climate change: background

Over recent years there has been increasing and widespread acceptance that human-influenced climatic changes are occurring, and that these shifts are causing impacts that are, for the most part, unforeseen and difficult to predict (IPCC 1995, 1997, 2001). Some degree of change is, of course, natural, thus the interest here lies less in climatic shifts *per se*, but rather in the accelerated rate and magnitude of change over recent years, and the predicted persistence of these trends for the foreseeable future.

There have been some attempts to regulate greenhouse gas emissions worldwide, but regardless, it is certain that some climatic shifts will occur, and consequently some future adaptation will be necessary (Holman *et al* 2002). Ongoing studies of the implications of climate change are based on the most current understandings of the factors involved;

however, predictions based on such a complex range of variables comprise inherent uncertainties. Modelling work over recent years has nonetheless provided some concrete projections upon which the design and implementation of necessary mechanisms to deal with such changes are based. Predictions are focused on the effects of two primary climatic variables, temperature and precipitation, the latter showing more variable fluctuations over the short term (Hulme & Barrow 1997).

A series of generally accepted models indicate the following trends for the UK environment (Broadmeadow 2002; Cook & Harrison 2001; DETR 2000; Harrison *et al* 2001; Hulme & Barrow 1997; Hulme & Jenkins 1998):

- wetter winters and likely drier summers with more intense precipitation events;
- a recent warming of 0.1 to 0.2 degrees Celsius per decade with fewer cold days and more hot days (resulting in a longer growing season);
- a predicted 21st century warming of approximately 0.1 to 0.3 degrees Celsius per decade with a more rapid warming in the southeast;
- potential changes to the current storm regime (non-robust findings);
- a rise in sea level.

2.2.2 Modelling climate change impacts on vegetation

It is generally accepted in the field of plant geography that, apart from human intervention, climate has been the primary cause of changes in the distribution and abundance of vegetation since the last ice age (Lamb 1974; Savidge 1974). In contrast to much of the thinking during the twentieth century, recent years have brought about a resurgence in the view that climate is dynamic rather than constant (Hulme & Barrow 1997).

Climate change is now widely recognised as a threat to both floral and faunal biodiversity conservation (Botkin & Nisbet 1992; Broadmeadow 2002; Cook & Harrison 2001; European Commission 2002; Harrison *et al* 2001; Hart *et al* 1992; Holman *et al* 2002; Hossell *et al* 2000; Hulme & Jenkins 1998; Hulme *et al* 2002; Jenkins *et al* 1992; Kennedy 1999; Kräuchi 1992; Peters & Darling 1985; Savill 2001; Sykes *et al* 1996; Woodland Trust 2001; Woodland Trust 2002). This phenomenon may catalyse rapid alterations in terrestrial landscapes, causing significant shifts in the vegetation state of many areas (Gardner *et al* 1996). Boreal forests are likely to experience the largest and earliest climate change-induced impacts, but other types of vegetation will also be affected (IPCC 2001).

In the British Isles, plant distributions generally show strong correlations with climatic variables (Hendry & Grime 1990). Not surprisingly, many British environmental resources are noted as being highly sensitive to climate and weather (Raper *et al* 1997), woodlands being a prime example.

Over the past five years, there has been some focus in the UK on the implications of climate change for native flora, an area that has yet to grasp media attention or, consequently, public interest. The concrete impacts are very difficult, if not impossible, to discern due to the multitude of uncertainties involved in building models of possible scenarios. Thus, the results from related studies provide an indication of general trends only, rather than a detailed description of the exact magnitude of impacts (Holman *et al* 2002, Wade *et al* 1999).

Temporal changes in vegetation due to changing environmental conditions are both common and natural; however, they are often difficult to observe and quantify (Burrows 1990), especially over the short term. The added complication of escalating rates of change due to human influence only makes forecasting more complex.

Predictive studies on climate change impacts on species and communities fit broadly into four categories: effects on physiology, effects on distributions, effects on phenology, and capacity for species adaptation (Hughes 2000). Impact scenario modelling has gained currency as a method of predicting possible outcomes for vegetation based on a series of assumptions (DoE 1995; Harrison *et al* 2001; He *et al* 1999; Hossell *et al* in press; Hulme *et al* 2002; Linder *et al* 1996; Lindner *et al* 1997; Sykes *et al* 1996), the fundamental one being that climate is a key determinate in species' distribution (Botkin & Nisbet 1992; Harrison *et al* 2001; Loehle & Leblanc 1996).

Some individual vegetation responses to predicted climate change are easily identifiable, whereas overall predictions of alterations in community structure and function are almost impossible to make. Often, interactions among the many factors cause cumulative rather than additive outcomes (eg climate change may directly affect the form and function as well as the environmental conditions surrounding a particular species) (Broadmeadow 2002; Holling *et al* 1995). Further factors are the likely synergistic effects between climate change pressures and other environmental stresses such as habitat destruction and fragmentation, and invasion by alien species (Kappelle *et al* 1999; Kirschbaum 1998) that can multiply the overall impact.

Modelling studies are becoming increasingly complex as we learn more about the impacts environmental factors have on each other. Predictions become difficult upon consideration of the primary range of factors that affect plants, including: temperature, precipitation, light, gases, soil, abiotic disturbing factors, exogenous biota, animals and fungi/monera (Burrows 1990). Each individual species has a range of tolerance to environmental factors that determines the climate space within which it can survive (Savidge 1974).

The impacts of climate change on vegetation are recognised to include a range of direct and indirect influences, which may interact with each other to produce a wide range of consequences (Kirschbaum 1998; Kramer 1995). Direct effects of climate change on organisms are thought to include: damage to trees due to temperature extremes, storm damage, changing soil and water conditions, altered seasonality impacts on woodland flora and fauna, changes in insect pest abundances, and increased greenhouse gas concentrations. Indirect impacts on disturbance regimes may have secondary effects on plant growth and function (Broadmeadow 2002).

The potential consequences of climate change for forests, in particular, have come to the forefront as a matter of increasing concern. Potential changes in forest composition, forest dieback and loss of forest cover have been predicted based on various studies using simulation models. (Cook & Harrison 2001; Lindner *et al* 1997; Loehle & Leblanc, Harrison *et al* 2001; Hossell *et al* 2000; Sykes *et al* 1996; Sykes *et al* 1992). Likely trends for vegetative distribution include extensions in range northwards for southern species and towards higher elevations for lowland species. As well, a loss of habitat for species with northern and high-altitude distributions is expected (Hendry & Grime 1990).

These trends provide only general indications of long-term spatial alterations of individual species' 'climate space'. However, many studies indicate that species within the same ecosystem respond individualistically to change (Beerling & Woodward 1994; Harrison *et al* 2001; Hossell *et al* in press; Huntley 1991; Huntley 1992; Kennedy 1999; Packham *et al* 1992; Peterken & Mountford 1996; Pigott 1974). For instance, shallow-rooted tree species such as beech may be vulnerable to an increase in extreme weather events like storms and hurricanes, and the predicted decrease in microclimatic moisture levels due to drier, warmer summers may have the most immediate effect on woodland vegetation in the southeast (Wade *et al* 1999). Particular species may also migrate at different rates, causing unique assemblages to be created (Beerling & Woodward 1994).

The initial effects of climate change may be subtle shifts in the composition of existing communities through alterations in the balance of inter-species competitive relationships (Ford 1984; Kramer 1995; Lindner *et al* 1997), rather than extensive changes in distribution (Hendry & Grime 1990). While certain types of species are likely to be favoured, others, such as those with narrow temperature tolerances, slow growth patterns and/or poor dispersal mechanisms, will be adversely affected (Kirschbaum 1998). When predicting possible changes in the distribution and abundance of species, it is important to consider that species will respond more quickly to worsening climate than to improving climate (Lamb 1974), thus the risk of habitat loss for individual species may not be counterbalanced by expanding ranges of others.

Current models give a general overview of expected changes in floral distribution over specific time periods under both low and high impact scenarios. Currently they are only able to calculate and output average changes over large regions of the country. Further work must be done to create models that allow a more detailed assessment of climate change scenarios for specific sites (Kirby 2001a). Changes in global climatic conditions will not manifest themselves uniformly over time and space; physical environmental factors affect populations at a variety of scales. In addition to the overlying general warming trend, environmental conditions will fluctuate at shorter timescales and between sites (Holling *et al* 1995). Some factors may be more dominant in certain locations, consequently causing a greater impact on local floral diversity (Pimm 1991).

Criticisms of past modelling efforts (eg Loehle (1996) and Lohele & Leblanc (1996) indicate that models predict unrealistic forest dieback) are a reminder that results should be considered and evaluated carefully, and not taken to be 100% factual. The complexity and precision of modelling continues to develop over time as further research introduces new information and understandings about the complex interactions among climatic variables and their impact on the natural world (Loehle & Leblanc 1996). In spite of this, scenario modelling provides a 'best guess' of what future vegetation distributions could be.

2.2.3 MONARCH Project: modelling impacts on UK vegetation

A broad study of climate change impacts on UK nature conservation, carried out in 2000, revealed that relatively little work had been previously published on climate change implications for species and habitats of special conservation interest in the UK. In response to an increasing need for this type of information, the UK Climate Impacts Programme (UKCIP) was initiated in 1997 to develop an integrated strategy to assess impacts and adaptations at regional levels (Hossell *et al* 2000). Two climate change modelling projects were recently undertaken with UKCIP support: the Regional Climate Impacts Assessment

Project (REGIS), which monitors impacts on rural and coastal landscapes and the interactions among them, and the Modelling Natural Resource Reponses to Climate Change (MONARCH) study, which evaluates impacts on a range of British wildlife and geomorphological features in varied environments (Cook & Harrison 2001; Harrison *et al* 2001; Holman *et al* 2002; Hossell *et al* 2000; Paterson 2000).

Modelling work within the MONARCH study derives from the 'climate space' concept, which delineates the likely availability of suitable climate to support specific species over time. Estimated temporal shifts in species range were determined using the Spatial Estimator of the Climate Impacts on the Envelope of Species (SPECIES) model, a neural network computer program (Paterson 2000). In order that the uncertainty of predicted conditions was taken into account, high, medium and low scenarios were modelled based on Hadley Centre climate data (Cook & Harrison 2001).

The MONARCH model results indicate the probable extent of a species' *fundamental* niche (or potential habitat), but do not take into account other influences that limit a species to its *realised* niche (Paterson 2000). The model results show the entire spatial extent where it is possible for a particular species to survive. Factors other than climate, such as the ability of a species to migrate and the ecological suitability of the new climate space, are vital determinates of future distributions, yet they are not included in the modelling study. Additional influential factors are inter- and intra-specific competition, natural barriers (eg topography), and anthropogenic barriers (eg habitat fragmentation) (Cook & Harrison 2001).

Uncertainties and gaps in knowledge noted in the project report indicate the need for more research in the following areas: determining the key climatic variables that influence 'climate space', assessing the potential rate of migration of species, and evaluating the types of changes wildlife communities are likely to experience (Cook & Harrison 2001). The limitations of the model must also be taken into account. The study does not include information on land cover changes, habitat availability and management practices, nor does it take account of species-specific variables (eg summer drought combined with high temperatures may increase damage to beech) (Broadmeadow 2002).

2.3 Beech woodlands in the UK

2.3.1 Native range

Over millennia, beech spread across the European continent through natural distribution to occupy its current range from central Poland, through Germany and France, northwards to southern Sweden and to what is now southern England. It is found at higher elevations as far south as the Pyrenees and in the mountains bordering the Mediterranean, and as far east as mainland Greece (Broadmeadow 2002). Beech woodland is now classified as a distinctive element of European forest types (Ellenberg 1988).

Beech arrived on the British Isles via the land bridge from the continent, about 8000 years ago, and is now one of the approximately 35 tree species considered native to Britain (White 1995). Its distribution seems initially to have been limited to the extreme south of England as it initially experienced difficulty invading closed forests. Once a foothold was established, it spread naturally during the Holocene period to occupy its current 'native' range in southern and eastern England and southern Wales (Clapham & Nicholson 1975; Rodwell & Patterson 1994).

The definition of 'native' species includes those that have established themselves through natural generation since the last glacial period (White 1995). There has been some difficulty, however, in defining the natural range of beech because human influences, beginning with clearance for agriculture during the Neolithic period, have caused large-scale alterations to the landscape from the climax forest of the postglacial era (JNCC 1993; Lamb 1974; White 1995). Thus, although there exist some indications that beech may have spread naturally to Cornwall, north Wales and north Norfolk, its accepted native range is confined to the southern half of England and southeastern Wales (Ratcliffe 1977).

The character of UK semi-natural woodland has evolved over centuries under relatively stable climatic conditions, and thus is representative of that climate. Because species compositions tend to reflect their environmental conditions, it is expected that individual distributions will shift with a changing climate. It is thus possible that current compositions of 'native' semi-natural woodland may, in the future, no longer survive in specific regions. In light of this, we must evaluate the permanency of such ecosystems in the face of climate change, and re-examine our use of the term 'native', as applied to species.

2.3.2 Beech description

Beech are large deciduous trees that reach about 30 metres in height at maturity. Native populations occur over a wide range of soils; beech is most associated with chalk and limestone, but also grows on sands and loams that provide deep rooting and enough moisture reserves. The species can also tolerate a large variation in pH, from 3.5 to 7.5, although optimal growth occurs at a pH of 5 (Grime *et al* 1988).

Beech nut distribution is limited within native populations as annual seed production is generally low (Watt 1934). Effective dispersal occurs mainly during masts, or heavy seed crops, that transpire every five to ten years. With a lifespan of approximately 300 years, beech typically fruit for the first time at 60 years, although more favourable conditions may allow earlier fruiting (the earliest example being 28 years) (Broadmeadow 2002; Grime *et al* 1988).

Beech grows well up to an accumulated temperature of approximately 3000 day-degrees (based on the climatic warmth index), but is less tolerant to elevated moisture deficit where 240mm is probably the upper limit (based on the climatic wetness or droughtiness index) (Rodwell & Dring 2001). Past studies indicate particular susceptibility to drought (Paterson 2000), where responses include damaged tree crowns, reduced radial growth, reduced shoot extension, and outright death (Peterken & Mountford 1996).

Even within the natural range of beech, associated woodlands show signs of former management acting to encourage the species' dominance (Rodwell & Patterson 1994). Planting beech for both forestry and ornament has occurred widely throughout the British Isles, where the species has often become naturalised. Extensive planting outside of its currently accepted 'native' range has positioned beech as the third most common tree of deciduous woodlands in Britain (Broadmeadow 2002). The Forestry Commission's National Inventory of Woodlands and Trees indicates that beech constitutes about 6.5% of British forest cover, approximately 71 000 hectares, in a non-uniform distribution (Forestry Commission 2001; see Appendix A for a breakdown by county). Cultivation and management are now declining, however, as demand for furniture and other beech products decreases (Ingram 2001).

2.3.3 The basis for beech woodland conservation

Conservation policy in Europe and Britain

Historically, prior to the existence of human influence, the extent and pattern of vegetative distributions was entirely determined by non-human environmental factors. In recent times, in Britain and across the European continent, the impacts of increasing human populations have caused profound changes to the functioning of natural systems. Thus, the structure and function of current ecosystems have been determined by a combination of historical and current interactions among biotic, abiotic and human factors (Paterson 2000; Peterken 1996).

Human activities have acted in many cases to diminish and degrade truly natural habitats, placing ever-increasing pressures on ecosystem biodiversity (DoE 1995; Kennedy 1999). Under the Convention on Biological Diversity 2002, Article 2, the term 'biodiversity' is defined as:

> The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

As signatories to the convention, European member states have specific conservation commitments, many of which are addressed in the Habitats and Species Directive, adopted by the European Union in 1992 (European Commission 1992). The Habitats Directive, in conjunction with the Birds Directive, adopted in 1979, provide the framework for a Europe-wide network of conservation sites, called Natura 2000. The latter requires the establishment of Special Protection Areas (SPAs) for birds, while the former requires that Special Areas of Conservation (SACs) be designated for other species and for habitats (English Nature 1998). The UK, through the Wildlife and Countryside Act of 1981, has developed a method for determining and notifying Sites of Special Scientific Interest (SSSIs), many of which, if deemed important in the European context, will then be proposed as SACs (DoE 1995).

Several authors have noted the need for increased flexibility in national and European conservation strategies, including the UK Biodiversity Action Plans (BAPs). In a world of continual change, increasing emphasis must be placed on habitat re-creation and the establishment of new space for species experiencing shifts in range. This will necessarily imply a re-assessment of current conservation targets, and of how objectives and targets are met (Broadmeadow 2002; Cook & Harrison 2001; Kennedy 1999).

Conservation of beech

In Britain, beech woodland has been deemed an important semi-natural woodland type; it was designated a key national habitat type in Ratcliffe's (1977) *A nature conservation review* and under the guidelines for identifying SSSIs (NCC 1989). The importance of beech woodland as a vegetation type of European significance was formally recognised under the Habitats Directive (European Commission 1992). Within this directive, several beech woodland types were identified as requiring protection at a European scale, two of which are commonly found in the UK. This designation raised the status of beech on the national conservation agenda, and, as a consequence, two woodland types – 'Old beech woods with yew and holly rich in epiphytes' on acidic soils and *Asperulo-Fagetum* on base-rich and mesotrophic soils – were put forward as SACs (Kirby 2001a, p.8). The significance of beech woodland has been further expressed through the designation of protected sites and general conservation policies under the UK BAP.

English Nature (the UK government's consultative body on conservation in England), under the Habitats Directive and domestic legislation, aims to maintain or restore to 'favourable condition' the elements for which conservation sites (SSSIs and SACs) have been designated as important. The term 'favourable condition' is recent and its slightly vague definition is still evolving; however, for beech woodland it would include the following components (Kirby 2001a; Kirby & Solly 2000):

- maintenance of existing woodland, especially if ancient;
- maintenance of a significant proportion of beech in each woodland, although not necessarily beech dominance;
- maintenance of a diversity of structural types both within and throughout the range of beech woodlands, focusing on ensuring a continuity of conditions on the broad scale;
- adequate regeneration, focusing on enhancing possibilities for natural regeneration;
- assessing special individual characteristics of each woodland, eg floral richness, rare species, and dead wood abundance.

Due to anthropogenic fragmentation of the existing landscape, natural woodland cover in the UK is all but nonexistent, thus ancient woodlands are often referred to as 'semi-natural' (JNCC 1993). Historically, beech has long been favoured by human activity through the clearance of competing oaks, and through active planting and management for the furniture industry. As the industry declines, however, many woods are losing beech as a dominant canopy tree, and numerous woods continue to be partially or completely re-planted or inter-planted with more marketable conifers (Killick *et al* 1998). A loss of semi-natural vegetation types and associated species causes irreversible damage to cultural heritage and deteriorates environmental quality (Pigott 1984). In light of these trends, one of the national conservation policy aims is to maintain the existing range of semi-natural woodland in the UK irrespective of the diversity associated with each type.

Woods are seen to be an essential component of England's landscape and culture. It is recognised that trees, woods and forests are important British assets whose attributes are often difficult to value in economic terms (Forestry Commission 1999). The Forestry Commission now supports a relatively new, multi-purpose policy, as noted in recent England Forestry Strategy publications. The Countryside Agency (formerly Countryside Commission) also backs this position. The government is committed to a forestry policy with two main aims: 1) sustainable management of existing woods and forests, and 2) steady, continued expansion of woodland area to increase social and environmental benefits. One of the four key programs in the government's forest strategy focus directly on forestry as it relates to environmental and conservation objectives. The strategy recognises the importance of woodlands in the maintenance of a healthy environment, upholding cultural heritage values, and also in achieving government conservation, biodiversity and climate change objectives (Forestry Commission 1999; Countryside Commission 1993).

Perspectives on beech woodland conservation, however, show stark differences between the regions to be considered in this project. In the Chiltern Hills, designated an Area of Outstanding Natural Beauty (AONB), the management plan places particular emphasis on the conservation of beech and yew woodland habitat (Chilterns Conservation Board 2001). In Devon, where beech is considered to be at the edge of its native range, the Dendles Wood National Nature Reserve (NNR) management plan advocates beech protection, following Peterken's (1987) analysis that beech 'should be treated as native' on this site (Lamboll & Page 1997).

In northern England and in Cornwall, outside the accepted natural range of beech, the prevalent attitude, expressed through management plans for this woodland type, is altogether different. In Cornwall, beech in Golitha NNR and SSSI is classed as invasive and is set for eradication (Davies 1995). In Cumbrian sites, Forest Enterprise practices the removal of non-native tree species, including beech, from woodlands through a long-term programme of felling and thinning (Clavey 2002; Colledge 1998; Murphy 1997). Also, the uprooting of beech seedlings has commonly been practiced in the Derbyshire Dales NNR (Le Bas pers. comm.).

