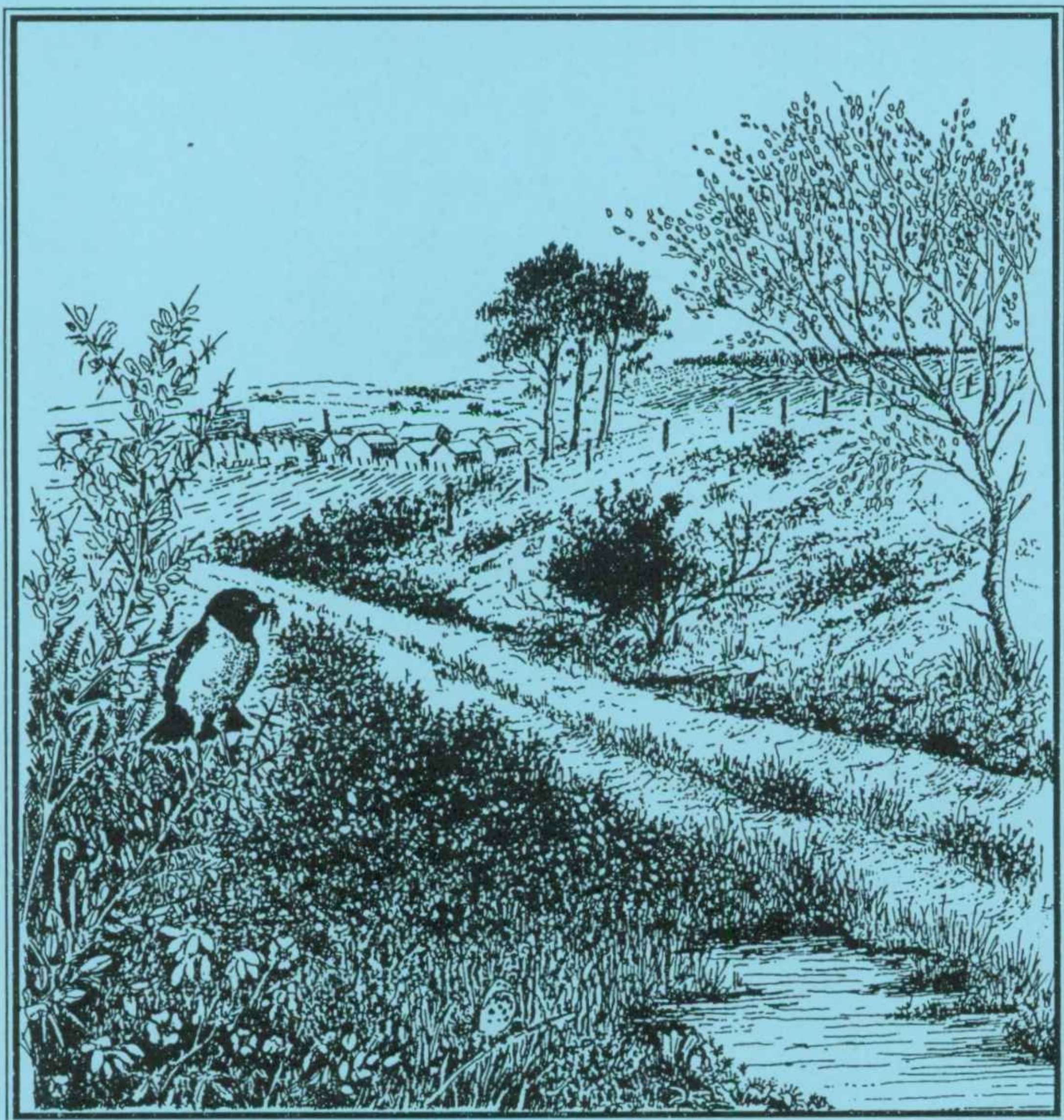
Department of the Environment



Current status and prospects for threatened habitats in England

Part 1

Lowland heath landscapes

ITE/ERM/UCPE contract report
to the
Department of the Environment

Current status and prospects for threatened habitats in England

Part 1

Lowland heath landscapes

Edited by

C J Barr

Institute of Terrestrial Ecology
Merlewood Research Station
Grange over Sands
Cumbria LA11 6JU

This Report is one of a series describing work on threatened habitats commissioned by the Department of the Environment. Views expressed in it do not necessarily concide with those of the Department.