The above examples indicate the extent to which conservation is based on the underlying philosophy regarding native range. Although beech is native to the UK, where resources are invested for its protection in some areas, it is treated as a weed in others. Changing conditions only complicate the issue. In light of this, Broadmeadow (2002) submits two fundamental suggestions regarding the future of UK woodland conservation in the face of uncertainty of potential climate change impacts:

- The common designated sites approach must be counterbalanced by further strengthening countryside-wide strategies that allow species and ecosystems to adjust to change both in geography and composition. The habitat network concept should be applied at a variety of levels.
- There exists a need for re-examining the considerations upon which UK conservation policy is based. The amount of time, effort and financial commitment to maintain species at the edge of their range must be reconsidered in light of the predicted shifts in vegetation distributions due to underlying trends or the impact of extreme events.

2.3.4 Beech woodland classification

There are different levels of abstraction upon which floral classifications can be made, most of which are determined by underlying environmental trends. Traditional procedures used in the classification of vegetation have focused on the identification of uniform areas in order to simplify the process. These are often done at the level of vegetation types, eg Peterken's stand types (1993) and the phytosociological series described by Klötzli (1970). Woodlands are, however, complexes of vegetation types that vary within the larger contiguous area. More recent work by Bunce (1989) uses the heterogeneity within the larger woodland site as a basis for their classification.

To achieve the goal of biodiversity protection across a range of habitat types, however, the assessment of sites of conservation interest must be based on an accepted, systemised classification of variations in vegetation structure. The National Vegetation Classification

(NVC) provides this reference in the UK (Cooke & Kirby 1994; Pigott 1984). It is a broad-based phytosociological classification of floral communities according to community structure, providing comprehensive coverage of vegetative assemblages in Great Britain (excluding Northern Ireland) from all natural, semi-natural and major artificial habitats (Rodwell 1991). This system facilitates the comparison of British habitat types to those on Continental Europe, a necessary mechanism for the consideration of conservation priorities at European and international levels (Cooke & Kirby 1994; Rodwell in press; Rodwell & Dring 2001).

The NVC community designations are based on a large number of samples from across the country. Each one is characterised by the constancy of occurrence of a species within it and the range of cover-abundance (using the Domin scale; see Section 5.2.2) of that species (Malloch 1990). British beech woodlands are, under the NVC, divided into three types, based on soils and species composition (Rodwell 1991):

1) *Fagus sylvatica-Mercurialis perennis* woodland (NVC W12) occurs on base-rich soils and represents about 40% of beech habitat.
2) *Fagus sylvatica-Rubus fruticosus* woodland (NVC W14) is found on brown earths of low base status, often with slightly impeded drainage. It represents about 45% of beech habitat.
3) *Fagus sylvatica-Deschampsia flexuosa* woodland (NVC W15) occurs on infertile soils usually with a pH below four, and makes up about 15% of beech habitat.

The distribution of each woodland type largely depends on edaphic factors, although climate may play a part in the absence of natural W15 stands in drier East Anglia and in the cooler, wetter north and west (Rodwell 1991). Although the range of beech extends across much of the European continent, outside of the UK, similar vegetation types to those described above are found only in northern France (Rodwell in press; Rodwell & Dring 2001).

Beech woodlands are known to exhibit low ground flora species-richness and cover compared to many other woodland types, such as oak, pine plantations and conifer-broadleaf mixtures (Kirby 1988b). However, they do support a high diversity of fungi and deadwood invertebrates, many of which may be physiologically tied to beech trees themselves (Kirby 2001a). Public interest in beech woodlands is also considerable. Beech woods are valued for their recreational, amenity and conservation significance and as defining landscape features in some areas (Render 2002a; Render 2002b). They are also prized as living monuments to English heritage (Rodrick 2001).

The present study focuses on vegetative communities that provide the conditions for such benefits to be maintained. Such communities exhibit a number of recognisable, variable properties (Table 1).

Table 1: The easily recognisable, variable properties of vegetation (after Burrows 1990).

Property	Explanation
Species composition	Ranges from simple to complex, depending on habitat conditions and relative richness of the local flora.
Structure	Structural patterns arise from different stature and growth forms of the constituent plant species and their spatial disposition relative to one another. Structure can be simple or complex.
Physiognomy	The general appearance of vegetation results from the relative abundance of species possessing distinctive stature, form, colour and texture of shoot systems and foliage.
Spatial patterns	The species composition of vegetation varies in space because the component species respond differently to sets of habitat conditions, which are themselves spatially variable.
Temporal patterns	The species composition of vegetation varies with time due to the influence of environmental factors.

The focus here will be mostly on the observed and predicted spatial and temporal variation experienced by compositions of species associated with beech woodland habitats.

2.3.5 Climate change impacts on floral biodiversity

Climate change is increasingly being recognised as a threat to both floral and faunal biodiversity conservation (European Commission 2002), spurring research in this field. Historically, natural climate changes have occurred over long periods of time, but accelerated change due to human influence has left scientists worried that terrestrial species may not be able to keep apace of shifting conditions (Bazzaz 1996; Ennis & Marcus 1996).

June 2000 saw the completion of the first systematic assessment of climate change impacts on key habitats and species of important conservation value in the UK. This study identified the key drivers relevant to each BAP species and Priority Habitat, although it should be noted that the vulnerability of each species or habitat depends on spatial and temporal exposure to these drivers. The study also indicated mitigating options to reduce impact significance, and available policy options (Hossell *et al* 2000).

Preliminary indications from various studies show that beech woodlands are sensitive to climate change, in large part due to predicted increases in drought, a major factor that drives vegetation change (Lindner *et al* 1997; Paterson 2000). The balance of precipitation and evapotranspiration is the primary environmental factor that will determine the prospects for ancient woodland survival in England and Wales (Beerling & Woodward 1994). Table 2 indicates the major drivers and impacts relevant to UK beech woodlands.

Through studies on the future of specific UK habitat types, researchers predict a significant decrease in the vitality of lowland beech woodland habitat in areas of current conservation due to climate change impacts (Broadmeadow 2002; Harrison *et al* 2001; Hossell *et al* 2000; Kirby 2001a; Savill 2001; Sykes *et al* 1996). Hossell *et al* (2000) and Broadmeadow (2002) indicate various direct impacts, including dieback due to soil moisture stress, increased net nitrogen mineralisation and invasion of more drought tolerant species, changes in timing of bud burst, increased wet acid deposition with increased winter rainfall, and enhanced plant vigour but with a possible decline in beech due to higher levels of carbon dioxide. These factors cause changes in community composition, habitat structure, species distributions, and species productivity levels, potentially reducing the viability of maintaining species targeted for conservation over the long term.

Table 2: Impacts of climate change for lowland beech and yew woodland habitat (UK BAP Priority Habitat) and associated species (adapted from Hossell *et al* 2000)

Driver (Spatial extent)	Impact	Significance	Effect	Evidence
Changes in soil moisture content (National)	Die-back due to soil moisture stress. Increase in net N mineralisation	Change in community composition. Change in habitat structure	Negative	Modelling work
Reduced summer precipitation (South, especially in SE)	Die-back of beech	Change in community composition. Change in habitat structure	Negative	Experimental evidence. Recent trends
Increased periods of drought (National)	Die-back due to moisture stress (esp. bryophytes). Invasion of more drought tolerant species	Change in community composition. Change in habitat structure	Negative	Modelling work
Elevated winter temps. (National). Earlier start to spring season (National)	Changes in timing of bud burst	Change in species competitive ability. Change in community composition	Unknown	Recent trends
Increased atmospheric CO_2 (National)	Enhanced vigor in plants but some evidence of decline in beech with higher CO_2 levels	Change in species competitive ability. Change in community composition	Unknown	Experimental evidence. Theory
Increased acid precipitation (especially in N)	Increased wet acid deposition with increased winter rainfall	Loss of species productivity	Negative	Theory
Increased number of storms (National). Increased severity of storm events (S&E)	Tree felling/destruction of biomass	Change in community composition. Change in habitat structure	Negative	Theory

Bazzaz (1996) notes that plants have three options when faced with climate change conditions: 1) migration, 2) extinction, or 3) *in situ* adaptation to the new environment. Due to the large size and long life span of trees, forest ecosystems will be slow to react to changing climatic conditions, both in taking advantage of environmental amelioration and in registering climatic deterioration (Ford 1984; Woodward 1987). Whether for conservation or forestry interests, woodland management is a long-term undertaking, where the effects of decision-making only become apparent many years later (Broadmeadow 2002). This ecological constraint, coupled with the doubt that human activities will significantly and positively improve the effects of climate change on woodlands, demonstrates the importance of being able to predict long-term forest response patterns (Loehle & Leblanc 1996).

2.3.6 Beech and climate change: MONARCH models

Paterson (2000) modelled the potential changes in beech distribution based on Hadley Centre climate data (high and low scenarios for 2020 and 2050) using an artificial neural network. His model, focused on W12, *Fagus sylvatica – Mercurialis perennis* woodland, indicated a probable shift away from beech-dominated communities in the driest sites in southeastern England. Low 2020 scenarios showed little change in beech range, with a slight move away from parts of Kent that would become too dry. The High 2020 and High 2050 scenarios are similar, showing movement away from southeast Kent, and movement into more of Suffolk and Cambridgeshire. The High 2050 scenario indicates that almost the entire county of Kent and parts of Sussex will become inhospitable to beech (Figure 1). Decreased moisture availability is predicted to shift species composition towards a dynamic mixture of more drought-tolerant species such as the oaks (especially *Quercus robur* L.), whitebeam (*Sorbus aria* (L.) Crantz.), and yew (*Taxus baccata* L.). Modelling of beech communities by Harrison *et al* (2001) support these findings.

Predictions for two species associated with beech, *Anemone nemorosa* (wood anemone) and *Sanicula europea* (sanicle), indicated that neither would suffer losses of suitable climate space under any of the scenarios modelled, as long as some form of woodland cover is maintained. Thus, it is possible that some species distributions may not be directly affected even though the surrounding community structure may change as other species are lost (eg beech). However, there remains the potential for indirect or synergistic effects to occur, as these are not included in the model (Broadmeadow 2002).

The overall trend indicated through MONARCH modelling work is that: a) the increasingly warmer and drier southeastern climate is likely to become *unsuitable* for beech due to high moisture deficiency, b) northeast Scotland will become *very suitable* for beech where it is currently *marginally suitable*, and c) northern England and the west midlands will become *suitable* where they are currently *very suitable* (Broadmeadow 2002). (Previous modelling work by Sykes *et al* (1996) indicated an even more extreme shift, suggesting that beech may decline over a greater area of southeast England.)

This predicted ecological shift would likely have major implications for areas of current conservation focus for beech. Of the total beech area within English SSSIs, 75% is found in the southeast, whereas less than two percent is currently under protection in northern England (English Nature 2002c; Appendix A). As well, England's network of SACs is focused entirely in the southeast, apart from one site in Gloucestershire (southwest) and one in Essex (east) (English Nature 2002b).

The speed and magnitude of changes in vegetation are unknown, and it is unclear as yet whether the overall influence on the planet's habitats and ecosystems, and beech woodlands in particular, will be beneficial or detrimental. It is quite certain, however, that future systems will be dynamic rather than static, where change is continuous.

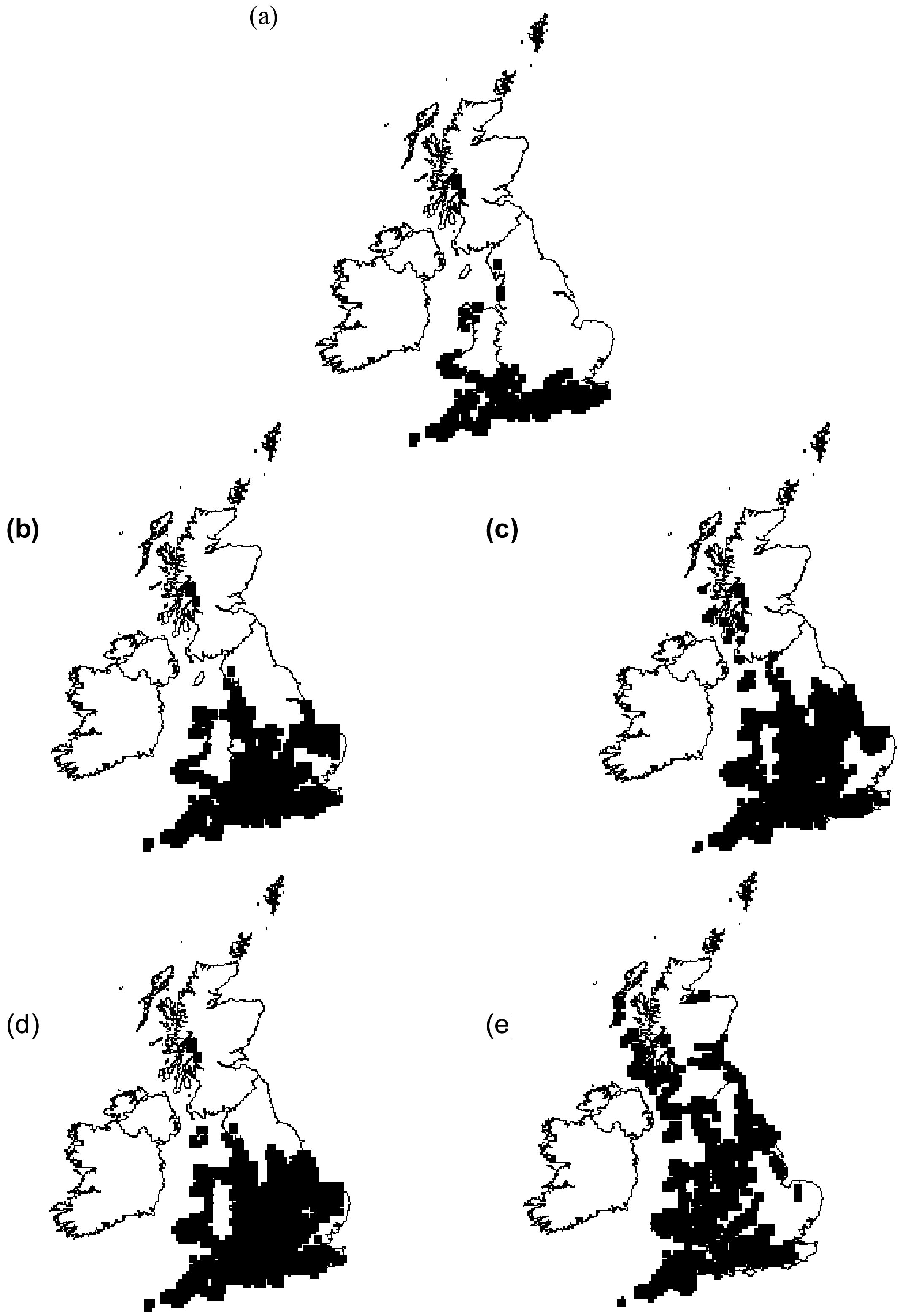


Figure 1: SPECIES model results for *Fagus sylvatica* (beech): (a) simulated current distribution (1961-90); (b) 2020s Low scenario; (c) 2020s High scenario; (d) 2050s Low scenario; and (e) 2050s High scenario (after Harrison *et al* 2001).

2.4 Concluding remarks

The necessity of integrating climate change into conservation policy is becoming increasingly apparent, but in practice, the actual application of this idea is complicated and raises many questions. In order to plan for uncertainty, flexibility and adaptability at all levels is key. Continued research is required to further understand and respond effectively to the physiological and sociological barriers to change.

The MONARCH study indicates the possibility of losing specific species, such as beech, in certain areas; however, it also raises the possibility for conserving them in other locations. Projections of shifts in the climate space of individual species, however, are based on broad-scale patterns and cannot predict what changes will occur at local levels. There has been little research done to investigate possibilities for specific habitat types of conservation interest in the UK to be recreated in areas beyond their current range but within their projected future climate space. It is this idea that prompted the current study.

3. Expert survey

3.1 Introduction

Conservation management prescriptions for British ancient woodland have emphasised particularly the maintenance of what Peterken (1993, 1996) calls the past natural composition of these sites. Thus invasive, non-native species such as sycamore have been removed where possible. This approach has also been applied to beech in areas beyond what is deemed to be its native range (see Section 2.3.1 for a discussion of range). The management plans for Whitbarrow and Dalton Park in Cumbria (Clavey 2002; Colledge 1998; Murphy 1997) and management practice in Derbyshire (Le Bas pers. comm.) make this clear, but there may be uncertainties where apparently native stands occur beyond their 'normal' range (eg Dendles Wood) (Lamboll & Page 1997). Moreover, if species ranges are changing, and particularly if parts of the past or current native range of certain species or floral communities will become unsuitable, this approach must be reconsidered.

Our understanding of the impacts of climate change on nature conservation policy is still at a very early stage. As with any new idea, it is likely to be developed first amongst 'experts' in the field and then only gradually disseminated and adopted by those concerned with site management at a practical level. Therefore, a short questionnaire was circulated to 25 professionals in the field, including conservation and forestry specialists in governmental and non-governmental organizations, to explore whether there exists a developing consensus about the impact of climate change on woodland vegetation and its conservation.

3.2 Methodology

Individuals involved specifically in conservation and/or woodland issues were targeted to complete a questionnaire (see Appendix B, sample questionnaire) on the implications of climate change for vegetation, especially beech and associated species, in the UK. A total of twenty people responded to the questionnaire, across a range of organizations, including English Nature, the Forestry Commission, county Wildlife Trusts, the National Trust, the Woodland Trust, and academia (see Appendix C for names of consultees and affiliated organizations). The idea behind this exercise was to gather a better understanding of the issues from experts who have knowledge about the subject area and about possible consequences to present and future management decisions. This method provided an effective way of gathering qualitative evidence within the limitations of the project timescale.

The individuals targeted for the survey were encouraged to share their personal opinions based on their own expertise; thus, institutional policy is not necessarily reflected in their responses. However, their knowledge of the issues ensures that responses are based on current best available scientific evidence and its applicability to existing management challenges.

The issues discussed in this chapter stem mainly from the consultee questionnaires, but are not referenced to any one person to maintain confidentiality.

3.3 Results and analysis

3.3.1 Climate change and natural systems

Results indicated general agreement among those consulted that human-induced climate change is indeed occurring, and that it will impact on the natural environment both in the UK and globally (Table 3: Questions 1-4). This would probably not have been the case ten to fifteen years ago when the basis for much of current conservation policy was being developed. Most consultees identified a link between climate change and conservation management (Questions 5 and 6), and indicated that the issue should be considered in the development of future conservation policy and strategies in the UK and throughout the rest of Europe (Questions 7 and 8).

Table 3: Overall attitudes to climate change. Results from the climate change consultation showing the number of responses (of 20 total) by question, where 1=strongly agree, 2=agree, 3=neither agree nor disagree, 4=disagree, 5=strongly disagree, and N/A=not applicable/no response. The highest score for each question is **bolded**.

#	Statement	1	2	3	4	5	N/A
1	Human-influenced climate change is occurring at a global level	**10**	**10**				
2	Human-influenced climate change is affecting the climate of the UK	9	**11**				
3	Climate change will have an impact on the natural environment at a global level	**11**	8	1			
4	Climate change will have an impact on the natural environment in the UK	**11**	9				
5	There exists a strong link between climate change and conservation management	4	**10**	4	2		
6	Conservation efforts will suffer from the impacts of climate change	4	**8**	5			3
7	Climate change should be a consideration in the development of conservation policy and strategies in Europe	**16**	3	1			
8	Climate change should be a consideration in the development of conservation policy and strategies in the UK	**14**	6				

There exists a general acceptance, both in the literature (DoE 1995; Gardner *et al* 1996; Harrison *et al* 2001; He *et al* 1999; Hossell *et al* in press; Hulme *et al* 2002; Linder *et al* 1996; Lindner *et al* 1997; Sykes *et al* 1996) and within expert opinion, that climate change will cause the ranges of species to shift. Climatic conditions have changed over centuries, but current trends could lead to catastrophic changes to environmental functioning with few precedents. The magnitude of anticipated change in floral community structure will depend to a large degree on the nature of environmental changes, their degree, and the speed at which they take place.

There remains a lack of scientific understanding of the multitude of factors that may have both direct and indirect impacts on species, and of the interrelationship among these factors, but it is expected that some species will experience a reduction in suitable habitat due to climatic changes, whereas others will expand their ranges. Species adaptations and/or extinctions, coupled with losses and gains in the short term, at local and regional scales, will determine both 'winners' and 'losers' depending on differing individual responses to climate variables (direct) and to alterations in species interactions with their biotic and abiotic environments (indirect). At a wider ecosystem level, changes to the length of growing seasons, the reduction or elimination of the dormant season, or differential effects on pests and diseases may all modify the nature of natural ecosystems. Over the long term, such variations could cause shifts in genetic variability in and between populations.