CONTRACT

No. CR0 102

1996

CONTENTS

EXECUTIVE SUMMARY

Survey

1. In 1992, the Department of the Environment commissioned a research project to investigate the threatened habitats occurring within the landscape types included in the original Countryside Stewardship Scheme, of which lowland heath was one. The general aim of the project was to build on the work of the Countryside Survey 1990 and examine in more detail the distribution and quality of these habitats within the landscape types in England. This examination forms a basis against which future ecological changes, resulting from changing policies or specific initiatives, may be compared and measured.

2. The first step was to define the current geographical extent, and potential future extent, of the lowland heath landscape type. The broad geographical extent of the existing and potential areas was determined by soil type characteristics (acid, sand or peat soils) and altitude. The resulting database of 1 km squares was called the 'lowland heath mask'.

3. The next step was to characterise the lowland heath mask in terms of ecology, landscape features and archaeology. The 1 km squares were stratified according to landscape type (arable or pastural landscapes) and designation status (designated or non-designated). Squares in these four strata were then randomly sampled, and land cover, vegetation in quadrats, landscape features and historical features were recorded. Historic features were also collected from existing archaeological datasets and archives.

Current status

4. Just 5% of the lowland heath mask area was estimated to be lowland heath habitat. This habitat comprised a range of vegetation types from wet heath and bogs, through dry heath, to vegetation dominated by grass or scrub; 56% of the lowland heath mask contained one or more designation type but 74% of lowland heath habitats was designated. Nearly all wet heath and bogs were designated but a substantial proportion of dry heath occurred in areas that were not designated.

5. In addition to the core heathland vegetation, areas of modified heathland vegetation were identified, which had been colonised or planted with trees, but still contained a recognisable heathland flora. These modified heathland areas occurred throughout the lowland heath mask, but were most common on designated land and on drier soils.

	Area (ha)
Lowland heathland habitat	44 000
Modified heathland vegetation types	67 400
Lowland heath mask	853 800

6. Objective measures of vegetation (recorded in quadrats) have been related to quality criteria, to provide an empirical evaluation of the quality of heathland vegetation in different parts of the lowland heath landscape. Using at least two separate measures of each of the quality criteria, the four survey strata were ranked. Based on quadrat information, heathland in the designated pastural stratum ranked highest for all measures and the designated arable was the next highest, except for one measure of representativeness and one of fragility (where non-designated pastural land was higher). This finding confirms the relationship between designated land and 'good-quality' heath.

7. From examination of historic records, the lowland heath mask was shown to contain features from all historic periods, although representation of the Early Medieval period is sparse. The frequency of features was higher in designated than in non-designated strata. There appears to be a strong correlation between Scheduled Ancient Monument designation and other types of designation, particularly Areas of Outstanding Natural Beauty. It is not possible to say whether designation status has helped to preserve sites or whether, by contrast, designated sites have been subject to more intensive examination.

8. It was recognised that, without time-series data, it was difficult to assess the effect of designation. It was not known, for example, whether correlations between 'good' areas of lowland heath and some form of designation were because the designation had been effective, or whether the designation was

made because of the quality of the heath. However, this study provides for the first time an essential baseline, necessary to conduct future monitoring of the effectiveness of designations.

Threats

9. Lowland heathlands are usually found on acidic soils with a low weathering rate in areas which are particularly vulnerable to the acidifying effects of acid deposition. During the period 1989–91, 93% of the lowland heath mask was in exceeded areas (ie where the pollutant deposition exceeds the weathering rate of the soil), with only a few areas of the Brecklands and the Lizard peninsula in unexceeded areas. In lowland England, the soil acidity critical load was exceeded in 57% of the total area.

10. Current emission reduction scenarios appear to be relatively ineffective at protecting the lowland heathland areas of England. There is insufficient quantitative information on the effects of sulphur deposition on heathland fauna and flora to be certain of how damaging these exceedances will be to lowland heathland ecosystems as a whole.