With regards to beech, summer drought may limit survival in the southeast and may prompt a shift in tree species dominance in these woodlands. However, current beech wood compositions are far from natural. The actual consequences for vegetation will depend on local circumstances; ie soil type, site aspect, habitat connectivity, continuity of management, and other variables will all influence individual species' capacity to respond to change.

Given the natural range of beech across Europe, one consultee noted that the 'climate space' of ground vegetation associated with beech woods is expected to change more dramatically than that of beech itself. Ground flora species with shorter life spans will likely respond more immediately to shifting conditions. However, many of the rarer plants and insects associated with beech appear to be thermophilic, thus they may benefit from warmer springs and summers. Such conditions are common in northern France, where beech woods display substantially higher plant species diversity. Lichens, associated with ancient beech boles and continuity of humidity, may benefit or decline, depending on fluctuations in the distribution of annual rainfall. We must expect the natural appearance of new assemblages and of altered interactions within a changing environment, where the balance between species of varying strategy types may shift (see Section 5.2.4 for an explanation of strategy types). Invasive species may also become more of a problem as new climate space becomes suitable to them.

3.3.2 Beech woodland conservation policy

With regards to general attitudes towards the issue of beech woodland conservation, a slightly broader spread of opinions exists (Table 4). Half the consultees agree that conservation efforts in the southeast are still justified (Question 9); however, responses indicate strong support for taking a more positive approach towards beech in the north (Questions 10 and 12), compared to the line in many existing management plans. The resounding message in these answers is that the issue of shifting species range must be taken into account.

Table 4: Attitude to the specific habitat issue. Results from the beech woodland habitat consultation showing the number of responses (of 20 total) by question, where 1=strongly agree, 2=agree, 3=neither agree nor disagree, 4=disagree, 5=strongly disagree, and N/A=not applicable/no response. The highest score for each question is **bolded**.

#	Statement	1	2	3	4	5	N/A
9	We should strive to maintain beech woodlands in areas of current conservation focus in southeast England (Kent, Chilterns)	**6**	4	4	4	2	
10	The existence of beech in the north of England is undesirable because it is considered to be non-native to that area			3	**10**	7	
11	The current conception of the beech's native range will hinder efforts to conserve this habitat type in future	3	**12**	4	1		
12	Beech woodland should be actively encouraged as a future natural woodland type in Cumbria and the Peak District	1	**8**	**8**	2		1

Consultees reiterate that species dispersal to new 'climate space' and the loss of some species' current 'climate space' will impact on existing conservation policy, objectives, targets, and management practices which are largely focused on maintaining the *status quo*. Conservation organizations may be slow to react to shifts dictated by ecological parameters, and may continue to focus on those species and habitats in locations where they may become impossible to conserve. Consultees suggest a reappraisal of current management plans so that time, energy and valuable conservation finances are not wasted on counteracting species shift and dieback. Management strategies that focus on maintaining biodiversity through the designation of habitat-specific conservation areas may increasingly become unsuitable as the rate of climate change increases. An interesting caveat is that some of those developing models would stress that they are not yet sufficiently robust to dictate action (Hossell *et al* in press).

The current notion of 'native species' and 'native range' as a static concept will lose its relevance under increasing climate change conditions. The understanding of the concept is likely to require redefinition to allow a more dynamic and flexible application in the area of conservation policy. The majority of consultees echo the need for increased flexibility in national and European conservation policy.

3.3.3 The development of more flexible programmes?

The first step in addressing the impacts of climate change on conservation efforts is through the collection of information, for example, the MONARCH project (Cook & Harrison 2001; Harrison *et al* 2001). A subsequent, essential step is the dissemination of results, outlined in lay terms, through established network linkages. This should ensure that relevant information is understood and incorporated into decision-making procedures, and backed by an environmentally aware public.

Expert opinion calls for the development of common agendas within the conservation community, based on a new, more dynamic approach. This will encourage political and public acknowledgement that climate change is indeed a key driver in all aspects of nature conservation policy and practice. Focus should be directed towards the development of large area conservation programmes, where diversity provides system robustness (taking uncertainty into account by increasing ecosystem resilience) and allows ecosystem dynamics to function naturally, limiting major losses. Thus, a shift away from habitat restoration towards the facilitation of new habitat development is recommended.

Several consultees suggested the following 'no regrets' measures that would likely enhance conservation efforts:

- nature conservation should be seamlessly integrated with all components of the countryside, especially with agricultural enterprises, to maximise gains and minimise losses;
- designations of conservation areas should be relaxed to allow for change within the habitat or ecosystem over time;
- the value of 'wild places', allowed to develop naturally with minimum management, should be recognised; such areas provide controls against which to test the effectiveness of management decisions and activities ;
- concurrent attempts to reduce pressures external to conservation (eg minimising activities that amplify climate change) may help achieve positive results through the wise use of limited conservation resources.

These useful principles will, however, be difficult to achieve unless adopted across a wide range of statutory and non-statutory bodies.

3.3.4 Floral conservation policy and management

Question 13 (Table 5), an ecological query regarding the possibility of beech wood floral reassembly in the north, elicited the highest uncertainty score, suggesting that there is little known about this area of study. Amongst the consultees, action to ensure the continuity of current vegetation assemblages in the UK is generally supported; but at the same time, an overwhelming majority supports the valuation of newly developing floral assemblages in conservation terms (Questions 14-17). This provides backing for recent movement towards the development of a new protocol to evaluate alterations in NVC-designated habitat types (Strachan & Jackson in press).

Table 5: Attitudes towards the conservation of vegetation communities. Results from the consultation on floral conservation showing the number of responses (of 20 total) by question, where 1=strongly agree, 2=agree, 3=neither agree nor disagree, 4=disagree, 5=strongly disagree, and N/A=not applicable/no response. The highest score for each question is **bolded**.

#	Statement	1	2	3	4	5	N/A
13	There is potential in Cumbria to create similar assemblages of beech woodland floral communities to those which currently in the south (Kent/Chilterns)		6	**8**	3	2	1
14	Steps should be taken to ensure the continuity of current vegetation assemblages in the UK	2	**10**	3	3	2	
15	The translocation of species (particularly slow-colonising woodland specialists and rare species) should be considered as a potential strategy for ensuring floral community re-assembly		**10**	5	5		
16	New floral assemblages developing under beech woodlands should be valued in conservation terms	8	**11**	1			
17	The UK National Vegetation Classification should be re-written as vegetation assemblages change over time	3	**13**	3	1		

Several consultees noted the practicality of boosting conservation efforts and promoting beech community reassembly at local levels by supporting natural systems through the development and maintenance of existing habitat networks where ‘green’ corridors facilitate species movement and colonization. On a wider landscape scale, however, evidence that vegetatively reproducing plant species would benefit from habitat corridors remains inconclusive (Hill *et al* 1993). One consultee mentioned the use of *ex-situ* conservation of rare species if necessary. A number of consultees also supported the idea of key species translocation on a limited scale to ensure the survival of threatened flora that may not be able to adapt to changing conditions in their current habitats, an activity supported by the Woodland Trust (2002).

The aforementioned strategies were supported to varying degrees by the consultees. Several individuals noted that limited resources might be better spent in other areas, cautioning against potential ‘over-management’ through extreme interventionist measures. Most were willing to support minor interventions and continued research, with the objective of maintaining general habitat conditions as far as is possible. A small minority of consultees were sceptical that climate change would have such significant impacts on beech woodlands, and several pointed out that the damage caused by grey squirrels was of more immediate concern. All indications point to the necessity for further research before major steps are taken.

3.3.5 UK beech woodland conservation: the future

There exists a general consensus among consultees that beech communities should be allowed to develop and naturalise in the northwest. It is not essential to recreate existing NVC communities in new areas of conservation interest, and reassembly should be allowed to occur naturally without excessive human intervention. The conservation of rare species should, however, be taken into account and efforts be made to maintain populations into the future.

There exists, within the responses, a general call for more process-oriented and experimental studies before major changes in strategy are made. MONARCH modelling is based on large-scale distribution patterns and does not shed light on more localised processes such as the effects of different soil types on climate responses. Meanwhile, however, initial steps should be taken in the development of more flexible and open approaches to management.

Community change is a long-term prospect, and this should be reflected by conservation responses. Attitudes towards applicable strategies were divided between the acceptance of a degree of proactive human intervention to guide the physical development of new habitats and the more *laissez faire* approach of monitoring, modelling and safeguarding systems that are favoured to survive. Nonetheless, a majority of consultees indicated that the following endeavours be undertaken:

- sites in the southeast likely to remain suitable for beech should be identified as areas where particular emphasis should be placed on managing and extending existing beech wood communities;
- feasibility studies and environmental impact assessments should be undertaken to assess the potential for maintaining and expanding beech communities for conservation in the northwest.

3.4 Discussion

The consultation results suggest a definite split between expert opinions in research and those reflected by current national conservation policy. Why should this be? Conservation policy should ideally follow scientific evidence, but first there must be consensus about the findings. Agreement that human activities are enhancing natural climatic shifts is relatively new (IPCC 1995, 1997, 2001), and the study of climate change impacts on vegetation in the UK is also in its early developmental stages - the first MONARCH report (Harrison *et al* 2001) was only recently published. Thus, it would follow that this topical shift in expert knowledge and understanding about the underlying issues is only beginning to filter into conservation decision-making processes, as it takes time to modify underlying philosophies.

It is important to establish links between sectors so that information is effectively passed from researchers to decision-makers. The significance of results must be translated into general terms to increase inter-disciplinary communication and understanding. As well, policy is often influenced by the attitudes of the general public and by the wishes of economically endowed corporations. Thus, links must be made between the activities of these interests and the conservation sector, to set a base upon which proactive strategies may be founded. A longer-term, detailed study of perceptions and attitudes of policy-makers and the general public towards the issue of floral conservation under climate change should be considered.

One recurring theme within the questionnaire responses is the concept of change being both natural and unpredictable. These qualities reflect the inherent challenges in the practice of conservation management. The idea of change limits the application of defined and commonly accepted boundaries between what is natural and what is unnatural. This philosophical issue guides current understanding of the term 'native range' and prompts continual discussion on the types of actions to be taken to reduce climate change, considering that it is a product of combined natural and human-influenced phenomena. The unpredictability of change, on the other hand, manifests itself in the form of scientific uncertainty, which, in turn, may hinder agreement on the implementation of new policy measures, particularly if unpopular or expensive. This lack of certainty is common in areas of conservation decision-making, where actions and policies must be taken based on best available knowledge, even though the supporting evidence is imperfect.

Thus, conservation managers and decision-makers should act steadily, focusing on conserving what exists at present while remaining open to new possibilities. There currently exists, in conservation, a need for increased emphasis on both species and community mobility and greater attention to sedentary communities like ancient woodland. Some acceptance of beech moving into other woodland types is desirable and should not be seen as a threat to other broadleaved woodland types in northern Britain. Future-oriented conservation strategies should reflect potential climate space and water availability over time, and the ability of species to disperse into and colonise that space (bearing in mind ecological, geological and land use constraints). This entails further assessment on potential species availability for colonization in different regions.

The essence of the general attitudes and ideas towards conservation under climate change scenarios as expressed by the consultees, and backed by ecological evidence, is denoted by this questionnaire response:

> We must plan for bigger more connected places where natural processes are allowed room to unfold, and escape the fractured, piecemeal, pocket-handkerchief [approach to] habitats. We also have to be ready to accept a far wider range of structures and compositions.

The historical ecology approach (eg the ancient woodland concept) has been extremely important in the success of woodland conservation in the UK over the past decades. In the eyes of the public, it has given 'conservation' a meaning far beyond simple species lists, garnering more widespread support than could otherwise have been achieved. As evidence and understandings about floral responses to climate change increase, we must build on this approach by taking on more flexible attitudes towards the valuation of natural systems.

As policymakers gain a better understanding of the issues surrounding climate change and conservation, and if they remain open to change, a more flexible, future-oriented planning strategy should emerge in the UK. The upshot would include a more responsive and empirical approach to conservation combined with the incorporation of conservation values into the objectives of wider landscape management.

4. Study of county floras

4.1 Introduction

The type and character of flora present in a wood is determined by factors such as climate, local soils and treatment of the wood (both past and present), but also by the regional species pool. Many woodland plants, often referred to as 'ancient woodland indicators' or 'woodland specialists', are relatively poor colonists (Kirby *et al* 2000; Peterken 1974). It is improbable that such species would be able to migrate from the south of England and colonise northern woodlands in line with the predicted rates of climate change (Hill *et al* 1993). *A priori* it would therefore seem unlikely that the types of beech wood communities currently found in southern England could be 'reassembled' in the north, particularly the 'woodland specialist' component of that assemblage.

In practice, however, the flora of beech woodland contains many species that may also occur within other woodland types. A high proportion of the plant species associated with beech stands in the south may already be present in northern counties. Thus, the potential to develop beech wood communities comparable to those described in the NVC in areas beyond beech's current native range may be greater than it initially appears.

To address this question, the NVC species lists for *Fagus sylvatica* woodland types (W12, W14 and W15) (Rodwell 1991) were compared with the floras in each of four English counties where beech currently thrives. The counties include two in the southeast (Oxfordshire and Kent) within the native range of beech, and two in the northwest (Cumbria and Derbyshire), where beech is not currently treated as native, but which lie within its future projected climate space under MONARCH scenarios (Harrison *et al* 2001). Such an assessment indicates the degree to which the regional pool of species found in the northwest might permit development of characteristic beech wood types.

This study is based on the vegetation information found in the NVC (Rodwell 1991), the most recent floras of Kent (Philp 1982), Oxfordshire (Killick *et al* 1998) and Cumbria

(Halliday 1997), and on a recent Derbyshire floral checklist (Moyes & Willmot 2002a) and associated raw data (Moyes & Willmot 2002b). (The most recent flora of Derbyshire, published in 1969, was out of date. For the purpose of simplicity, the Derbyshire floral checklist and raw data will be referred to as the 'Derbyshire Flora'.) Bryophytes were omitted from this study as many are difficult to identify and are not included in county floras; while checklists are available for some counties, these may not provide consistent coverage.

Little, if any, work has been done previously to answer this type of question; however, it would seem an important area of study to aid the development of effective conservation strategies under changing conditions.

4.2 Methodology

4.2.1 Data Collection

Initially, the list of plants found in W12, W14 and W15 NVC classification tables was compiled (hereafter referred to as 'beech woodland species'). NVC frequency values were noted for each species; these indicate how often a plant is found on moving from one sample plot to the next, rather than the area of ground layer it covers. Differences among NVC sub-communities were not considered, as these would have introduced too much variability to support with field sample data within the short time period of the project. In practice, the distinctiveness of the sub-communities is also questionable.

Each of the four floras was consulted in turn to assess the occurrence of individual beech woodland species. The floral records indicate species occurrence by tetrad (a 2X2 km square). For every species it was noted a) whether the species occurred, and b) at what frequency it occurred in each county. Frequency calculations were based on the number of tetrads in which the species was found compared to the total number surveyed, focusing on areas where beech woodlands might be found. Thus, scores were calculated based on the total number of county tetrads in both Kent and Derbyshire; in Oxfordshire, only the tetrads in the Chilterns area were considered; in Cumbria, only the lowland tetrads were considered. Only ground flora were considered in this assessment. Codes follow NVC conventions (Table 6).

Table 6: Species frequency key.
Codes indicate the percentage of county tetrads within which a species occurs.

Code	Percentage Frequency
1vr (very rare)	<2%
1	2-20%
2	21-40%
3	41-60%
4	61-80%
5	81-100%

In spite of intensive sampling by competent botanists, it is likely that species are overlooked in every tetrad, especially those difficult to identify (eg grasses, sedges and aquatics) or localised in their occurrence. The time of year that sampling took place may affect results (eg winter annuals may be missed); plants in some tetrads in marginal or difficult to access areas may be overlooked. The floral records for these publications were also collected over several years during a time of unprecedented change in the history of the British countryside, thus records may be more representative of specific periods over the last decades, and inevitably are not completely up to date. Nevertheless the floras do provide a good overview of the species that exist in each region. Also, given that they are being used to compare with NVC tables that are likely to be composed of the commoner species, the omissions are probably not critical.

4.2.2 Treatment of data

The frequencies of beech woodland species were compared between counties to give an idea of the structure of the regional pools.

The number of woodland specialists was also compared. Kirby *et al* (2000) used NVC tables, Ellenberg Indicator Values and Functional Attributes (strategy types) to characterise 'woodland specialist' species, which include but go beyond previously determined 'ancient woodland indicator' species. Members of this group are highly linked to woodland habitat and tend to be more shade and stress-tolerant than other species. Woodland specialists tend to be more sensitive to variations in environmental conditions and are more likely to be recorded as decreasing in abundance, thus may potentially be used as indicators of change in woodland habitats. The occurrence of woodland specialist species is an important factor in determining a site's conservation value.

4.3 Results

Many of the species associated with beech woodland communities in the NVC show similar frequencies of occurrence (whether high or low) in the northern counties as compared to the southern counties (see Appendix D for NVC woodland type and county frequency tables for beech woodland species). Notable exceptions are shown in Table 7.

All of the plants associated with beech woodland in the NVC, with the exception of *Vaccinium myrtillus*, which is not present in the Oxfordshire flora, occur in both Kent and Oxfordshire. All of the NVC associated plants, with the exception of *Cephalanthera damasonium* (marked as extinct in both counties) and *Ruscus aculeatus* (marked as extremely rare in Cumbria and extinct in Derbyshire) also occur in both northern counties.

A majority of the exceptions that characterise both regions, noted in Table 7, are woodland specialists. However, most of them occur at very low frequencies within beech habitats, based on NVC designations. The plants more suited to southern conditions are mostly associated with the W12 community type, whereas those more suited to the north are generally found in W14 and W15 habitats.

There are no significant differences in the number of woodland specialists that appear at each frequency in southern (Oxfordshire and Kent) and northern (Cumbria and Derbyshire) regional species pools (Figure 2). In each frequency category, even when county scores may not be equivalent, the total number of woodland specialists in each region is similar (eg frequencies 1 and 5).

Table 7: Beech woodland associated species showing notable differences in occurrence between northern and southern regions. Species appearing significantly higher frequencies are noted by region, and those that are very rare or extinct in the opposite region are **bolded**. NVC community type, frequency of occurrence within that type, and woodland specialist status are indicated.

(a) Southern county regional species pool

Southern Abundance	Woodland Type	NVC Frequency	Woodland Specialist
Campanula trachelium	W12	1	Yes
Carex sylvatica	W12, W14	1, 1	Yes
Clematis vitalba	W12	1	No
Tamus communis	W12	2	Yes
Cephalanthera damasonium	**W12**	**1**	**Yes**
Cynoglossum officinale	**W12**	**1**	**No**
Daphne laureola	**W12**	**1**	**Yes**
Euphorbia amygdaloides	**W12, W14**	**1, 1**	**Yes**
Iris foetidissima	**W12**	**1**	**Yes**
***Neottia nidus*-avis**	**W12**	**1**	**Yes**
Ruscus aculeatus	**W14, W15**	**1, 1**	**Yes**

(b) Northern county regional species pool

Northern Abundance	Woodland Type	NVC Frequency	Woodland Specialist
Hypericum pulchrum	W14	1	Yes
Luzula pilosa	W14, W15	2, 1	Yes
Oxalis acetosella	W14, W15	2, 1	Yes
Quercus petraea seedling	W15	1	N/A tree
Sorbus aucuparia seedling	W14, W15	1, 1	N/A tree
Blechnum spicant	**W15**	**1**	Yes
Molinia caerulea	**W15**	**1**	No
Vaccinium myrtillus	**W15**	**2**	no

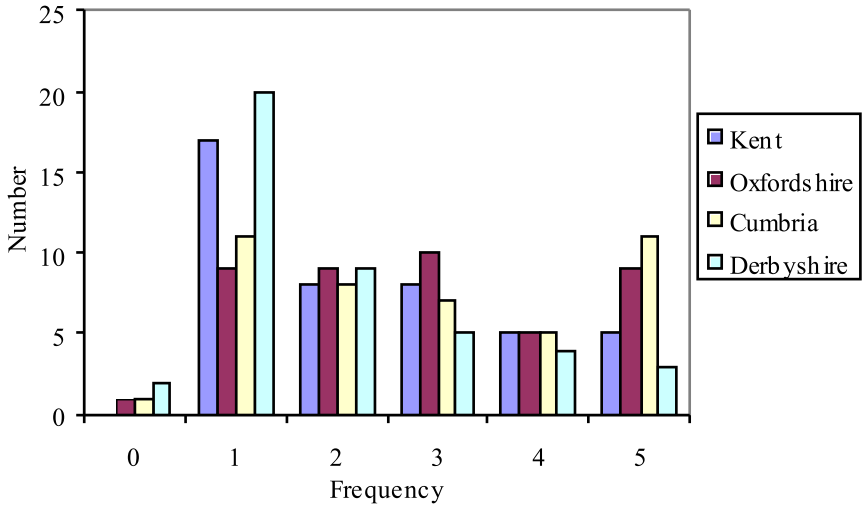


Figure 2: Number of woodland specialists associated with NVC beech woodland types, by county.