11. Average atmospheric deposition of nitrogen (NO_x and NH_x) in heathland areas is 17 kg nitrogen ha^{-1} yr^{-1}, which is similar to that received by other parts of lowland England (18 kg nitrogen ha^{-1} yr^{-1}). Areas with high N deposition (>20 kg) occur mainly in the west Midlands, the north-west, Hampshire and Surrey. Heathlands in designated squares are more likely (26%) to be receiving over 20 kg nitrogen ha^{-1} yr^{-1} than those in non-designated squares (16%).

12. These rates of atmospheric N deposition are low compared to average agricultural inputs, and there is no experimental information describing the long-term effects of these rates on lowland heathlands in Britain. However, experimental results from grasslands on peat soils elsewhere suggest that the low rates of atmospheric N will have a significant effect on community composition in lowland heathlands, with gradual nutrient enrichment leading to a loss of plant species diversity and a transition from heath to grass.

13. Other threats to heathland include:
    - landtake for urban expansion, arable use, afforestation, mineral extraction and road building;
    - fragmentation as a result of encroachment associated with all of the above;
    - changes to land use and practices on adjoining lands, particularly afforestation and agricultural intensification;
    - recreational use of surviving commons.

Prospects

14. To consider what vegetation changes may take place under different scenarios of perceived threats, the study has made use of the 'Competitors: Stress-tolerators: Ruderals' (C-S-R) classification of functional types, and the TRISTAR2 model which predicts vegetation change in response to environmental and/or management change scenarios and also the composition of the new steady-state vegetation in terms of its component functional types.

15. Most of the 'core' heathland vegetation is composed of stress-tolerator and stress-tolerator/competitor species. The remaining vegetation plot types are representative of all other combinations of functional types.

16. The TRISTAR2 model calculated the predicted change in abundance of the functional types under a range of scenarios chosen to simulate the combined effects of grazing pressure, pollution, eutrophication and climatic warming, and an index of vulnerability was produced. Lowland heath habitat consists of a heterogeneous grouping of heath, grassland and woodland vegetation, all of which are relatively unproductive. The ecological hypothesis that such vegetation is likely to be resilient to changes in environmental conditions, at least in the short term, is supported by the results with only one class of vegetation (damp, acid grassland) reaching even 'moderate' vulnerability. In general, grassland plot classes are among the more vulnerable, with woodland being the best protected and heathland vegetation occupying a middle position.

17. Heathland is a valuable landscape, dominated by a non-climax vegetation type. Because the vegetation is non-climax, intervention is required to prevent heathland turning into scrub/woodland; heathland therefore requires management to maintain its condition. The survey results indicate that, of the area within the lowland heath landscape (853 000 ha), about 650 000 ha may at one time have been heath and is still

in a land use which could revert, such as forestry or agriculture. However, the 67 000 ha of modified heathland vegetation types which have been colonised or planted with trees, but still contain a recognisable heathland flora, provide the best opportunity for heathland restoration.

Estimates of existing heathlands in England by category (area in ha)

	Estimates	
	Field survey	Other
Core lowland heaths	36 100	32 000
Recently modified, potential for restoration	67 400	22 000
Never heathland, significantly modified, some potential for (re-)creation	642 200	N/a
Unavailable, no potential	108 100	N/a
Total lowland heath mask	853 800	N/a

18. Working from the *Biodiversity Action Plan* draft objectives (as published in 1994) as a starting point, it is possible to establish the following objectives:
    - to bring 5400 ha of core heath in private ownership and not covered by existing enhancement schemes under good management;
    - to restore 6000 ha of modified heathland and maintain this under good management, focusing on expansion and linking between existing core heath sites;
    - to re-create heathland habitat on *c* 600 ha of former heathland landscape to provide priority linkages between core heath sites.

19. If such targets are seen as being realistic, it is recommended that they are achieved by extending existing schemes offering incentives for restoration and management on private land and implementing re-creation on Forestry Commission land.

20. To ensure that the benefits of these measures are retained in the long term, and transferred to other areas, it is also essential that effective management approaches are identified and publicised and that awareness of the value of lowland heath habitats is raised.

Chapter 1 INTRODUCTION: PURPOSE AND CONTEXT OF THE REPORT

1.1 Policy background

1.1.1 Despite much concern over the loss of semi-natural habitats in recent decades, there are inadequate levels of information as to the location and status of some rare and important habitats on a national scale. This information is becoming available through thematic and local surveys and is essential if assessments are to be made of the likely impacts of changing policies (eg Common Agricultural Policy, Habitats Directive, Biodiversity Action Plan) or of current incentive schemes (eg Countryside Stewardship) on the distribution and quality of these habitats.

1.1.2 To add to knowledge and understanding in these areas, the Department of Environment (DOE) commissioned a research project to investigate the threatened habitats occurring within the landscape types included in the original Countryside Stewardship Scheme. These are:

i. lowland heath landscapes
ii. chalk and limestone grasslands landscapes
iii. upland landscapes
iv. coastal landscapes
v. river valleys and waterside landscapes

1.1.3 These landscape types, together with their constituent habitats (see Box 1), are seen as areas which have suffered serious losses and degradation of habitats in the past and appear to be still under threat. They are perceived as having great value for wildlife, landscape, history and amenity/public enjoyment.

1.1.4 The general aim of the project was to build on the work of the Countryside Survey 1990 and examine in more detail the distribution and quality of threatened habitats within the landscape types in England. This examination forms a basis against which future scenarios of change, resulting from changing policies or specific initiatives, may be measured and compared. The project has also attempted to develop a methodology for measuring change at the national level; it reviews current policy instruments affecting threatened habitats and considers prospects for the future.

1.2 Research context

1.2.1 Countryside Survey 1990 (CS1990), a project carried out by ITE, jointly funded by NERC, DOE and the former Nature Conservancy Council, was developed from earlier surveys of GB and included field surveys of land cover, landscape features and vegetation quadrats. It also included soil surveys of all sample squares and was linked to a project mapping the land cover of GB using satellite imagery (Barr *et al.* 1993).

1.2.2 For the Countryside Survey 1990 fieldwork, a standard sample unit of 1 km x 1 km square has been used. Squares visited in the earlier surveys (1978 and 1984) were surveyed in 1990 and an additional 124 squares were added to the sample, giving a total of 508 squares.

1.2.3 Although the 1978, 1984 and 1990 Countryside Surveys provide comparatively

> *Box 1.1*
>
> In the context of this project, the lowland heath **landscape type** is a conceptual term for geographical area(s) in which lowland heath occurs or has occurred, historically, and includes other land cover types (eg farmland) which form mosaics with heath. The **mask** is a cartographic term which, in this project, is a map which includes both the lowland heath landscape type and areas which have the potential to be included in the landscape type. Individual **habitats**, such as lowland heath, scrub woodland and grassland, occur within the landscape type.

up-to-date information on general changes in the British countryside, the sample-based system was not designed to yield data on rarer, or localised, habitats. Thus, there was a need for information about these habitats which are perceived to be under threat, or which represent areas of concern to the Department. This Report describes work undertaken on the lowland heath landscape type.

1.3 Objectives

1.3.1 The objectives for each landscape type were to:

i. determine the distribution of the landscape type in England;

ii. survey the habitats (including major land cover types and ecological features such as hedgerows) and historic features within each landscape type;

iii determine, on a regional basis and in relation to current designations, the composition of each landscape type in terms of the quantity and quality of the surveyed features;

iv. develop models to predict the effect of environmental and management changes on the distribution and quality of the landscape types and their constituent habitats;

v. in the light of the above, make recommendations on ways in which policy instruments may be refined to further protect, enhance or re-establish the habitats which characterise each landscape type; and

vi. establish a baseline and develop a methodology for measuring change in these habitats which is sufficiently robust and precise to assess the effectiveness of policies, at a national (England) scale.

1.4 General approach

1.4.1 To meet the objectives of this project, a consortium was assembled which brought together the ecological and modelling knowledge and skills of ITE and the NERC Unit of Comparative Plant Ecology (UCPE) with the policy-related expertise of Environmental Resources Management (ERM). Giving additional support, in relation to historical aspects, was the Archaeological Unit of the University of Lancaster.