4.4 Analysis

These findings show very crudely that the 'regional species pools' for the four counties surveyed are similar. This concept is important because the composition of a site is influenced by the species present within the broader region. Thus, results show the possibility for beech-associated floral assemblages to be recreated, at least to a degree, in northern England. It is unclear whether these species actually currently occur in existing northern beech woods, but their presence within the region leaves open the possibility for colonization at local scales. The considerable regional species pool overlap would also limit the number of rare species translocations from south to north, should a future attempt to recreate existing floral assemblages for beech woodlands be made.

The results show a significant trend regarding the comparative frequencies with which regional species occur. All species, with the exception of one, that are rare in the north but abundant in the south belong to the W12 woodland type. Conversely, all species, except one, that are rare in the south and abundant in the north are associated with W15. This seems to indicate that: (a) the character of W12 assemblages may be the most prone to loss due to climate change, and (b) northern vegetation structure shows a slight tendency towards assemblages more closely related to acid beech wood types (W14, W15) than to calcareous W12. The occurrence of the plants in Table 7 with high southern abundance is quite low for NVC beech communities, however; thus the potential exclusion of some of them from northern beech woods would not cause major alterations in the NVC-designated vegetative character. On the other hand, the potential for supporting W15 associated species in the north may encourage further establishment and conservation of this habitat type.

Indications that the range of woodland specialists associated with beech habitats (in the NVC) occur in similar proportions in southern and northern counties give a boost to current conservation priorities. The above findings provide an initial indication that ecological attributes may not be limiting factors to reassembly, as may have initially been expected.

5. Field study

5.1 Introduction

There appears to have been little, if any, study of the vegetation found in beech woods beyond their native range and how it compares to stands within the current native distribution. Thus, a lack of experience exists regarding the potential for reassembly of beech woodland floral communities in the north (Section 3.3.4, Question 13).

In light of this, the aim of this study was to sample at least two, preferably more, stands from both base-rich sites (corresponding to W12 in the NVC) and more nutrient-poor sites (NVC W14) in both the Chilterns and Cumbria. The sites were chosen largely on the basis of ease of access at short notice; no pre-selection of the vegetation was carried out. The fieldwork carried out in this study does not provide a representative sample of flora in northern and southern regions; insufficient time was available for this. Instead, the results are intended to help illustrate some of the similarities and differences that might be expected between beech woods in southern and northern England.

5.2 Methodology

5.2.1 Site selection

The collection of field data was carried out at various beech woodland sites in both the Chilterns and Cumbria. Most of the sites used are government or NGO owned and managed, with several that are privately owned. Sites were chosen based on the following attributes: accessibility, size, location, percentage of beech cover, and maturity of the woodland, with a preference towards ancient woodland sites. The predominant use of public or NGO sites was partially due to the ease of contact and access, and allows a more free and widespread distribution of the results. All but one of the sample sites in the Chilterns (Aston Wood) are located within the county of Oxfordshire, providing congruency with the floral comparison study in Chapter 3. Aston Wood lies on the southern edge of Buckinghamshire, only two kilometres from the Oxfordshire border.

Six sites were sampled on both calcareous (W12) and acid (W14) soils in the Chilterns. Only three sites of Cumbrian W12 were sampled, due to access limitations. Field data was collected from seven W14 sites in Cumbria. The seventh site was the third Dalton Park site to be sampled, and was not characteristic of other W14 sites, showing extremely low species diversity (two ground flora species only), likely due to elevated plantation density and the extremely sloped location. To facilitate direct comparisons with Chiltern sites, and to avoid skewing results towards Dalton Park assemblages, it has been kept separate or was excluded from most of the analyses.

5.2.2 Data collection

One or two sites were chosen within each woodland, depending on the size of the beech stand, the diversity of environmental conditions, and the variation in soil type. At each site, five samples were taken at minimum 50-meter intervals on a broadly systematic basis. A measurement of fifty meters was paced off from the initial sample site and, assuming the new location was suitable, a transect was laid from that point to the north, or if unsuitable, to the south. If, for some reason, the new location was not suitable, a further 20 meters was paced off, and this continued until a suitable location was found. For a site to be deemed suitable, it required a minimum (average) of 50% beech canopy cover over a 25 meter distance, and that the transect be removed from the edge of the wooded area.

Much of the methodology used to carry out the fieldwork was based on the techniques used in researching and developing the NVC (see Rodwell 1991), the main difference being that, to save time, the tree layer was sampled over a smaller area, and was thus more closely related to the ground flora plots. Each sample consisted of a 25 meter transect intersecting a five square meter quadrat at its centre. General site descriptions were made along each transect to help define overall characteristics of the woodland area. Numbers of beech saplings and seedlings, canopy cover, canopy species, and shrub layer cover were assessed, and the number and diameter of any beech stems within two meters of the transect were also recorded to provide a simple structural record of each stand (see Appendix E for site descriptions).

Within each quadrat, species were identified and respective frequency scores were recorded. Percentage figures for relative cover were logged for bare ground, litter, bryophytes and field layer. The *Domin scale* (Table 8) was used to provide a quantitative measure of abundance of each plant species present in the plot. This measure of cover is assessed by eye as a vertical projection onto the ground of all the live, aboveground parts of the plants in the plot.

Table 8: Domin scores for vertical percentage cover by species
(after Rodwell 1991).

Domin	**%**	
10	91-100	
9	76-90	
8	51-75	
7	34-50	
6	26-33	
5	11-25	
4	4-10	
3		-with many individuals (frequent, but <4)
2	<4	-with several individuals (scarce)
1		-with few individuals (rare)

The obvious vertical layering of woodland was taken into account by dividing each transect vertically into various levels, including canopy, shrub layer, field layer, and ground cover layer, where percentages of cover were recorded for each. Species presence and percentage cover in the canopy and field layers were listed separately as part of the same sample.

5.2.3 Sources of error

By taking the above approach, the variability found within the samples was consequently limited. Beech woodlands are naturally patchy in terms of consistency of beech cover and of variability within the canopy structure. By ensuring a minimum 50% beech cover over each transect and by sampling away from forest boundaries, the variability found in more open canopy, forest gaps and forest edges was not recorded. This approach was desirable because the focus of the study is clearly on species found under a beech-dominated canopy rather than the full variability found within beech woodland areas.

The less common plants or individual small, undeveloped specimens may have been misidentified, which could slightly skew the results. Having samples verified by experienced botanists, if the species names were in doubt, minimised these errors.

Some specimens may have remained unnoticed, thus unrecorded, in plots with very dense field layers and in cases where species have died off after an initial spring bloom. These errors were minimised in the following manner: (a) fieldwork was performed in June when most vegetation still thrives, and (b) extra care was taken in scrutinizing each plot for species. As well, much of the vegetation found under beech is naturally sparse to begin with.

Species, canopy and ground cover estimates are quite general and subjective, and although every attempt at consistency was made, some variations may have occurred. Therefore, their use in the subsequent analysis has been limited.

There may also have been errors during the transfer of data from field sheets to computer spreadsheets; however, the final version was checked for inconsistencies.

5.2.4 Treatment of data

General graphing techniques and comparison tables were used to explore relationships between various factors in different sample sites. NVC woodland type designations and community structure were investigated using ecological computer programs (MATCH and DECORANA). A calculation of community overlap was also undertaken, based on Sorensen's Similarity Index. Ground flora species were characterised using three accepted methods: Woodland Specialist designations, Ellenberg Indicator Values, and Grime Strategy Types. Species groupings were subsequently analysed for occurrence and distribution.

The MATCH program was used to help assign the sampled floral assemblages to NVC community types. The program works mathematically to compare the constancy of constituent sample species with the characteristic profile of a particular NVC type. Results include a list of closest matching NVC types, coefficients of similarity for each type, and details of any significant departures of the collected data from the diagnoses (Malloch 1990). For each community type (Chiltern calcareous, Cumbrian calcareous, Chiltern acid, and Cumbrian acid), field data from all quadrats, including ground, shrub and canopy species, was processed to determine the most similar NVC designation.

Using the field data, the woodland specialist species (see Section 4.2.2 for a description of woodland specialists) were identified based on the list defined by Kirby et al (2000), (Appendix F). The percentage occurrence was then compared by region and by woodland type.

The primary strategy for each of the ground flora species sampled was used to characterise the types of species occurring by region and woodland type (Figure 7). Primary strategies reflect the type of response expected by a plant exposed to a combination of environmental stresses and disturbances, in other words, 'recurrent types of specialization associated with particular habitat conditions or niches' (Grime *et al* 1988, p.2). These strategies conform to three distinct functional types - *competitors* (C), which exploit conditions of low stress and low disturbance, *stress-tolerators* (S), which exploit high stress and low disturbance conditions, and *ruderals* (R), which thrive in low stress and high disturbance conditions. Thus, including intermediate positions between these extremes, seven ecological strategies are associated with this model - Competitor (C), Ruderal (R), Stress-trolerator (S), Competitive Ruderal (CR), Stress-tolerant ruderal (SR), Stress-tolerant competitor (SC), and C-S-R general strategist (CSR). The identification of a plant's functional type can help to explain three things: its successional role, its level of sensitivity to vegetational perturbation ('resistance'), and its capacity to recover from disturbance ('resilience') (Grime 1979; Grime *et al* 1988).

The DECORANA computer program was used to help determine underlying structure in the beech community field data (Section 5.3.3.2). Using the correspondence analysis method, the field data was ordinated to find relationships between both species and samples (quadrats) (Centre for Ecology & Hydrology 2002; Pisces Conservation 2002). By analysing various combinations of data from field sample plots, broad species abundance patterns and similarities between regional plot positions were ascertained.

The Ellenberg Indicator Values for each species were plotted using the ordination results to determine the primary factors that distinguish the regional beech communities (page 48). These values are scales of reference of ecological behaviour based on geographical classifications determined by Ellenberg, used to classify the likely types of plants to occur at particular sites. Values have been modified by Hill *et al* (1999) to reflect the conditions found in Great Britain. Of these, Light (L), Moisture (F), Reaction (R), and Nitrogen (N) apply to beech woodland species.

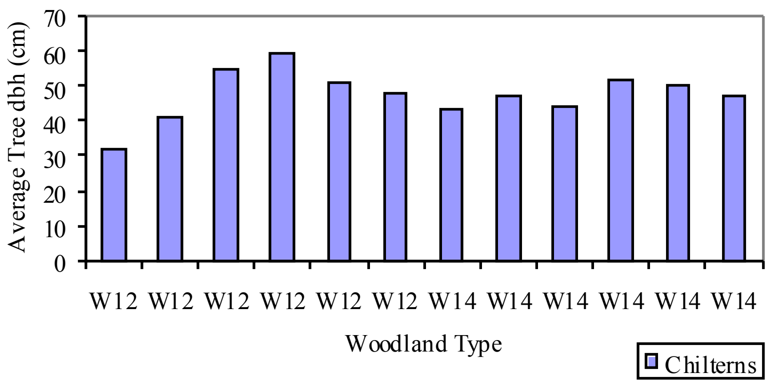
5.3 Results

5.3.1 Site characteristics

The majority of the Chiltern sites are characterised by mature beech of 100 years and older, whereas the Cumbrian sites tend to be younger, the majority having been planted approximately 50 years ago. Beech showing moderate to rapid growth averages the following trunk widths at various ages: 40 years, 12-18 cm; 80 years, 30-45 cm; 120 years, 49-68 cm (James 1982). Trunk widths in Figure 3 reflect the age of the woods in both regions.

Figure 4 shows the regeneration pattern in each woodland type by region. Cumbrian sites seem, on average, to be experiencing superior regeneration of beech seedlings (Figure 4b), whereas Chiltern W12 sites, especially, contain very few seedlings (Figure 4a). Sapling regeneration, on the other hand, is quite low in both regions (Appendix E).

(a) Chilterns stands



(b) Cumbrian stands

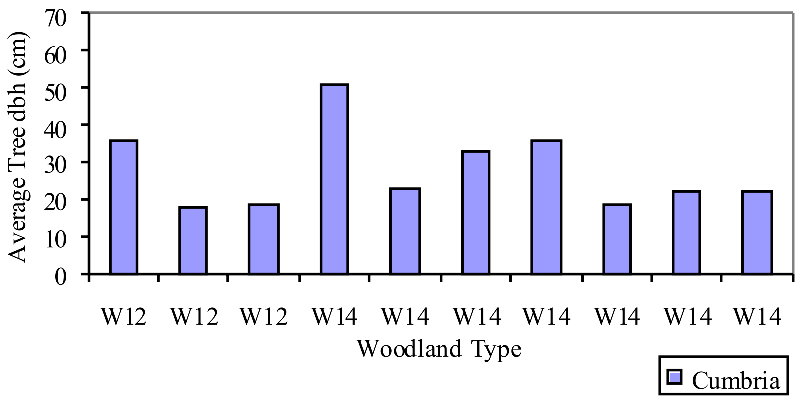
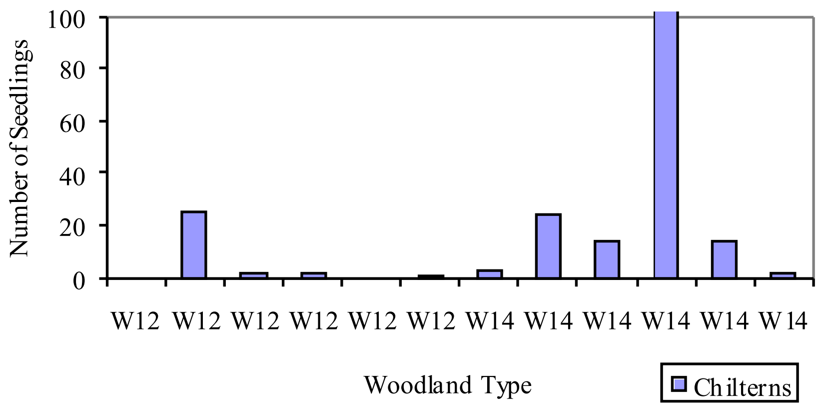


Figure 3: The average trunk width of beech along plot transects. Width is noted in centimetres as diameter at breast height (dbh); trees below 10cm dbh were excluded.

Cumbrian woods display a more extensive bryophyte cover than Chiltern woods, with W12 sites in both regions showing slightly higher average cover than W14 sites. The one exception is Castlehead Wood site, which shows high values for both bryophyte cover and bare soil (Appendix E).

Canopy elements other than beech vary markedly between regions. The southern woods show an elevated abundance of ash whereas sycamore and oak are more common in the north (Appendix E). Dogwood and field maple, elements common to the southeast, occur in the Chiltern samples, whereas the Cumbrian samples include bird cherry, common to the northwest (Perring & Walters 1982).

(a) Chilterns stands



(b) Cumbrian stands

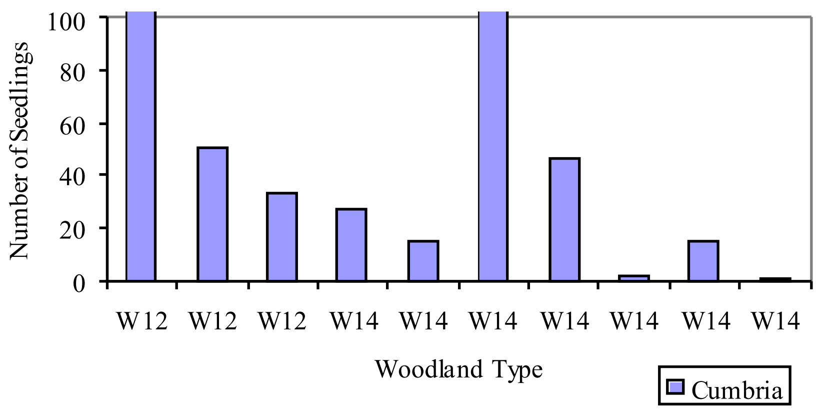


Figure 4: Total number of seedlings by stand. Seedlings are specimens smaller than 50cm; the number of seedlings was not counted past 100.

5.3.2 Woodland stand classification

NVC Classification: MATCH

The output from the MATCH program designated the samples to the expected NVC community in all cases except for the Cumbrian woods on acid soils, which were matched to W10 or W15 (both with almost equal scores) instead of the expected W14. The W12 coefficients for both calcareous sample types are fairly strong, with the Chiltern samples showing slightly higher correlations. The Chiltern acid site, on the other hand, shows a weaker correlation with W14 than the Cumbrian acid site (Table 9).

Each of the four sample groups also overlaps significantly with W10, *Quercus robur-Pteridium aquilinum-Rubus fruticosus* woodland. The floral compositions of the beech woods on acid soils in both regions also overlap closely with the W8 community type (Table 9).

Table 9: NVC communities most closely matching the sample data (using the MATCH program).

Woodland type	Closest matches	Matching coefficient (%)
Chiltern calcareous (CHW12)	W12	55.8
	W8	53.9
	W10	40.5
	W14	39.4
	W9	35.7
Cumbria calcareous (CUW12)	W12	50.9
	W10	47.9
	W8	44.2
	W14	43.0
	W9	36.6
Chiltern acid (CHW14)	W14	44.8
	W10	43.5
	W12	40.6
	W15	34.0
	W8	32.8
Cumbria acid (CUW14)	W10	49.5
	W15	49.2
	W14	46.0
	W16	41.3
	W12	40.9

One caveat regarding MATCH is that because the NVC is not totally comprehensive in its coverage of vegetation types, there may be field data that cannot sensibly be matched to a designated community type without referring to the supplementary explanations in Rodwell (1991). Thus, results should be taken as indications rather than as statements of fact (Palmer 1992).

Additionally, the input information in this study was restricted to vascular plant frequencies. The lack of bryophyte and macro-lichen data may have reduced the effectiveness and/or the coefficient score of the matching procedures (Malloch 1990).

Sorensen Similarity Index

Following Sorensen's Similarity Index, results show an approximate 50% overlap in similarity of woodland ground flora species when comparing W12 sites and W14 sites between regions (Table 10). The significance of this value was tested through a similar comparison between Chilterns W12 sites (Table 11). Since, according to the community ordination (Section 5.3.3.2), the Chiltern W12 sample sites showed the least variation of the four communities considered, there should be significant species overlap between sites. Sorensen values were calculated for three different combinations of W12 sites chosen randomly for this exercise.

Table 10: Sorensen Similarity Index calculation of the presence community coefficient to compare the inter-regional similarities within W12 stands and withinW14 stands (formula from Mueller-Dombois & Ellenberg 1974).

ISs= 2N /(A+B) x 100		A = total # of species in sample A B = total # of species in sample B N = # of species in common
W12 **Chilterns** **Cumbria**	 A = 56 B = 48 N = 26	 2(26)/(56+48) x 100 = **50%**
W14 Chilterns Cumbria	 A = 32 B = 37 N = 17	 2(17)/(32+37) x 100 = **49.3%**

Table 11: Sorensen Similarity Index calculation of the presence community coefficient to compare the similarities between two Chilterns W12 sites; three examples (formula from Mueller-Dombois & Ellenberg 1974).

ISs= 2N /(A+B) x 100		A = total # of species in sample A B = total # of species in sample B N = # of species in common
W12 Chilterns 1 Chilterns 2	 A = 21 B = 33 N = 13	 2(13)/(21+33) x 100 = **48.1%**
W12 Chilterns 1 Chilterns 6	 A = 21 B = 25 N = 15	 2(15)/(21+25) x 100 = **65.2%**
W12 Chilterns 3 Chilterns 4	 A = 26 B = 15 N = 11	 2(11)/26+15) x 100 = **53.7%**

Results from the Chilterns W12 tests show a variation in community overlap ranging from 48% to 65% (Table 11). These values are comparable to those in Table 10, indicating that the overlap between assemblages on similar soil types between regions is also significant.

5.3.3 Ground flora

Species occurrences

The site data indicates a more extensive field layer in the southern woodlands as compared to the north, especially in W12 plots. The W14 sites in Cumbria display lower cover values for undergrowth than W12 sites (Appendix E). The cumulative number of species sampled begins to level off after the data for several sites is considered for Chiltern and Cumbrian W12 stands and for Chiltern W14 stands (Figure 5). Although only three sites were sampled, the cumulative species numbers for Cumbrian W12 stands reaches a level comparable to that of Chiltern W12 sites.