1.4.2 The general approach used by the research team can be summarised in the diagram below.

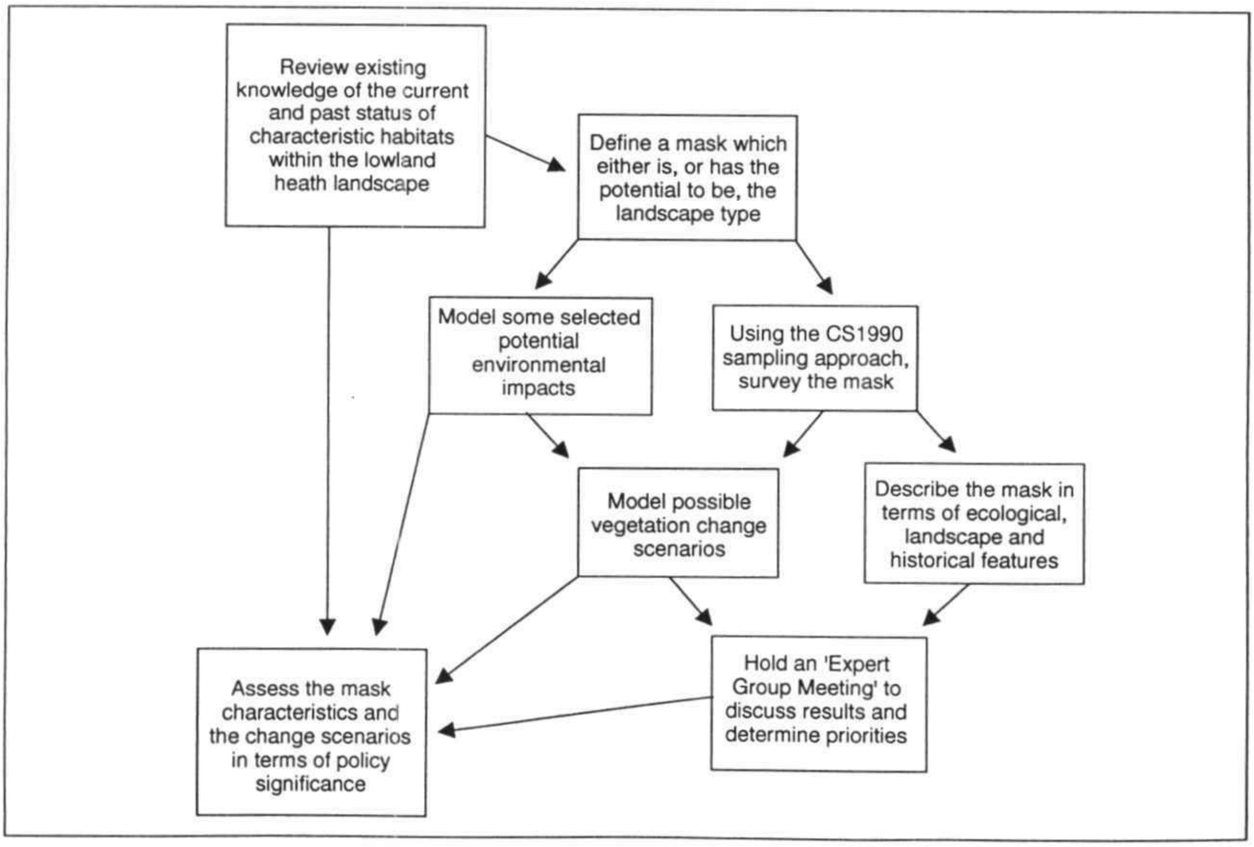


Figure 1.1 General approach used by the research team

1.5 Structure of the Report

1.5.1 The task of compiling this Report was undertaken jointly by members of the research team. The structure of the Report reflects the overall approach, as shown in Figure 1.1, with steps in the research being reported as separate Chapters. The final Chapter brings together the main conclusions from each phase of the work and gives a summary of the project, in relation to the objectives.

Chapter 2 BACKGROUND: THE IMPORTANCE OF LOWLAND HEATH

2.1 Introduction

2.1.1 This Chapter is based on a review of existing literature and gives a general definition of lowland heath and its distribution within England. It describes its distinctive ecological, scenic, recreational and historical characteristics, and explains why lowland heath is important in a national and international context. The evolution of lowland heath, and the factors important to its maintenance are discussed. Trends for change and threats to the lowland heath resource are briefly reviewed and the need for conservation and enhancement is highlighted.

2.2 Lowland heath – a general definition

2.2.1 Lowland heath in England comprises areas of open ground characterised by acidic podzolised mineral soils that are low in nutrients, mainly as a result of soil deterioration in prehistoric times. It carries a distinctive vegetation dominated by heather (*Calluna vulgaris*) and gorse (*Ulex europaeus*), and generally lies below 100 m OD. Its survival is dependent upon grazing, cutting or burning, without which reversion to woodland would occur quite quickly. Lowland heath was once much more extensive than it is today. The largest remnants are concentrated in the New Forest, Breckland, the Suffolk Sandlings, east Hampshire and Surrey, Dorset and the Lizard peninsula. A very high proportion of England's lowland heath is covered by one or more protective designations, including Sites of Special Scientific Interest (SSSIs), National Nature Reserves (NNRs), Environmentally Sensitive Areas (ESAs), National Parks (NPs), Areas of Outstanding Natural Beauty (AONBs), Heritage Coasts (HCs) and Green Belt (G Belt). This correlation, which is examined in more detail in Chapters 4 and 8, is indicative of the high value that is often placed upon lowland heath as an ecological, scenic, recreational and historical resource.

2.3 Lowland heath as an ecological resource

2.3.1 Geological and climatic contrasts between lowland and upland Britain are recognised as having a fundamental influence upon habitat types and distribution (Ratcliffe 1977). Most of the well-described areas of lowland heath habitat in England lie south-east of a line between the Severn and the Humber which divides lowland from upland Britain. The term 'heath' refers to a low-growing semi-woody undershrub belonging to the same family as heather, the Ericaceae. It also means a tract of land where the vegetation is characterised by such plants.

2.3.2 Lowland heaths differ from upland heaths in their ecological character and processes. They only occur on acid soils, never on calcareous soils (though complex mosaics of vegetation including heathland types may develop where shallow layers of acid drift overlie chalk). Usually they lie on well-drained mineral soils such as sands, rather than upon peat. These heathland soils ('podzols') are notable for their marked division into different horizons, and may have conservation importance in their own right. They are very acidic (pH 4–5) and extremely poor in nutrients.

Table 2.1 Lowland heath and related communities in the National Vegetation Classification

Dry	H1	*Calluna vulgaris–Festuca ovina* heath	Eastern England eg Breckland
	H2	*Calluna vulgaris–Ulex minor* heath	Weald, Hampshire basin
	H6	*Erica vagans–Ulex europaeus* heath	Cornwall: the Lizard
	H8	*Calluna vulgaris–Ulex gallii* heath	SW England, Wales
	H9	*Calluna vulgaris–Deschampsia flexuosa* heath	English Midlands, N England
Humid	H3	*Ulex minor–Agrostis curtsii* heath	Hampshire basin
	H4	*Ulex gallii–Agrostis curtsii* heath	SW England
Wet	H5	*Erica vagans–Schoenus nigricans* heath	Cornwall: the Lizard
Maritime	H7	*Calluna vulgaris–Scilla verna* heath	Coastal
	H11	*Calluna vulgaris–Carex arenaria* heath	Coastal
Mires	M1	*Sphagnum auriculatum* bog pool	Widespread
	M16	*Erica tetralix–Sphagnum compactum* wet heath	Lowland England
	M21	*Narthecium ossifragum–Sphagnum papillosum* valley mire	Southern lowlands
	M25	*Molinia caerulea–Potentilla erecta* mire	S and SW Britain

2.3.3 Lowland heath habitats tend to develop in areas with relatively dry climates, although some wet and maritime heath types also occur. The National Vegetation Classification (NVC) (Rodwell 1991) recognises 22 types of heathland (Table 2.1 shows the major types), of which five are lowland dry heaths with three transitions to damper heath, and two are maritime heaths of cliffs or sand dunes (the remainder are all upland or montane types). Similar types of lowland heath occur in continental Europe. In broad terms, dry heaths in Europe are more or less confined to areas bordering the North Sea (Sweden, Jutland, north Germany and The Netherlands), while heaths similar to the wetter heaths of south-west England are mainly found in western France and north-western Spain.