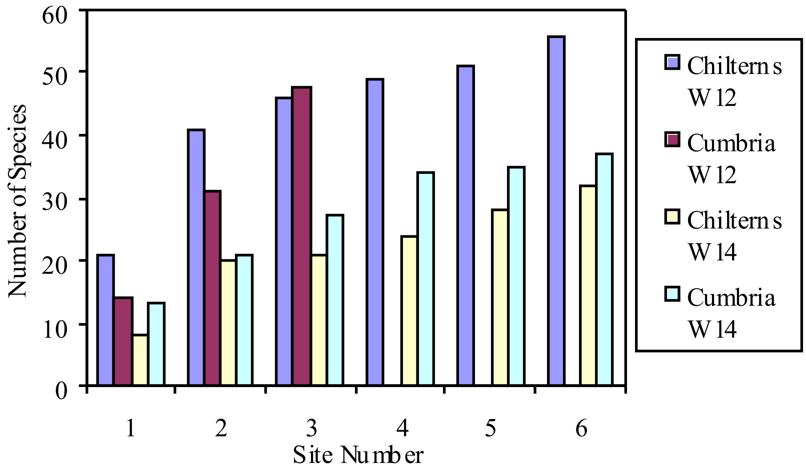


Figure 5: Cumulative species numbers by site.

Figure 6 shows that the proportion of species, both associated and not associated with NVC beech woodland communities, is approximately the same within each woodland type between northern and southern regions. Thus, the proportion of overlap of Cumbrian assemblages with designated NVC species is similar to that of the Chiltern assemblages.

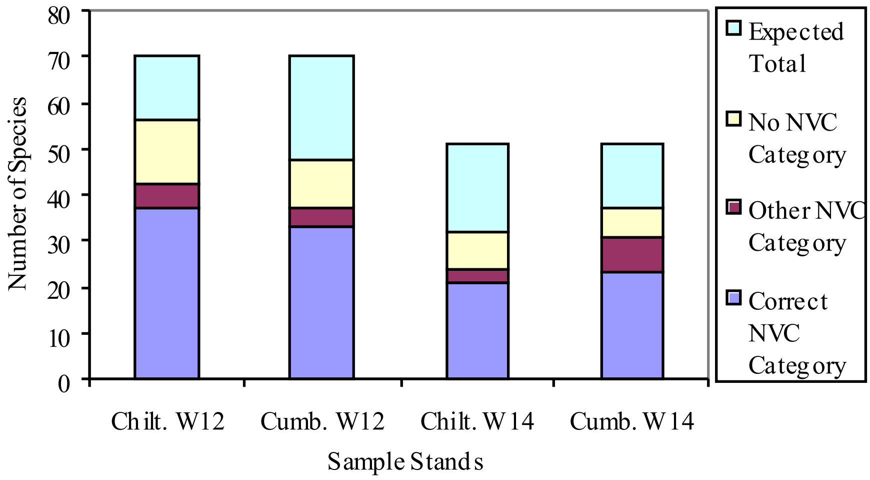


Figure 6: The occurrence of sampled species across three categories: (1) the correct NVC community type, (2) another beech woodland NVC community type, or (3) not belonging to any of the NVC beech woodland types. The 'expected' value shows the number of species considered to be associated with the community type in question, based on NVC tables.

The three major species found to occur extensively in both the north and south are *Fraxinus excelsior* seedlings, *Fagus sylvatica* seedlings and *Ilex aquifolium* seedlings. However, there are several species that, due to their frequency within the field sample plots, noticeably separate the two regions (Table 12).

Comparisons of species frequency (Appendix G) show that *Urtica dioica*, *Galium aparine*, *Galium odoratum*, *Lamiastrum galeobdolon*, *Deschampsia cespitosa*, and *Rubus idaeus* are abundant in Chiltern W12 sites and are either absent or scarce in Cumbrian W12 locations. Of the six, *Deschampsia cespitosa* and *Rubus idaeus* are the only species that occur in abundance in W14 sites, where the former tends more towards Cumbrian than Chiltern sites and the latter only occurs in Cumbrian W14. *Mercurialis perennis* appears in all W12 sites, but exhibits higher density in the Chilterns than in Cumbria.

Table 12: Species occurring on similar soils that demonstrate the greatest differences between northern and southern regions. Primary species are those that show a marked abundance in one region and a marked deficit in the other, and secondary factors show a less marked variation. (The designation of primary and secondary categories is subjective.)

(a) W12 stands

	Chilterns W12	**Cumbria W12**
Primary	*Deschampsia cespitosa*	*Dryopteris dilatata*
	Galium aparine	*Euonymus europaeus*
	Galium odoratum	*Phyllitis scolopendrium*
	Lamiastrum galeobdolon	*Potentilla sterilis*
	Urtica dioica	*Quercus spp.* seedling
Secondary	*Geranium robertianum*	*Acer pseudoplatanus* seedling

(b) W14 stands

	Chilterns W14	**Cumbria W14**
Primary	*Rubus fruticosus* agg.	*Agrostis capillaris*
	Rubus idaeus	*Deschampsia flexuosa*
		Quercus spp. seedling
Secondary	*Brachypodium sylvaticum*	*Lonicera periclymenum*
	Carex sylvatica	
	Prunus avium	

Circea lutetiana is much more abundant in the Chilterns (especially W12) and *Prunus avium* only occurs in the Chilterns (W12 and W14), but at low abundance. *Dryopteris dilatata* is common in Cumbrian W12 sites, but is absent from Chiltern W12 sites (although it shows moderate abundance in both W14 woodlands). *Arum maculatum* is present at much higher density and abundance in Cumbrian W12 than Chiltern W12 sites, and does not occur in the W14 samples. *Allium ursinum* was only found in one Cumbrian W12 site, Serpentine, but is known to exhibit patchy distributions with varied local abundances (Stace 1997).

Acer pseudoplatanus seedlings were noted at much higher abundances in Cumbrian W12 only, but appear in all plots. *Carex remota* shows a slightly higher occurrence in Cumbria.

Conopodium majus, *Holcus mollis*, *Solidago virgaurea*, *Quercus spp*. seedlings, *Anenome nemorosa* and *Blechnum spicant* only crop up in the Cumbrian samples. *Agrostis capillaris* does not appear in any Chiltern W14 sites whereas it does appear, although in low abundances, in five of six Cumbrian W14 sites.

Oxalis acetosella, usually found in W14 and in abundance in W15 woodlands is absent from W12 sites in the Chilterns. It is, however, present in two of three of the W12 sites in Cumbria. The same species is more frequent in the Cumbrian W14 sites (five of six) than in the Chiltern W14 sites (two of six).

Hyacinthoides non-scripta occurs in all four sample areas, but is more frequent in Cumbrian W14 sites. *Deschampsia flexuosa* is only present (and in abundance) in Cumbrian W14 stands. On the other hand, *Brachypodium sylvaticum* occurs in all sites except Cumbrian W14. As well, *Rubus fruticosus* agg. is abundant in all sites except Cumbrian W14.

It is possible that, due to the limited sample size, some species appeared by chance in some plots, and their occurrence is not representative of the overall character of the wood. Several species, however, fit accurately into the ranges designated in the *Atlas of the British flora. Lamiastrum galeobdolon, Carex sylvatica,* and *Prunus avium*, frequent in the Chilterns samples, are common in the southeast but not in the northwest. On the other hand, *Phyllitis scolopendrium* and *Deschampsia flexuosa*, frequent in Cumbrian samples, are common in the north, but not in the south (Perring & Walters 1982).

Species classification

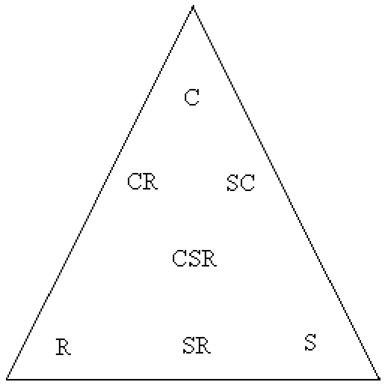
Species were characterised by their strategy types to give an idea of the character of, and resilience within, the system. Figure 7 shows minimal differences between the types of species sampled in each region, especially within the W12 woodland types. Within W14 stands, the proportion of competitors is slightly elevated in the Chilterns, whereas more stress-tolerators appear in Cumbria.

There is also little difference between the number of woodland specialists present in the sampled northern and southern beech woodlands; the proportion of woodland specialist species appearing in Cumbrian sample plots is at least equivalent to that in Chiltern plots (Table 13).

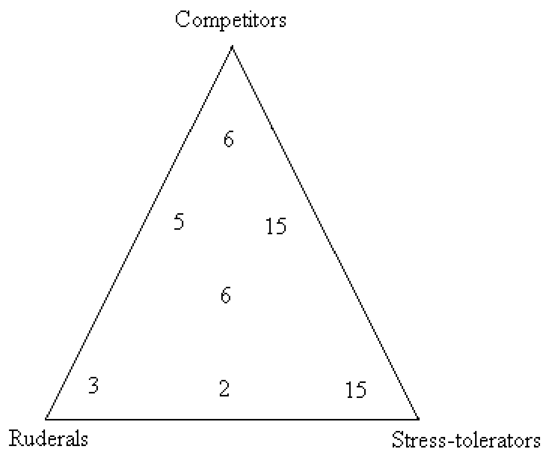
Table 13: The number and proportion of woodland specialists (WSs) for W12 and W14 stands in the Chilterns and Cumbria (see Appendix F for a list of woodland specialists).

	W12		W14	
	Chilterns	**Cumbria**	**Chilterns**	**Cumbria**
WSs	19	19	8	13
Total # species	56	48	32	37
% WSs	**34%**	**40%**	**25%**	**35%**

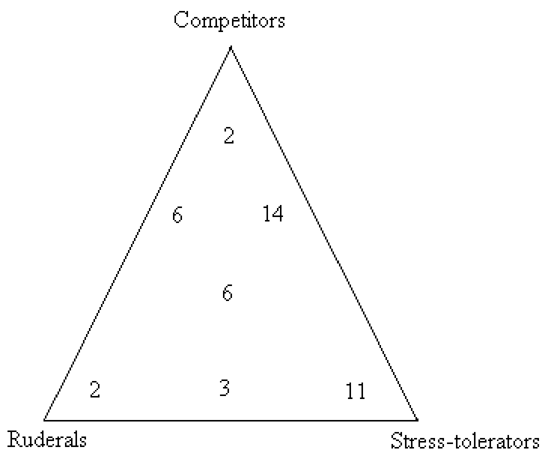
An ordination analysis of quadrats from both W12 and W14 sites in both regions shows four distinct vegetation communities that display some overlap along the X-axis (Figure 8). It is presumed that the variation along the X-axis in the DECORANA ordination reflects species' requirements for a specific environmental factor. Figure 9 shows that the variation between samples is primarily due to an environmental gradient determined by pH and nutrient availability, corresponding to R and N Ellenberg Indicator Values.



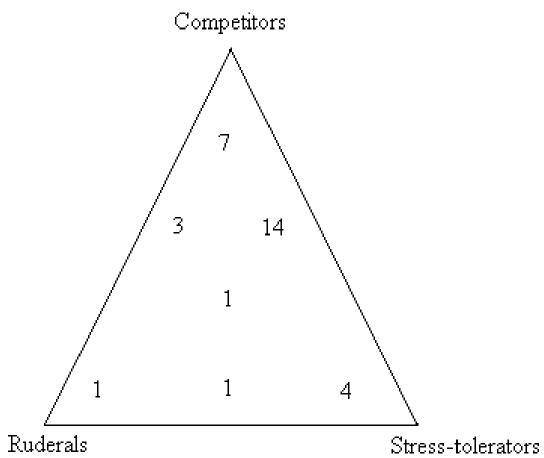
CSR Key



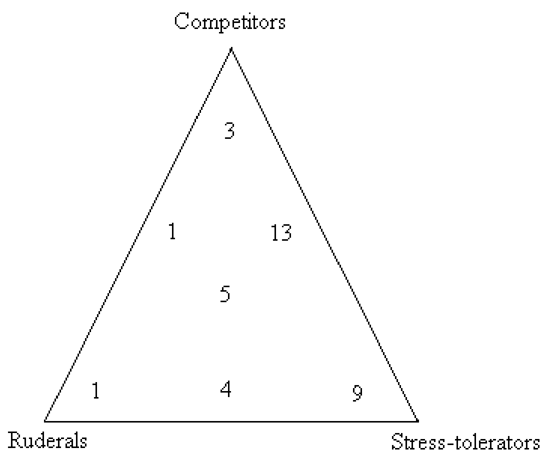
a) Chilterns W12



b) Cumbria W12



c) Chilterns W14



d) Cumbria W14

Figure 7: Primary strategies for sample species by region and woodland type (from Grime *et al* 1988).

The sample ordination (Figure 8) indicates that the Chiltern sites are located, on average, on more calcareous soils with higher nutrient values than those in Cumbria. In fact, soil acidity and nutrient content supporting Chiltern W14 stands overlaps broadly with those of Cumbrian W12 stands.

The coordinates of specific species help to define the floral assemblage character in different areas (Figure 10; see Appendix H for a full list of species). Outliers include: *Betula pubescens/pendula* and *Rhododendron ponticum* for Chilterns W12; *Urtica dioica, Corylus avellana,* and *Laurus nobilis* for Chilterns W14; *Dactylis glomerata, Epilobium montanum, Dactylorhiza fuchsii, Narcissus pseudonarcissus, Ophioglossum vulgatum, Prunella vulgaris,* and *Potentilla sterilis* for Cumbrian W12; *Pteridium aquilinum, Anthoxanthum odoratum, Betonica officinalis,* and *Polystichum setiferum* for Cumbrian W14.

It should be noted that field sample sites were not chosen entirely on a random basis. It was clear during the sampling process that sites within the same region show marked differences in their vegetation; thus, it is to be expected that DECORANA ordinations would portray some differences. The program is intended to demonstrate which species are driving those differences as well as indicating where communities overlap. Several other ordinations were performed, but did not reveal any significant information not already shown here.

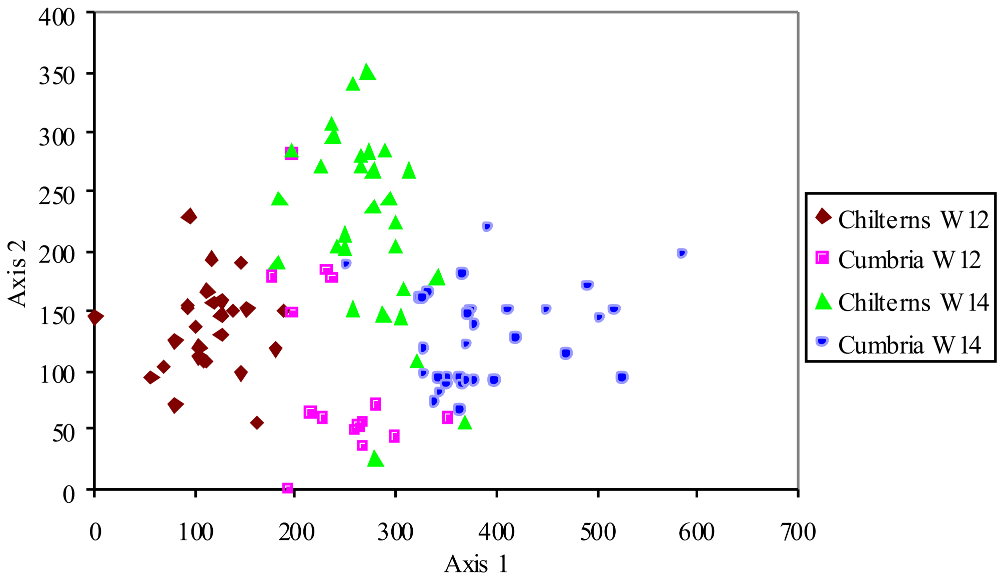
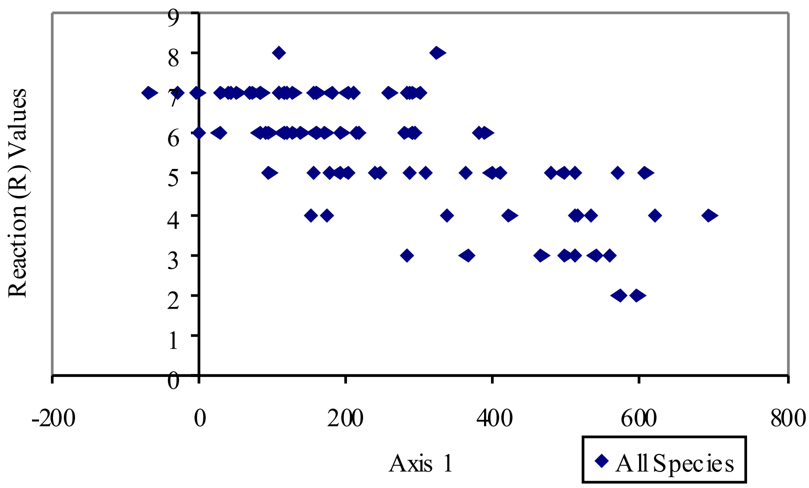


Figure 8: Sample (quadrat) scores for axes 1 and 2 of the DECORANA ordination.

(a) Reaction (R) Values



(b) Nitrogen (N) Values

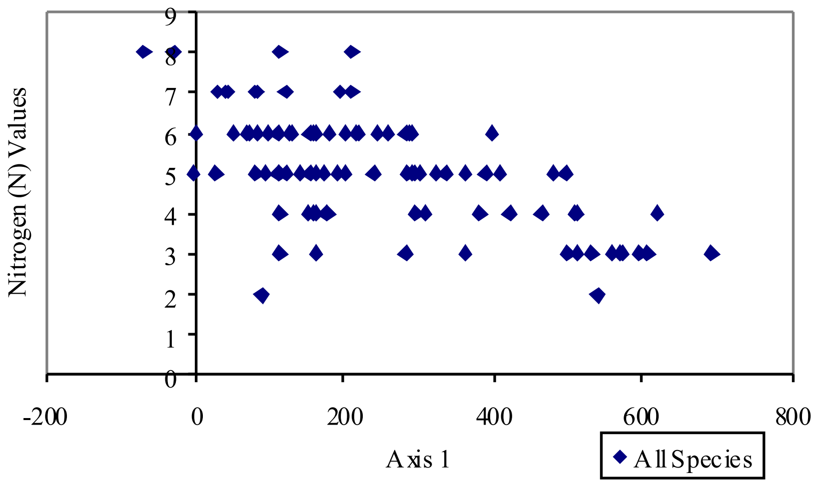


Figure 9: Ellenberg Indicator Values for all species from all quadrats against axis 1 of the DECORANA ordination.

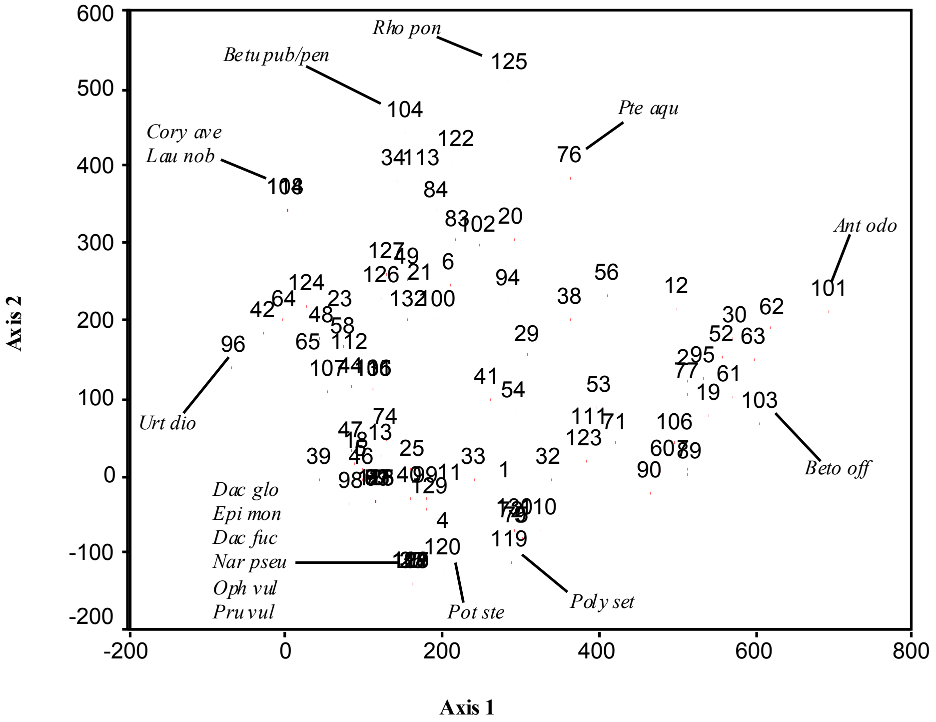


Figure 10: Species scores for axes 1 and 2 of the DECORANA ordination (see Appendix H for a full species key).