2.3.4 Lowland heath is a very valuable habitat in the British Isles as it supports many scarce and locally important species of flora and fauna. Species which are more or less confined to lowland heath include: Dartford warbler (*Sylvia undata*); smooth snake (*Coronella austriaca*); sand lizard (*Lacerta agilis*); silver-studded blue butterfly (*Plebejus argus*); about 30 species of macromoths; five species of grasshoppers and crickets; three species of dragonfly; marsh gentian (*Gentiana pneumenantle*); slender cottongrass (*Eriophorum gracile*); pilwort (*Pilularia globulifera*); great sundew (*Drosera anglica*); pale butterwort (*Pingicula lusitanica*).

2.3.5 According to Farrell (1989), Britain has 60 000 ha of heathland (all types) compared with 280 000 in the rest of Europe, that is about 18% of the total. Farrell concludes that British heaths are important in nature conservation terms, first because they form such a large proportion of the European resource, and, second, because of the occurrence of certain special wet heath and maritime heath vegetation types which are relatively rare.

2.4 Lowland heath as a scenic resource

2.4.1 Lowland heaths are characterised by a feeling of wilderness that is unusual in lowland England. Typically they lie within open, sweeping landscapes on flat, gently undulating or rolling topography, with long views and huge skyscapes. However, the heath itself is often only part of a complex mosaic of land cover types, which may include grassland, valley bog, and pine (*Pinus* spp.) or birch (*Betula* spp.) woodland, and this mosaic gives detailed visual interest and patterning.

2.4.2 In scenic terms, lowland heath is often enhanced through the proximity of other land cover types. In particular, the contrast between heathland and adjoining woodland may serve to accentuate the feeling of wilderness, and may create attractive edge landscapes that many people seem to find particularly appealing. Perhaps the best example is in the New Forest where the core areas of ancient woodland and plantation are interspersed with open landscapes that are predominantly dry heath but include streamside grass lawns, acidic grassland, self-sown Scots pine (*Pinus sylvestris*), wet heath and bog. This intimate mix of open and enclosed landscapes is recognised as one of the special qualities that gives the New Forest its unique aesthetic appeal (Land Use Consultants 1986).

2.4.3 Although the detailed character of other lowland heath landscapes differs from that of the New Forest, the same principle applies. For instance, in Breckland, pine windbreaks and conifer plantations punctuate and enclose the landscape; while in south-east Dorset the Purbeck heathlands are bordered by a patchy mosaic of pasture, birch, oak (*Quercus* spp.) and pine woodland. These ragged outlines around a core area of open heath are very distinctive and are linked to the piecemeal conversion of heath to farmland or woodland.

2.4.4 The wilderness character of lowland heath has inspired many writers and artists, especially in the last two centuries. For instance, the poetry of John Clare, the novels of Thomas Hardy and the paintings of John Constable were frequently set within lowland heath landscapes, from which they drew their atmosphere. These works have influenced people's image of lowland heath landscapes and may be an additional reason for their popularity.

2.4.5 This popularity has led to the inclusion of many surviving areas of heath within National Parks or AONBs, which are recognised as being landscapes of national importance for reasons of rarity, aesthetic quality, conservation interest and cultural associations.

2.5 Lowland heath as a recreational resource

2.5.1 Lowland heath is very widely used for recreation. This is partly because of its scenic popularity, described above. Of equal relevance, however, is the fact that many areas of heathland have historically been common land, with a tradition of customary access. Today, heathland is ideal countryside for walking, picnicking, horse riding and orienteering cycling.