5.4 Analysis and discussion

5.4.1 Stand and soil types

In order to simplify the ground flora comparison between the regions, the Cumbrian field sites were initially classed into two types of woodland, namely W12 and W14, based on soil type and prevalent indicator species. Since these woodlands are considered as non-native, they have not been surveyed for inclusion into the NVC; however, MATCH results indicate that the designations are fairly accurate and that comparisons between the W12 and W14 types are valid between regions.

The correlation coefficients for both calcareous stands with the NVC W12 type and both acid stands with the NVC W14 type show similarities between the regions; however, their moderate values indicate differences between sampled communities and expected (NVC-designated) vegetative compositions.

The strong overlap of Cumbrian samples on acid soils (CUW14) with W15 flora adds weight to the trend noted Chapter 4. It seems that species associated with W15 may thrive better in the north on acid soils than they do in the south, indicating the possibility of conserving beech woods with a character closer to that of W15 which is of limited occurrence in the south.

The soils available in the north will have an impact on the types of species that thrive there. It would be beneficial to undertake further field sampling in northern beech woods in areas with more calcareous soils, such as Derbyshire, to gain a better understanding of the range of conservation possibilities.

5.4.2 Site characteristics

Part of the reason for the variations in species composition, canopy elements, and field layer cover may be due to the varied management strategies undertaken in each region, both past and present. The majority of the Chiltern woods exhibit mixed age beech stands with mature trees (100 years and older) that, even if initially planted, have become naturalised over time. By contrast, the majority of Cumbrian woods are more recent, even-aged plantations that contain approximately 50-year-old beech. These tend to display higher trunk and canopy density, possibly shading out some species that might otherwise appear.

The two Cumbrian sites that show some anomalies compared with other sites of the same types are Serpentine (W12) and Castlewood (W14). These are both located on the outskirts of towns (Kendal and Keswick, respectively) and are heavily used by dog-walkers. This excessive use and proximity to urban centres may reduce the amount of natural herbivorous grazing (Serpentine's thick undergrowth may reflect this), and increase trampling damage (especially in Castlewood where trails are not well defined), which likely alter the floral character. Thus data from these two sites may not be representative of the overall character of beech woods in Cumbria.

The low seedling frequency in Chiltern W12 sites indicates unfavourable conditions for regeneration. Beech on these sites exists across the entire age range (Appendix E), thus regeneration has obviously been ample in the past. This finding may reflect the recent shift away from traditional management practices that favoured beech. As well, the number of deer in the area has increased, amplifying grazing pressure on young trees (Ingram 2001).

The abundance of ash as a major canopy species of southern beech woodlands, especially W12, follows with the ecological indications that such woods would display a natural tendency towards a higher ash concentration if left unmanaged (Watt 1925).

Due to the increased rainfall and moisture in Cumbria, it is expected that this area would display increased bryophyte cover; this apparent trend could, however, be due to chance as limited data was collected.

5.4.3 Floral assemblages

Due to the young age of the Cumbrian stands, (a) associated floral communities might be expected to show a higher proportion of ruderal species than the Chiltern stands, and (b) Cumbrian stands might contain fewer ancient woodland indicators. Neither of these assumptions seems to be the case, however. Upon combination of R, SR and CR values, none of the regional sites stands out as having significantly more or fewer ruderal species than the others. This raises the potential for creating beech woods in the north that are not dominated by ruderals. In addition, the number of woodland specialists sampled in the Cumbrian sites and generally present within the northern counties (Section 4.3) are at least equal to those in the south, thus the conservation value of the northern stands is sustained (based on site selection criteria in Ratcliffe 1977).

One effect of the limited sampling regime may be the lower number of sampled species compared with the total number of beech-associated species expected from NVC community designations. However, the NVC tables are based on an amalgam of samples across a wide range of sites, therefore no set of samples from a small number of geographically limited sites will contain as many species. A levelling off of the cumulative number of species by site (Figure 5) indicates that the sampling regime was effective in gathering a fair proportion of the total species pool present within each woodland type.

Also it is important not to place too much weight on species that are only found in one or very few sample plots in a region. These may be random occurrences, or possible invasive species from unnatural habitats (eg *Valeriana pyrenaica* is a garden escape).

Differences in ground flora diversity and cover are often attributable to two major factors: variations in canopy cover species or in the age structure of a stand (Kirby 1988a). The low field layer density in the northwest compared to that in the southeast might thus be explained by several factors in combination. It may reflect reduced grazing pressure on lowland versus upland woods, which follows past and present management trends (Ratcliffe 1977). Also the relatively young Cumbrian stands surveyed generally display elevated trunk and canopy density, characteristics consistent with early woodland life cycle stages. Upon comparison of ground flora samples between plantation and semi-natural woodland sites, Kirby (1988a) found that vascular plant diversity and cover varied consistently with the age of the canopy trees. His study area showed a rapid increase in diversity and cover immediately after clear-felling, a subsequent decline as the young canopy closes (the 'thicket' stage), and a moderate recovery as plantations are thinned. These findings were for different canopy species, including oak, spruce, ash, larch and pine, where phased transitions for each species occur over varied timescales. It is probable that species associated with beech follow similar trends, although the exact timeframe of each stage has yet to be demonstrated.

The current differences in precipitation and temperature between northern and southern regions are reflected by the species presence in each area. The frequency of *Dryopteris dilatata* and *Blechnum spicant* in Cumbrian samples reflects higher surface acidity caused by increased soil leaching due to high rainfall conditions. Likewise, the absence of *Lamiastrum galeobdolon* in the northern samples is likely a factor of its limited ability to reproduce under cooler temperatures (Rodwell 1991).

The presence of *Oxalis acetosella* in Cumbrian W12 sites does not fit directly with the NVC designation. Rodwell (1991) notes the tendency of *Oxalis* to be abundant in W9 (*Fraxinus excelsior-Sorbus acuparia-Mercurialis perennis*) and W11 (*Quercus petraea-Betula pubescens-Oxalis acetosella)* communities, the northwestern counterparts of southern ash and oak woods, corroborating evidence that *Oxalis* tends to thrive in continually wet conditions. Watt (1925) noted the appearance of *Oxalis* throughout beech woods when they reach 50 to 55 years of age, whereafter it remains dominant for approximately 10 years. Thus, the frequency of *Oxalis* in the Cumbrian sites may be explained by a combination of high humidity and fluxes during the woods' maturing stages.

The elevated abundance of *Rubus fruticosus* agg. in the Chiltern W14 sites and its low occurrence in Cumbrian W14 sites, coupled with the absence of *Agrostis capillaris* in the Chilterns and its presence in Cumbria could indicate a suppressant of *Rubus* in the north. This might be due to increased canopy cover or to heavier grazing in Cumbria. New Forest beech wood studies show increased biodiversity when *Rubus fruticosus* agg. is heavily grazed

(Kirby 2001b), and may be comparable to the Cumbrian W14 situation. Grasses are more common in upland beech woods if they are grazed compared to the largely ungrazed (except by deer) lowlands (Putman *et al* 1989). Another factor to consider is the variation in intensity of plantation management. It is common that young stands are thinned and cleared, causing significant soil disturbance, which impacts on species diversity and abundance.

The frequency of sycamore (*Acer pseudoplatanus*) in Cumbrian W12 sites is expected, as this species is more likely to naturalise under northern rather than southern conditions (Stace 1997). On the other hand, the low occurrence of rowan (*Sorbus acuparia*) in Cumbria is somewhat surprising, as this species is typical of oak woods and acid soils in the northwest. It could be lacking due to the rather barren shrub component of the northern beech plantations.

Species such as *Urtica dioica, Galium aparine, Geranium robertianum, Hedera helix,* and *Deschampsia cespitosa* are common in NVC ash types W8 (sub-communities e, f &g) and W9 (sub-community a), which are the most likely forerunners for W12 in Cumbria (Rodwell 1991). Since these species do not come up in the Cumbrian W12 samples, sampling of W8 and W9 communities may be beneficial in exploring this relationship.

The W14 stands show more variation between regions than the W12 stands. These may be comparable to the differences between W10 (the acid counterpart to W8), the lowland oakwood equivalent of W14, and W11, the northwest oakwood partner to W10 (except it does not have a comparable beech wood type). The Cumbria beech woods have more *Deschampsia flexuosa, Agrostis capillaris* and *Oxalis acetosella*, and some *Anthoxanthum odoratum* and *Holcus mollis*, all more abundant in W11 than in W10. If W11 were the typical forerunner of more acid beech woods in the northwest, these differences would be expected.

The reasons for the differences between W10 and W11 and hence between the equivalent beech stands are due to a complex combination of factors. These are (a) partly climatic - certain species (eg ferns and *Oxalis*) may respond to the wetter conditions, (b) partly a consequence of more acidic soils in the northwest - higher rainfall leads to increased leaching of nutrients, and the soil also contains harder, more nutrient poor rocks in many cases, and (c) also related to grazing and overall management history. One caveat, however, is that the MATCH program did not relate the sample assemblages to W11 as would have been expected.

The stands sampled during this study were all still in early successional stages; this factor may have increased the number of differences found between regions. In spite of this, there are many overlaps of species presence between regions, and several indications that northern community structures are already in line with NVC designations.

Further sampling of a broader range of existing beech woods that vary in terms of both age and site characteristics would provide a more comprehensive picture of inter-community variations and similarities. The results from this limited survey, however, back the regional species pool evidence (Chapter 4) indicating that ecological barriers to community reassembly are likely to be minimal. Current community structure exhibits many similar characteristics to those currently valued within conservation policy at national and European levels.

6. Discussion and conclusions

6.1 Study limitations

The research reported here attempted to address a complex and multifaceted issue in a very short time frame. It was necessary to compromise on the depth of study of particular factors in order to gain breadth. Thus, there were several possible criticisms of the approach taken which had an impact on the findings. These include the following:

- *County flora regional pool study:* Although the study of the county floras indicated that most species associated with beech woodland are present in the northern counties, there is no guarantee that these species actually did or could occur in beech woods in the area.

- *NVC tables to designate 'beech woodland associated species':* The NVC tables were constructed from a relatively small number of samples across a range of community types. Thus, they may not necessarily be representative of good (ie high conservation value) woods *per se*.

- *Limited field study:* Ideally, a more objective sampling strategy would have been used, involving a greater number of samples across a wider range of sites. Difficulties in gaining access to a sufficient range of sites on varied soil types in the allocated timeframe set limitations on the field study. Further study of northern beech vegetation on calcareous soils may be used to supplement the information herein.

- *Study focus on flora:* The present study is focused on vegetation only, whereas other aspects of diversity (eg invertebrates, fungi, and animals) may not show similar patterns of response to change, and their conservation may require the implementation of different management strategies. However, since many beech conservation sites were initially selected on floristic grounds, this seems a reasonable starting point.

- *Limited questionnaire distribution:* The questionnaire survey of expert opinions may seem quite limited, but, the number of individuals involved in UK woodland conservation is itself quite limited, thus the results likely do represent a reasonable spread of opinions.

6.2 Emerging themes

In spite of the above limitations, the study clearly highlights several emerging themes:

- There appears to be recognition by conservation experts that climate change is occurring and that it will necessarily result in shifts in conservation practice in the UK. This has not, however, been discussed widely at more local levels where current practices (eg clearance of beech in northern woodlands) may, in hindsight, prove undesirable in a few years time.
- Focus on the potential for vascular plant species migration may not be an issue of overwhelming concern with regards to community reconstruction; most beech

woodland species are quite widespread in their distribution and may already be present in the regional species pools of northern counties. There may, however, remain some concern over the plight of individual rare plant species. Also, the status of certain other groups of organisms (eg invertebrates, fungi) may be different, especially if their survival is more closely tied to the presence of beech trees. These might be absent or at best scarce in northern locations. Most birds and mammals are fairly mobile, thus are more likely to be able to migrate in a similar pattern to plant species.

- Assemblages that develop naturally in northern beech woods over time will almost certainly be different to those found currently in the south and to those found in the north at present, due to a variety of influential factors. The current trend away from some W12 component species and towards W15 species in the north may provide an indication of possible future assemblages (Sections 4.3 and 5.3.2). The climatic conditions in the north will also change over time, which may cause a range of impacts at local levels.
- Underlying geographical and topographical differences exist between northern and southern sites, and soil type and structure vary between regions. Past land use also plays a role, where higher levels of stock grazing in the northern uplands will have influenced the development of current floral community structure. Given that most beech woods can be seen as analogues of ash (W8 and W9) and mesotrophic oak woods (W10 and W11) we might expect parallel differences in beech woods in the northwest compared to the southeast. Some indications of these similarities were seen in the field sample results (Section 5.3.3).

6.3 Implications

6.3.1 Conservation philosophy

The wider acceptance that UK beech woodland habitat types will vary over time feeds into the debate regarding current conservation philosophy. Much of the current understanding of conservation, especially within the decision-making and public realms, rests on attitudes and belief structures that may or may not be consistent with the needs and interactions of the underlying ecological system. To animate this debate, let us consider three possibilities:

- If beech woods are valued primarily for their rarer species, and these species are still expected to survive within different woodland types under climate change conditions, then we may not need to be as concerned about the loss of beech in southern England;
- If we value beech woodland as a fixed 'community', we know now that this temporary agglomeration of species will not be re-created elsewhere under climate change, thus the character of this community is not sustainable, and its value is lost;
- If we regard the beech 'community' as a more loosely defined concept - as something that will change, but nevertheless shows some similarities and overlap with current compositions - the Cumbrian sites may potentially be seen as valuable for future conservation.

Current conservation philosophy assumes implicitly that vegetation communities are fixed entities that can be identified by specific characteristics. On the other hand, recent studies, current information, and analytical reasoning indicate that we should be moving towards a new, more dynamic philosophy.

When considering the implications of climate change on vegetation, it seems reasonable that the conservation focus for specific communities will shift over time as environmental conditions change. Thus, an appropriate approach to beech woodland conservation in the UK might be to focus community conservation in locations other than the existing ones, and to allow for changes in species combinations and community character. Such a perspective may be applied to other species and habitat types within the UK and elsewhere.

6.3.2 Conservation policy

The findings in this study bring to light several inconsistencies between ecological and political responses to climate change. It is evident that ecological shifts are occurring and will continue to occur over the foreseeable future. Conservation policy must follow suit by developing methods that allow for, and even support, such change.

Individual species and broader habitat types will vary in their responses to climate change. For some, climate space will expand, while others face declining ranges. Thus, altered policy designations may or may not be necessary for the protection of all species. The current protected sites approach will remain valid; however, it cannot endure in its current state as the sole focus of future conservation policy. In order to incorporate a relatively new dynamic systems concept into overarching policy, conservationists must accept more fluid classifications that allow for reassessment of current practices where necessary. Thus, a shift away from habitat restoration towards the creation of new habitats is recommended. Important conservation bodies are slowly recognising this need. In a position statement on environmentally sustainable forestry and woodland management, English Nature (2002a, p. 2) clearly supports 'new strategies to cope with the nature conservation implications of climate change'.

In order to back this policy shift, methodological instruments are needed, including:

- guidelines for determining a site's conservation status (ie favourable, unfavourable) under changing conditions (Hossell *et al* 2000);
- criteria and indicators for reassessing site boundaries, size and connectivity (Hossell *et al* 2000);
- a protocol for describing new variations in the NVC as community compositions change (Strachan & Jackson 2003).

The traditional disciplinary focus within the scientific community is changing as the need for interdisciplinary understanding and action is realised, especially in relation to environmental issues. Cross-disciplinary efforts are imperative where decisions impact on ecological, sociological, economic and political levels. Decision-makers at various levels often have diverse agendas and interests to protect, and may base judgments on distinct philosophies, depending on their particular contextual perspective (eg beech conservation is valued differently at regional and national scales). The effective functioning of such endeavours relies fundamentally on communication linkages between sectors. The creation of inter-disciplinary networks and, potentially, central information banks for specific issues, is imperative when dealing with issues such as climate change that have far-reaching, complex and uncertain outcomes.

Public perception of beech woods also plays a part in their conservation, although usually not for scientific reasons. Cultural and emotional attachments to the woods leave the public loathe to accept change, thus it is important to maintain beech woodlands in areas like the Chilterns no matter how unnatural they may be. These issues raise the need for increased public awareness of ecological issues, to garner support for institutional change.

6.3.3 Conservation practice

It is clear that climate change will influence the range of many species, either positively or negatively. This, of course, opens the debate on the treatment of existing ecosystems in areas of new conservation focus for specific habitat types. By accepting ecological shifts and allowing them to take place, new species assemblages may have consequent effects on existing flora and overall ecosystem character. Thus, a balanced approach is necessary in order to respond appropriately to the combination of possible effects.

Current conservation practice regarding beech, as noted in several SSSI management plans, follows traditional conventions based on the static concept of 'native range'. As the philosophy underlying this concept is increasingly questioned, responses will require changes to existing management plans, particularly the practice of clearing beech from woodlands in northern England.

The results from the combined field and floral surveys show that, even if species failed to appear in the samples, they are present within the northern region, indicating potential for beech community reassembly to occur naturally. Although there exists no intrinsic need for recreating NVC assemblages, this may remain a priority in the short term if Natura 2000 commitments are to be satisfied. Where beech woods have begun to naturalise in northern England (although not necessarily where sampling took place), it seems counterproductive to completely transform their evolving habitat character solely based on the definition of beech as non-native, especially when efforts are being made to protect such communities elsewhere. In areas where beech has long been part of the ecosystem, it should not be deemed a threat to other floral structures.

Woodland management is a long-term undertaking, and decisions that alter the character of existing woodlands in very short time periods should be avoided unless backed by sound evidence to the contrary. Excessive and irreversible action should not be taken until further research is completed, a notion that should apply to beech habitats both in northern and southern regions.

These preliminary findings indicate the need for the distribution of conservation resources (eg time, money, expertise) beyond the regional level to be re-evaluated. In the meantime, the continued protection of southern beech woods seems valid, while clearance of beech in northern woods should be delayed until a more concrete strategy has been devised; existing woods should instead be left to regenerate in the interim.

6.4 Summary and conclusions

The aim of this study was to evaluate the impacts of climate change for floral conservation in the UK. The initial objectives were to (a) gain a better understanding of beech woodland ecology under changing climatic conditions, (b) assess the types of conservation policy changes needed to deal effectively with the declining vitality of floral communities, and (c) provide a basic methodological approach that may be adapted for use in comparable situations. To this end, beech community structures and compositions in southern and northern England were investigated, and the implications of climate change for conservation policy were addressed. A variety of methods were used, including a review of current literature, a consultation of experts, a county-based floral comparison study, and field sampling of ground flora in southern and northern counties. The results present a basis against which to evaluate the validity of current conservation philosophy. They also provide a framework for developing policy and site-level management strategies.

Study results showed that regional species pools of vegetation associated with beech woodland communities in Cumbria and Derbyshire are similar to those in southern England. These findings were supported by the field sample data, indicating that floral assemblages already developing in northern beech woods are comparable to those of current conservation interest. This increases the potential for the future conservation of beech woodland habitats in areas beyond their currently accepted native range.

With regards to conservation policy, the literature and expert opinion both indicate that current protected area designations and attitudes towards site management are not sufficiently flexible to allow for predicted shifts in environmental conditions. Potential considerations for policy development could include:

- the creation of a more effective communication network to ensure that scientific information is understood by decision-makers and the public;
- the cultivation, at national and international levels, of a more flexible attitude towards assessment and definition of conservation priorities and strategies;
- movement towards a more 'adaptive' approach to management, where (a) proactive decisions are taken in a conscious effort to increase knowledge of the system, and (b) 'lessons learned' are incorporated directly into the overall strategy in a timely manner.

Much of this project has focused on assessing the possibilities for future conservation of beech woodland species in the northwest based on the types and abundances of species that occur there at present. It is imperative to remember that environmental conditions in these regions will also be affected by climate change, and that the species compositions presently found there will undoubtedly also shift over time. This study attempts to provide some insight as to the types of species that are known to be supported by the current northwestern conditions, and predictions are made on the basis of potential (and generally probable) occurrences based on current knowledge and understanding of environmental conditions.

The findings in this study could provide a basis for further research into the physiological and sociological parameters that guide conservation efforts for particular habitat types. The methodological approach used may be applied across a broad range of community types to facilitate research and policy development in comparable situations.

Results from this study have shown that the ecological, philosophical and attitudinal contexts identified provide, together, a sound basis upon which to develop more flexible strategies.

6.5 Recommendations

Based on the current example, current management plans should be reappraised to ensure that conservation resources are not being wasted on maintaining species and habitats in areas where their long-term viability is in question. With regards to beech woodland, two types of action should be considered over the long term as viable options for their continued conservation in the UK: (a) selection of northern sites currently under beech canopy for conservation management towards naturalisation, and (b) establishment of new beech woodland communities in the north. Activities that undermine the presence of beech in the northwest should be deferred to allow the possibility for future habitat conservation in these areas. With time, as the definition of 'native range' is reassessed, such action may in fact be justifiable under national policy as currently framed.

Conservation management must involve continual adaptation to new circumstances rather than focusing on increasingly difficult efforts to maintain the *status quo*. This type of response describes what is known as 'adaptive management', defined by Parma & NCEAS (1998) as '[management] according to a plan by which decisions are made and modified as a function of what is known and learned about the system, including information about the effect of previous management actions' (p.19). Considering the complex nature of the conservation issue studied here, implementing this type of strategy would provide additional insight into the workings of the system we are attempting to protect, while allowing decision-makers the flexibility needed to deal with the effects of continuous change.

As part of this adaptive management strategy, guidelines should be developed for (a) adjusting the NVC over time, and (b) assessing the conservation status of protected areas as their characters change in response to shifting conditions.

In order to react effectively to change, the rate and magnitude of this change must be clearly understood. Thus, ecological monitoring systems should be established at regional levels to (a) determine baseline conditions regarding species and habitat status, and (b) enable the carrying out of periodic assessments. Results should be evaluated at intervals and fed into subsequent decision-making processes.

The implementation of science-policy workshops to bring together researchers, forestry officials, conservation officials and policy-makers is suggested. These may help to bridge gaps in communication and understanding between significant groups with complementary knowledge bases and develop stronger linkages among affiliated institutions. They also induce more dynamic, inter-disciplinary discussion that may aid development of conservation agendas that take a broader range of issues into account.

Similar public workshops could subsequently be used on a regional level to disseminate information and engage the participation of the general population. These could help garner support for changes in management strategies. An educational process such as this is a long-term endeavour, thus it would be in the best interest of the conservation community to start developing these links in a timely manner.

6.6 Further research

Regarding beech woodland conservation, this study provides a baseline upon which more in-depth, issue-specific research may be based. This includes:

- further field sampling in northern beech woods on more calcareous soils to provide a better understanding of the ecological variety in the area and the potential for conservation in a broader regional context;
- an assessment of potential sites for future conservation and naturalisation of beech in the northwest.

The current assessment, based on an example habitat type, incorporates both ecological and climatic dimensions as they relate to current conservation policy. It provides a methodological guideline for studying the implications of climate change for other floral community types of conservation interest in both the UK and the European Union. Further work in the field of habitat conservation would benefit from the following research:

- a more in-depth study of the attitudes and opinions of the public and policy-makers towards the effects of climate change on vegetation;
- initial assessments of potential sites for habitat development, backed by field studies, in areas of projected climate space;
- the development of site-level predictive models to advance research into climate change impacts and ecological implications at local scales;
- a reassessment of the treatment of invasive species that are alien to the United Kingdom.

The current research leaves the door open for further, detailed technical studies to be implemented over a longer timescale. At the same time, given the complex nature of conservation issues, multi-level, ‘open’ studies like the present one are also needed. Refinements of technique and methodology will continue to be necessary as our understanding of the environment develops, in order to understand how complex variables interact on different scales. It is clear that no single approach can include all aspects of a conservation issue, thus each case must be treated as unique; however, general methodologies can be applied and custom-tailored as necessary. Researchers should thus take an adaptive approach to exploring all avenues while maintaining an air of healthy scepticism. A study such as this one demonstrates the multiple challenges involved in conservation management, the most important one being our incomplete understanding of the environment and how it functions.

7. References

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Appendices

Appendix A. Beech woodland area by County

County	Total % high forest cover	Total beech area[a] (ha)	SSSI beech area[b] (ha)
Total Greater London	**6.3%**	**391**	**353**
Berkshire	4.9%	897	209
Buckinghamshire	23.7%	4,165	1183
East Sussex	4.3%	1,287	1377
Hampshire	12.5%	8,367	4658
Isle of Wight	15.5%	705	269
Kent	6.0%	2,369	1720
Oxfordshire	18.2%	3,319	325
Surrey	6.1%	2,291	1565
West Sussex	12.6%	4,726	1411
Total Southeast	**10.6%**	**28,629**	**12,717**
Avon	11.3%	945	0
Cornwall	2.4%	645	110
Devon	3.8%	2,533	322
Dorset	9.5%	2,732	188
Gloucestershire	17.1%	5,088	964
Somerset	6.2%	1,506	22
Wiltshire	11.3%	3,088	385
Total Southwest	**7.6%**	**16,114**	**1,991**
Hereford & Worcester	5.8%	2,069	0
Shropshire	5.8%	1,710	128
Staffordshire	1.9%	402	0
Warwickshire	0.9%	85	0
West Midlands	2.8%	77	0
Total West Midlands	**4.4%**	**4,333**	**128**
Bedfordshire	2.9%	222	15
Cambridgeshire	3.4%	419	0
Essex	4.5%	875	1460
Hertfordshire	6.0%	930	324
Norfolk	4.6%	2,426	103
Suffolk	2.7%	849	0
Total East	**4.1%**	**5,704**	**1,902**

County	Total % high forest cover	Total beech area (ha)	SSSI beech area (ha)
Derbyshire	5.9%	1,151	0
Leicestershire	1.7%	164	0
Lincolnshire	3.4%	643	8
Northamptonshire	1.5%	217	0
Nottinghamshire	4.0%	692	0
Total East Midlands	**3.6%**	**2,875**	**8**
Humberside	10.5%	954	0
North Yorkshire	3.9%	2,373	38
South Yorkshire	10.1%	1,167	0
West Yorkshire	18.6%	1,973	0
Total Yorkshire and the Humber	**7.1%**	**6,538**	**38**
Cleveland	6.9%	262	0
Durham	7.2%	1,119	0
Northumberland	1.7%	1,371	0
Tyne And Wear	9.3%	269	0
Total Northeast	**25.1%**	**25,820**	**0**
Cheshire	6.7%	693	0
Cumbria	2.5%	1,615	223
Greater Manchester	12.6%	592	0
Lancashire	7.1%	1,000	0
Merseyside	6.7%	166	0
Total Northwest	**4.2%**	**4,039**	**223**
Total England	**6.5%**	**71,298**	**17,360**

[a] **Total area of beech, by county** (Forestry Commission 2001)
[b] **SSSI areas containing beech, by county** (English Nature 2002c). (The survey omitted some planted stands, but the data gives an idea of current beech conservation emphasis. Beech may be minor and/or unwanted in particular SSSIs).

Appendix B. Sample questionnaire

To what extent do you agree or disagree with the following statements - Please indicate:

1 strongly agree
2 agree
3 neither agree nor disagree
4 disagree
5 strongly disagree

Overall attitude to climate change	**1**	**2**	**3**	**4**	**5**
1 Human-influenced climate change is occurring at a global level.					
2 Human-influenced climate change is affecting the climate of the UK.					
3 Climate change will have an impact on the natural environment at a global level.					
4 Climate change will have an impact on the natural environment in the UK.					
5 There exists a strong link between climate change and conservation management.					
6 Conservation efforts will suffer from the impacts of climate change.					
7 Climate change should be a consideration in the development of conservation policy and strategies in Europe.					
8 Climate change should be a consideration in the development of conservation policy and strategies in the UK.					

The MONARCH study results, based on complex computer modelling, indicate that climatic shifts will impact on the assembly, distribution and abundance of vegetative communities in the UK. Let's use beech as an example. The vitality and abundance of beech is expected to decline in the SE over the next 50 years.

Attitude to the specific habitat issue		**1**	**2**	**3**	**4**	**5**
9	We should strive to maintain beech woodlands in areas of current conservation focus in southeast England (Kent, Chilterns).					
10	The existence of beech in the north of England is undesirable because it is considered to be non-native to that area.					
11	The current conception of the beech's native range will hinder efforts to conserve this habitat type in future.					
12	Beech woodland should be actively encouraged as a future natural woodland type in Cumbria and the Peak District.					

Attitude towards the conservation of flora and vegetation		**1**	**2**	**3**	**4**	**5**
13	There is potential in Cumbria to create similar assemblages of beech woodland floral communities as exist currently in the south (Kent/Chilterns).					
14	Steps should be taken to ensure the continuity of current vegetation assemblages in the UK.					
15	The translocation of species (particularly slow-colonizing woodland specialists and rare species) should be considered as a potential strategy for ensuring floral community re-assembly.					
16	New floral assemblages developing under beech woodlands should be valued in conservation terms.					
17	The UK National Vegetation Classification should be re-written as vegetation assemblages change over time.					

Please elaborate on the following questions:

a) What role will climate change play in influencing the functionality of natural environmental systems?

b) How will climate change affect current conservation efforts?

c) Which steps, if any, should be taken to ensure climate change impacts on conservation are addressed?

d) In which ways, if any, should the strategy for the future conservation of beech woodlands in the UK be altered to accommodate the effects of climate change?

e) What types of strategies, if any, that should be considered with regards to floral community re-assembly, both at local and landscape scales?

Thank you very much for your time and interest.

Appendix C. List of questionnaire consultees

	Organisation	Name
1	Academia	Pam Berry
2	Academia	Peter Buckley
3	Academia	Julian Evans
4	Academia	John Good
5	Academia	George Peterken
6	Chilterns Project	John Morris
7	Countryside Council for Wales	Jim Latham
8	Cumbria Wildlife Trust	David Harpley
9	English Nature	Paul Hackman
10	English Nature	Mike Harley
11	English Nature	Ben Le Bas
12	Forestry Commission	Alan Betts
13	Forestry Commission	Mark Broadmeadow
14	Forestry Commission	Fred Currie
15	Forestry Commission	Keith Jones
16	Forestry Commission	Simon Pryor
17	Forestry Commission	Jonathan Spencer
18	National Trust	David Russell
19	Natural Environment Research Council	Mike Moorecroft
20	Woodland Trust	Richard Smithers

Appendix D. Beech woodland species frequencies

Species (in NVC W12, W14, W15)	NVC Occurrence W12	W14	W15	KENT	OXON.	CUMB.	DERB.
Acer pseudoplatanus seedling	1	1	1	5	5	5	5
Agrostis capillaris		1	2	4	5	5	4
Agrostis stolonifera		1		5	5	5	4
Ajuga reptans	1			4	5	5	2
Alliaria petiolata	1			5	5	5	4
Allium ursinum	1			1	3	4	2
Anemone nemorosa	1	1		4	5	5	2
Anthriscus sylvestris	1			5	5	5	5
Arctium minus agg.	1			3	5	5	4
Arrhenatherum elatius	1			5	5	5	5
Arum maculatum	1	1		5	5	3	3
Blechnum spicant			1	1	1vr	4	2
Brachypodium sylvaticum	2	1		5	5	3	2
Bromus ramosus	1	1		4	5	3	3
Bromus sterilis	1			5	5	2	4
Calluna vulgaris			1	1	3	4	2
Campanula trachelium	1			2	4	1	1
Carex flacca	1			2	5	4	2
Carex pilulifera			1	1	2	2	1
Carex remota		1		2	5	3	1
Carex sylvatica	1	1		3	5	2	1
Cephalanthera damasonium	1			1	4	0	0
Circaea lutetiana	1	1		4	5	4	2
Clematis vitalba	1			4	5	1	1
Crataegus monogyna seedling	1			5	5	5	5
Cynoglossum officinale	1			1	1	1vr	1vr
Dactylis glomerata	1	1		5	5	5	5
Daphne laureola	1			1	3	1	1vr
Deschampsia cespitosa	1	2		3	5	5	4
Deschampsia flexuosa		1	3	1	3	3	3
Digitalis purpurea		1		3	5	5	4
Dryopteris dilatata	1	1	1	2	5	5	4
Dryopteris filix-mas	1	2		5	5	5	5
Epilobium angustifolium	1		1	5	5	5	5
Epilobium montanum	1			3	5	5	4
Epipactis helleborine		1		1	2	1	1
Euphorbia amygdaloides	1	1		2	5	1vr	1vr
Fagus sylvatica seedling	2	4	3	4	5	5	4
Festuca gigantea		1		2	5	3	2
Fragaria vesca	1			3	3	4	2

Species (in NVC W12, W14, W15)	NVC Occurrence W12	W14	W15	KENT	OXON.	CUMB.	DERB.
Fraxinus excelsior seedling	2	1		5	5	5	5
Galium aparine	1			5	5	5	5
Galium mollugo	1			5	4	4	1
Galium odoratum	1	1		1	2	2	1
Galium verum		1		1	5	4	2
Geranium robertianum	1			5	5	5	5
Geum urbanum	1	1		5	5	5	4
Glechoma hederacea	1			5	5	4	4
Hedera helix	3	2	1	5	5	5	4
Heracleum sphondylium	1			5	5	5	5
Holcus lanatus		1	1	5	5	5	5
Holcus mollis		2	1	3	3	5	3
Hyacinthoides non-scripta	1	1	1	5	3	5	4
Hypericum hirsutum	1			2	3	2	1
Hypericum pulchrum		1		1	1	4	1
Ilex aquifolium seedling	1	1	2	5	4	5	5
Iris foetidissima	1			1	1	1vr	1vr
Lamiastrum galeobdolon	1	1		3	2	1	2
Listera ovata	1			1	2	2	1
Lonicera periclymenum	1	2	1	5	4	5	3
Luzula pilosa		2	1	1	1	3	1
Luzula sylvatica			1	1	1	2	1
Melampyrum pratense			1	1	1	1	1
Melica uniflora	2	2		3	2	2	1
Mercurialis perennis	4	1		4	4	5	4
Milium effusum	1	2		1	2	1	1
Moehringia trinervia		1		3	3	3	2
Molinia caerulea			1	1	1vr	3	1
Mycelis muralis	2			1	2	3	2
Neottia nidus-avis	1			1	1	1	1vr
Oxalis acetosella		2	1	2	2	5	3
Phyllitis scolopendrium	1			2	2	3	2
Poa nemoralis	2	1	1	3	3	2	1
Poa trivialis	1	1		5	5	5	4
Primula vulgaris	1			4	3	5	4
Pteridium aquilinum		3	3	4	3	5	4
Quercus petraea seedling			1	1	1	5	2
Quercus robur seedling		1	1	5	5	5	4
Ranunculus bulbosus	1			5	5	4	3
Ranunculus ficaria	1			5	5	5	3
Ranunculus repens		1		5	5	5	5
Rosa canina agg.	1			5	5	5	4
Rubus fruticosus agg.	3	5	2	5	5	4	5
Rubus idaeus		1		1	3	5	4

Species (in NVC W12, W14, W15)	**NVC Occurrence W12**	**W14**	**W15**	**KENT**	**OXON.**	**CUMB.**	**DERB.**
Rumex sanguineus	1			5	5	4	3
Ruscus aculeatus		1	1	1	1	1vr	0
Sanicula europaea	2			2	2	3	1
Silene dioica	1			3	3	5	5
Solidago virgaurea	1			1	1	2	1
Sorbus aucuparia seedling		1	1	1	2	5	4
Stachys sylvatica	1			5	5	5	5
Stellaria media		1		5	5	5	5
Tamus communis	2			5	5	1	3
Taxus baccata seedling	1	1		3	3	2	2
Teucrium scorodonia	1			3	1	4	3
Urtica dioica	1	1		5	5	5	5
Vaccinium myrtillus			2	1	0	4	2
Veronica chamaedrys	1			5	5	5	4
Viola riviniana/reichenbachiana	2	1		4	4	5	4

Appendix E. Site descriptions

Canopy Density Key

1- 61-70%; 2- 71-80%; 3- 81-90%; 4- 91-100%

#	Location	Site	Type	Canopy Density	Beech	Other Major	Other Minor
1	Chilterns (OX)	Hammond's Wood 1	W12	3	Mature	*Fraxinus excelsior*	*Corylus avellana* *Sambucus Nigra* *Cornus sanguinea* *Prunus avium* *Betula spp.* *Acer campestre* *Larix spp.* *Ulmus procera*
2	Chilterns (BK)	Aston Wood	W12	2	Near Mature	*Fraxinus excelsior*	*Sambucus nigra* *Crataegus monogyna*
3	Chilterns (OX)	Shirburn Wood	W12	3	Mature	*Corylus avellana* *Fraxinus excelsior* *Taxus baccata*	*Sambucus nigra* *Betula spp.*
4	Chilterns (OX)	Greenfield Copse 2	W12	3	Mature	*Fraxinus excelsior*	*Prunus avium* *Quercus spp.* *Acer pseudoplatanus*
5	Chilterns (OX)	Howe Wood	W12	4	Near Mature	*Fraxinus excelsior*	*Prunus avium*
6	Chilterns (OX)	Shamridge Wood 2	W12	4	Mature	*Fraxinus excelsior*	*Prunus avium* *Ulmus procera* *Sambucus nigra* *Sorbus aria* *Acer campestre* *Ilex aquifolium*
7	Chilterns (OX)	Hammond's Wood 2	W14	4	Mature		*Fraxinus excelsior* *Corylus avellana* *Ilex aquifolium* *Ulmus procera* *Sambucus nigra* *Prunus avium*
8	Chilterns (OX)	Harpsden Wood	**W14**	2	Mature		*Prunus avium* *Crataegus monogyna* *Sorbus aucuparia* *Betula spp.* *Picea abies* *Ilex aquifolium*
9	Chilterns (OX)	Withy Copse	**W14**	3	Mature		*Ilex aquifolium* *Betula spp.* *Prunus avium*

#	Location	Site	Type	Canopy Density	Beech	Other Major	Other Minor
10	Chilterns (OX)	Rummerhedge Wood	**W14**	4	Mature		*Quercus spp.* *Fraxinus excelsior*
11	Chilterns (OX)	Greenfield Copse 1	**W14**	4	Mature		
12	Chilterns (OX)	Shamridge Wood 1	**W14**	4	Mature		*Quercus spp.* *Fraxinus excelsior* *Sorbus aria*
13	Cumbria	Serpentine Wood	**W12**	4	Mature	*Fraxinus excelsior* *Acer pseudoplatanus* *Ulmus procera*	*Taxus baccata* *Ilex aquifolium*
14	Cumbria	Whitbarrow 1	**W12**	4	50 year	*Acer pseudoplatanus*	*Fraxinus excelsior* *Taxus baccata*
15	Cumbria	Whitbarrow 2	**W12**	4	50 year	*Fraxinus excelsior* *Acer pseudoplatanus* *Taxus baccata*	*Betula spp.* *Ulmus procera* *Prunus padus*
16	Cumbria	Beech Hill Wood	**W14**	2	Mature (100yr)		*Fraxinus excelsior* *Quercus spp.* *Taxus baccata* *Picea abies* *Betula spp.* *Ilex aquifolium*
17	Cumbria	Linsty Green	**W14**	4	50 year	*Betula spp.*	*Fraxinus excelsior* *Taxus baccata* *Ilex aquifolium*
18	Cumbria	Yewbarrow	**W14**	3	Mixed age		*Quercus spp.* *Betula spp.* *Acer pseudoplatanus* *Taxus baccata*
19	Cumbria	Castlehead Wood	**W14**	4	Mixed age	*Quercus spp.*	*Betula spp.* *Acer pseudoplatanus*
20	Cumbria	Dalton Park 1	**W14**	4	50 year	*Fraxinus excelsior*	*Acer pseudoplatanus* *Quercus spp.* *Betula spp.*
21	Cumbria	Dalton Park 2	**W14**	4	50 year		*Fraxinus excelsior* *Quercus spp.* *Betula spp.*
22	Cumbria	Dalton Park 3	**W14**	4	50 year		*Quercus spp.*

Field Layer Abundance Key	
1- <20%	3- 41-60%
2- 20-40%	4- 61-80%
	5- 81-100%

#	Understorey		Plot Cover			
	Other Major	Other Minor	(%avg) Bare Soil	(%avg) Litter	(%avg) Bryophytes	Field Layer
1	*Fraxinus excelsior*	*Corylus avellana* *Ulmus procera* *Sambucus nigra*	14	70	15	4
2	*Fraxinus excelsior*	*Ilex aquifolium* *Sambucus nigra* *Crataegus monogyna* *Corylus avellana* *Sorbus aria* *Ligustrum vulgare* *Rosa spp.* *Acer pseudoplatanus*	15	85	2	4
3	*Corylus avellana* *Sambucus Nigra*	*Crataegus monogyna* *Betula spp.*	29	61	11	4
4	*Fraxinus excelsior* *Acer pseudoplatanus* *Sambucus Nigra*	*Crataegus monogyna* *Ilex aquifolium* *Corylus avellana* *Rosa spp.*	18	76	3	2
5	*Fraxinus excelsior* *Ilex aquifolium*		23	77	<1	4
6	*Ilex aquifolium*	*Fraxinus excelsior* *Ulmus procera*	11	88	<1	3
7	*Ilex aquifolium*	*Corylus avellana* *Sambucus nigra*	2	96	2	3
8		*Betula spp.* *Ilex aquifolium* *Fraxinus excelsior* *Crataegus monogyna*	1	98	1	4
9	*Ilex aquifolium*		3	94	3	1
10		*Ilex aquifolium*	1	99	<1	3
11	*Ilex aquifolium* *Taxus baccata*	*Acer pseudoplatanus* *Sorbus aucuparia* *Sambucus nigra* *Fraxinus excelsior*	2	98	<1	2
12		*Ilex aquifolium* *Fraxinus excelsior*	2	98	<1	2
13	*Ilex aquifolium* *Fraxinus excelsior* *Ulmus procera* *Acer pseudoplatanus*	*Crataegus monogyna*	6	84	7	3
14		*Ilex aquifolium*	2	82	14	1
15			5	74	17	1
16		*Ilex aquifolium*	10	80	10	1
17			9	83	7	1
18			4	85	8	1

#	Understorey		Plot Cover			
	Other Major	Other Minor	(%avg) Bare Soil	(%avg) Litter	(%avg) Bryophytes	Field Layer
19			53	18	29	1
20			1	93	6	3
21			2	92	4	3
22			1	95	3	3

#	Understorey					(cm dbh)				
	Density	>50 cm Seedlings	50cm-2.5m Saplings	>2.5m-10cm dbh	11-20	21-30	31-40	41-50	51-60	60+
1	2	0	4	2	3	3	1	2	2	0
2	1	25	20	10	0	1	2	4	1	0
3	1	2	0	0	0	0	0	1	2	1
4	1	2	0	2	0	0	0	1	1	3
5	1	0	0	0	0	0	1	3	1	2
6	1	1	0	0	1	1	1	0	2	3
7	1	3	1	0	0	1	3	2	3	0
8	2	24	37	5	0	1	1	1	2	1
9	1	14	18	3	0	0	4	4	3	0
10	1	100+	6	9	0	0	0	1	2	0
11	1	14	2	0	1	0	1	1	5	2
12	1	2	0	0	0	2	2	0	4	2
13	4	100+	100+	34	4	0	0	0	0	3
14	1	50	0	2	26	13	0	0	0	0
15	1	33	0	8	13	10	1	0	0	0
16	1	27	0	1	2	0	0	0	0	5
17	1	15	0	1	9	17	4	0	0	0
18	1	100+	15	0	1	3	2	1	1	0
19	1	47	9	6	2	4	1	1	1	2
20	1	2	0	13	22	12	2	0	0	0
21	1	15	0	4	18	7	6	1	0	0
22	1	1	0	0	20	30	4	0	0	0

Appendix F. Woodland specialist list

List of species classed as woodland specialists; the number of ancient woodland indicator lists in which they were included; and their 'woodland specialist' score (after Kirby *et al.* 2000).

Aconitum anglicum	2	10	*Fragaria vesca*	1	5
Adoxa moschatellina	8	40	*Gagea lutea*	2	20
Agropyron caninum	5	25	*Galanthus nivalis*	1	15
Alchemilla filicaulis	1	5	*Galium odoratum*	11	45
Allium ursinum	7	45	*Geranium robertianum*	1	5
Anemone nemorosa	9	15	*Geranium sanguineum*	1	5
Aquilegia vulgaris	7	30	*Geranium sylvaticum*	1	10
Athyrium filix-femina	2	15	*Geum rivale*	6	30
Blechnum spicant	4	25	*Gymnocarpium dryopteris*	2	45
Bromopsis benekenii	1	5	*Helleborus foetidus*	1	15
Bromopsis ramosa	5	30	*Helleborus viridis*	5	20
Calamagrostis canescens	2	15	*Holcus mollis*	3	0
Calamagrostis epigejos	5	15	*Hordelymus europaeus*	3	35
Campanula latifolia	3	35	*Hyacinthoides non-scripta*	6	30
Campanula patula	1	10	*Hymenophyllum tunbridgensis*	2	25
Campanula trachelium	6	45	*Hymenophyllum wilsonii*	1	10
Cardamine amara	2	25	*Hypericum androsaemum*	5	10
Cardamine impatiens	1	15	*Hypericum hirsutum*	2	25
Carex acutiformis	1	5	*Hypericum pulchrum*	5	25
Carex elongata	1	30	*Hypericum tetrapterum*	1	15
Carex laevigata	8	30	*Iris foetidissima*	4	45
Carex montana	1	5	*Lamiastrum galeobdolon*	9	55
Carex pallescens	8	35	*Lathraea squamaria*	9	20
Carex pendula	9	50	*Lathyrus linifolius*	7	15
Carex remota	8	45	*Lathyrus sylvestris*	5	10
Carex strigosa	8	20	*Listera ovata*	2	40
Carex sylvatica	8	55	*Luzula forsteri*	5	20
Cephalanthera damasonium	2	30	*Luzula pilosa*	10	45
Cephalanthera longifolium	2	15	*Luzula sylvatica*	9	25
Chrysosplenium alternifolium	4	25	*Lysimachia nemorum*	8	45
Chrysosplenium oppositifolium	9	20	*Lysimachia vulgaris*	1	10
Colchicum autumnale	4	5	*Lythrum portula*	1	10
Conopodium majus	6	5	*Maianthemum bifolium*	2	10
Convallaria majalis	8	50	*Melampyrum pratense*	8	25
Corydalis claviculata	4	35	*Melampyrum sylvaticum*	1	20
Daphne laureola	4	45	*Melica nutans*	1	55
Dipsacus pilosus	5	10	*Melica uniflora*	10	55
Dryopteris aemula	3	20	*Melittis melissophyllum*	3	30
Dropteris affinis	5	35	*Mercurialis perennis*	4	35
Dryopteris carthusiana	4	15	*Milium effusum*	9	55
Epipactis helleborine	6	45	*Moehringia trinervia*	5	40
Epipactis leptochila	2	10	*Monotropa hypopithys*	2	20
Epipactis phyllanthes	1	10	*Myosotis sylvatica*	4	40
Epipactis purpurata	5	10	*Narcissus pseudonarcissus*	5	20
Equisetum sylvaticum	6	35	*Neottia nidus-avis*	9	30
Equisetum telmateia	1	25	*Ophioglossum vulgatum*	1	-5
Euphorbia amygdaloides	8	30	*Ophrys insectifera*	1	No data
Festuca altissima	1	45	*Orchis mascula*	7	30
Festuca gigantea	4	45	*Orchis purpurea*	1	15

Omalotheca sylvatica	1	15
Orobanche hederacea	1	10
Oxalis acetosella	7	35
Paris quadrifolia	10	10
Phyllitis scolopendrium	4	35
Pimpinella major	2	5
Platanthera chlorantha	6	40
Poa nemoralis	6	40
Polygonatum multiflorum	5	45
Polypodium vulgare agg	3	30
Polystichum aculeatum	6	20
Polystichum setiferum	1	30
Potentilla sterilis	5	30
Primula elatior	1	25
Primula vulgaris	7	30
Pulmonaria longifolia	2	15
Radiola linarioides	1	No data
Ranunculus auricomus	7	30
Ribes nigrum	4	30
Ribes sylvestre	5	35
Rosa arvensis	3	40
Ruscus aculeatus	4	35
Sanicula europaea	5	55
Scirpus sylvatica	5	25
Scrophularia nodosa	1	25
Scutellaria minor	1	15
Sedum telephium	5	15
Serratula tinctoria	2	10
Sibthorpia europea	1	10
Silene dioica	1	10
Solidago virgaurea	4	20
Stachys officinalis	4	5
Stachys sylvatica	1	15
Stellaria holostea	2	30
Stellaria nemorum	1	35
Tamus communis	3	30
Thelypteris limbosperma	4	15
Thelypteris phegopteris	2	45
Vaccinium myrtillus	4	10
Valeriana officinalis	1	5
Veronica montana	9	55
Vicia sepium	4	5
Vicia sylvatica	8	15
Viola odorata	3	30
Viola reichenbachiana	9	45
Viola riviniana	2	20
Wahlenbergia hederacea	2	15

Additional species included in the Peak District list only, and not included in the main analysis as 'woodland specialists'.

Brachypodium sylvaticum	-	35
Carex digitata	-	No data
Circaea intermedia	-	20
Cirsium heterophyllum	-	No data
Daphne mezereum	-	30
Lithospermum officinale	-	No data
Lonicera peridymenum	-	30
Polygonatum odoratum	-	10
Pyrola minor	-	50
Rubus caesius	-	30
Rubus saxatilis	-	35
Stellaria neglecta	-	10
Trollius europaeus	-	25
Viola palustris	-	20

Appendix G. Field species frequencies

Species Frequency By Stand (W12 and W14)

W12	**# Sites (# Plots)**	
Species	**Chilterns**	**Cumbria**
Fraxinus excelsior seedling	6 (27)	3 (14)
Mercurialis perennis	6 (29)	3 (5)
Rubus fruticosus agg.	6 (21)	3 (15)
Circaea lutetiana	6 (19)	2 (3)
Viola riviniana/reichenbachiana	6 (10)	2 (9)
Arum maculatum	5 (8)	3 (12)
Crataegus monogyna seedling	5 (12)	3 (8)
Geum urbanum	5 (13)	3 (4)
Brachypodium sylvaticum	5 (12)	2 (6)
Fagus sylvatica seedling	4 (6)	3 (12)
Dryopteris filix-mas	4 (5)	2 (8)
Carex sylvatica	3 (4)	2 (2)
Acer pseudoplatanus seedling	2 (2)	3 (11)
Fragaria vesca	2 (2)	2 (2)
Hyacinthoides non-scripta	2 (2)	2 (3)
Galium odoratum	5 (15)	1 (2)
Geranium robertianum	4 (7)	1 (3)
Hedera helix	3 (4)	1 (5)
Ilex aquifolium seedling	3 (3)	1 (2)
Taraxacum officinale	3 (3)	1 (2)
Poa trivialis	2 (4)	1 (1)
Oxalis acetosella	1 (2)	2 (4)
Veronica chamaedrys	1 (3)	2 (2)
Ajuga reptans	1 (1)	1 (2)
Alliaria petiolata	1 (1)	1 (1)
Lonicera periclymenum	1 (1)	1 (4)
Urtica dioica	6 (11)	0
Lamiastrum galeobdolon	5 (13)	0
Galium aparine	4 (9)	0
Deschampsia cespitosa	3 (5)	0
Cornus sanguinea	2 (2)	0
Festuca gigantea	2 (2)	0
Melica uniflora	2 (3)	0
Rubus idaeus	2 (2)	0
Agrostis gigantea	1 (1)	0
Carex flacca	1 (1)	0
Carex pendula	1 (1)	0
Carex remota	1 (1)	0
Corylus avellana	1 (1)	0
Glechoma hederacea	1 (3)	0

W12	**# Sites (# Plots)**	
Species	**Chilterns**	**Cumbria**
Hordelymus europaeus	1 (4)	0
Hypericum hirsutum	1 (1)	0
Laurus nobilis	1 (1)	0
Leontodon taraxacoides	1 (1)	0
Ligustrum vulgare	1 (1)	0
Mycelis muralis	1 (1)	0
Poa nemoralis	1 (1)	0
Prunus avium	1 (1)	0
Pteridium aquilinum	1 (2)	0
Ranunculus auricomus	1 (1)	0
Sambucus nigra	1 (1)	0
Sanicula europaea	1 (1)	0
Senecio jacobaea	1 (1)	0
Stachys sylvatica	1 (1)	0
Taxus baccata seedling	1 (2)	0
Ulmus procera	1 (1)	0
Dryopteris dilatata	0	3 (9)
Euonymus europaeus	0	2 (2)
Phyllitis scolopendrium	0	2 (4)
Potentilla sterilis	0	2 (2)
Quercus spp. seedling	0	2 (2)
Agrostis capillaris	0	1 (1)
Allium ursinum	0	1 (3)
Anemone nemorosa	0	1 (2)
Arctium minus agg.	0	1 (1)
Conopodium majus	0	1 (1)
Dactylis glomerata	0	1 (1)
Dactylorhiza fuchsii	0	1 (1)
Epilobium montanum	0	1 (1)
Narcissus pseudonarcissus	0	1 (1)
Ophioglossum vulgatum	0	1 (1)
Primula vulgaris	0	1 (1)
Prunella vulgaris	0	1 (1)
Scrophularia nodosa	0	1 (1)
Solidago virgaurea	0	1 (1)
Sorbus aucuparia seedling	0	1 (1)
Tilia cordata seedling	0	1 (1)
Valeriana pyrenaica	0	1 (1)

Note: Quadrat 22 was sampled as a seventh Cumbria W14 site; it was the third Dalton Park site to be sampled, and was not characteristic of other W14 sites sampled (showing extremely low species diversity, likely due to elevated plantation density). To facilitate direct comparisons with Chiltern sites, and to avoid skewing results towards Dalton Park assemblages, it has been kept separate or was excluded from most of the analyses.

W14	# Sites (# Plots)		Quadrat 22
Species	**Chilterns**	**Cumbria**	**Cumbria**
Ilex aquifolium seedling	6 (14)	5 (20)	
Rubus fruticosus agg.	6 (28)	2 (4)	
Fraxinus excelsior seedling	5 (13)	6 (23)	1 (1)
Fagus sylvatica seedling	5 (13)	5 (14)	
Dryopteris dilatata	4 (7)	3 (6)	
Pteridium aquilinum	4 (4)	3 (3)	
Hyacinthoides non-scripta	3 (8)	4 (15)	1 (5)
Dryopteris filix-mas	3 (4)	2 (2)	
Carex remota	3 (4)	1 (1)	
Deschampsia cespitosa	2 (3)	5 (7)	
Oxalis acetosella	2 (3)	5 (7)	
Acer pseudoplatanus seedling	2 (3)	1 (1)	
Crataegus monogyna seedling	2 (2)	1 (2)	
Poa trivialis	2 (2)	1 (1)	
Lonicera periclymenum	1 (1)	3 (5)	
Sorbus aucuparia seedling	1 (1)	2 (2)	
Hedera helix	1 (1)	1 (1)	
Rubus idaeus	4 (4)	0	
Brachypodium sylvaticum	2 (3)	0	
Carex sylvatica	2 (3)	0	
Prunus avium	2 (5)	0	
Agrostis gigantea	1 (1)	0	
Athyrium felix-femina	1 (1)	0	
Betula pubescens/B pendula	1 (1)	0	
Circaea lutetiana	1 (2)	0	
Epilobium angustifolium	1 (1)	0	
Geranium robertianum	1 (1)	0	
Juncus effusus	1 (2)	0	
Lamiastrum galeobdolon	1 (2)	0	
Polystichum setiferum	1 (1)	0	
Rhododendron ponticum	1 (1)	0	
Sambucus nigra	1 (1)	0	
Agrostis capillaris	0	5 (9)	
Deschampsia flexuosa	0	3 (9)	
Quercus spp. Seedling	0	3 (7)	
Blechnum spicant	0	2 (2)	
Conopodium majus	0	2 (3)	
Holcus mollis	0	2 (2)	

W14	**# Sites (# Plots)**		**Quadrat 22**
Species	**Chilterns**	**Cumbria**	**Cumbria**
Hypericum hirsutum	0	2 (3)	
Luzula pilosa	0	2 (2)	
Solidago virgaurea	0	2 (2)	
Anemone nemorosa	0	1 (2)	
Anthoxanthum odoratum	0	1 (1)	
Betonica officinalis	0	1 (1)	
Carex pilulifera	0	1 (1)	
Festuca rubra	0	1 (1)	
Luzula sylvatica	0	1 (5)	
Melampyrum pratense	0	1 (2)	
Ranunculus acris	0	1 (1)	
Taraxacum officinale	0	1 (1)	
Taxus baccata seedling	0	1 (2)	
Teucrium scorodonia	0	1 (2)	

Appendix H. Ordination species key

1 *Acer pseudoplatanus* seedling
2 *Agrostis capillaris*
3 *Agrostis stolonifera*
4 *Ajuga reptans*
5 *Alliaria petiolata*
6 *Allium ursinum*
7 *Anemone nemorosa*
8 *Anthriscus sylvestris*
9 *Arctium minus* agg.
10 *Arrhenatherum elatius*
11 *Arum maculatum*
12 *Blechnum spicant*
13 *Brachypodium sylvaticum*
14 *Bromus ramosus*
15 *Bromus sterilis*
16 *Calluna vulgaris*
17 *Campanula trachelium*
18 *Carex flacca*
19 *Carex pilulifera*
20 *Carex remota*
21 *Carex sylvatica*
22 *Cephalanthera damasonium*
23 *Circaea lutetiana*
24 *Clematis vitalba*
25 *Crataegus monogyna* seedling
26 *Cynoglossum officinale*
27 *Dactylis glomerata*
28 *Daphne laureola*
29 *Deschampsia cespitosa*
30 *Deschampsia flexuosa*
31 *Digitalis purpurea*
32 *Dryopteris dilatata*
33 *Dryopteris filix-mas*
34 *Epilobium angustifolium*
35 *Epilobium montanum*
36 *Epipactis helleborine*
37 *Euphorbia amygdaloides*
38 *Fagus sylvatica* seedling
39 *Festuca gigantea*
40 *Fragaria vesca*
41 *Fraxinus excelsior* seedling
42 *Galium aparine*
43 *Galium mollugo*
44 *Galium odoratum*
45 *Galium verum*
46 *Geranium robertianum*
47 *Geum urbanum*
48 *Glechoma hederacea*
49 *Hedera helix*
50 *Heracleum sphondylium*
51 *Holcus lanatus*
52 *Holcus mollis*
53 *Hyacinthoides non-scripta*
54 *Hypericum hirsutum*
55 *Hypericum pulchrum*
56 *Ilex aquifolium* seedling
57 *Iris foetidissima*
58 *Lamiastrum galeobdolon*
59 *Listera ovata*
60 *Lonicera periclymenum*
61 *Luzula pilosa*
62 *Luzula sylvatica*
63 *Melampyrum pratense*
64 *Melica uniflora*
65 *Mercurialis perennis*
66 *Milium effusum*
67 *Moehringia trinervia*
68 *Molinia caerulea*
69 *Mycelis muralis*
70 *Neottia nidus-avis*
71 *Oxalis acetosella*
72 *Phyllitis scolopendrium*
73 *Poa nemoralis*
74 *Poa trivialis*
75 *Primula vulgaris*
76 *Pteridium aquilinum*
77 *Quercus petraea* seedling
78 *Quercus robur* seedling
79 *Ranunculus bulbosus*
80 *Ranunculus ficaria*
81 *Ranunculus repens*
82 *Rosa canina* agg.
83 *Rubus fruticosus* agg.
84 *Rubus idaeus*
85 *Rumex sanguineus*
86 *Ruscus aculeatus*
87 *Sanicula europaea*
88 *Silene dioica*
89 *Solidago virgaurea*
90 *Sorbus aucuparia* seedling
91 *Stachys sylvatica*
92 *Stellaria media*
93 *Tamus communis*
94 *Taxus baccata* seedling
95 *Teucrium scorodonia*
96 *Urtica dioica*
97 *Vaccinium myrtillus*
98 *Veronica chamaedrys*
99 *Viola riviniana/reichenbachiana*
100 *Agrostis gigantea*
101 *Anthoxanthum odoratum*
102 *Athyrium felix-femina*
103 *Betonica officinalis*
104 *Betula pubescens/B pendula*
105 *Carex pendula*
106 *Conopodium majus*
107 *Cornus sanguinea*
108 *Corylus avellana*
109 *Dactylorhiza fuchsii*
110 *Euonymus europaeus*
111 *Festuca rubra*
112 *Hordelymus europaeus*
113 *Juncus effusus*
114 *Laurus nobilis*
115 *Leontodon taraxacoides*
116 *Ligustrum vulgare*
117 *Narcissus pseudonarcissus*
118 *Ophioglossum vulgatum*
119 *Polystichum setiferum*
120 *Potentilla sterilis*
121 *Prunella vulgaris*
122 *Prunus avium*
123 *Ranunculus acris*
124 *Ranunculus auricomus*
125 *Rhododendron ponticum*
126 *Sambucus nigra*
127 *Scrophularia nodosa*
128 *Senecio jacobaea*
129 *Taraxacum officinale*
130 *Tilia cordata sdl.*
131 *Ulmus procera*
132 *Valeriana pyrenaica*

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