2.5.2 Heathland's intrinsic value as a recreational resource is heightened by its proximity to large urban populations, for instance in Hampshire, Surrey and Dorset where it often lies within the urban fringe and may be very heavily used indeed. In addition, much lowland heath, such as the Suffolk Sandlings, is well visited because of its coastal location. National Park, G Belt and Heritage Coast designations underline the recreational importance of many areas of lowland heath.

2.6 Lowland heath as an historical resource

2.6.1 Lowland heaths are ancient landscapes created and shaped by human activity. Archaeologically, they are among the most important land cover types for the range of monuments represented and the excellent state of preservation at most sites (Darvill 1987). Darvill notes that many areas of heath preserve groups of interrelated sites, representing successive periods of use. Traditional heath management has prevented decay through ground disturbance or tree growth. There are often important environmental indicators, for example pollen profiles in patches of mire or bog. These tend to be rare in southern England, where many landscape types do not preserve pollen at all. Lastly, Darvill notes the amenity value of lowland heath, where good access offers much scope for the presentation and interpretation of the archaeological heritage.

2.6.2 The range of site types present on lowland heath is not random, but reflects its history and archaeological character. It is difficult to quantify or characterise the archaeological interest, particularly since the full extent of that interest is not known. However, it is evident that scheduled monuments are relatively dense on lowland heath. Darvill recognises two distinctive groups of sites: earthworks (particularly Bronze Age barrows) which generally pre-date the creation of the heathland habitat; and later features such as enclosures, linear boundaries, rabbit warrens and mining engine houses, which date from Roman times onwards. There are a number of very major and well-known sites, which include Grimes Graves in Breckland (Neolithic flint mines), Sutton Hoo in Suffolk (a Saxon ship burial), and the copper and tin mines of West Penwith in Cornwall.

2.7 The evolution of lowland heath

2.7.1 Understanding the evolution of lowland heath is important to its conservation and enhancement. Authoritative accounts of lowland heath history are given in Rackham (1986) and Darvill (1987), upon which the following account is based.

2.7.2 Before 6000 BC, lowland heath areas were covered with trees. Heaths first appeared in the Mesolithic era. The pace of heath creation gathered during the Neolithic, to peak in the Bronze and Iron Ages. Various farming practices may have contributed to heath formation, but grazing was probably the most important. In Saxon and medieval times most areas of countryside had access to some form of communal rough grazing. Often this was provided by heath, which also acted as a source of fuelwood and thatch. Heathland was highly valued economically, and in the medieval period was widely protected by various forms of statute, especially those relating to commons. Rabbits (*Oryctolagus cuniculus*) were locally a very important lowland heath product, with warrens often covering wide areas.

2.7.3 Lowland heath decline began during the Middle Ages and was related to a variety of social, demographic and agricultural changes. It became more rapid at the end of the 17th century with improvements in farming technology and continued during the 18th and early 19th centuries, when it was linked with the parliamentary enclosures. It slowed during the latter half of the 19th century, but picked up again during the 20th century due to afforestation and agricultural intensification. Today most areas of lowland heath are used for low-intensity grazing, military training and recreation.

2.8 The dynamics of lowland heath

2.8.1 As we have seen, the lowland heath vegetation type is not fully natural. It developed historically as a result of anthropogenic influences, and it is maintained by such influences. If land on suitable soils was left entirely to natural processes of ecological succession (the development of plant and animal communities through time), it would never turn into heathland. It forms where natural processes of succession are altered by management (called 'deflected succession') and arrested by continuance of management. Accordingly it is sometimes called a 'plagioclimax' vegetation type (as distinct from a 'climax' vegetation type – the endpoint of natural processes of succession). The principal anthropogenic influences and management practices concerned are cutting, burning, grazing and (in some places) turf stripping.

2.8.2 A modern view of lowland heath development and maintenance is given in the section headed *Lowland heaths brought about by farming* in the seminal work on European vegetation types by Ellenberg (1988). Lowland heaths are regarded as the product of former agricultural practice, mainly of a pastural kind. Rackham (1986) writes that 'the old belief that heathland is ... natural ... has been overtaken by events ... vast areas of heath have ceased to be cut, grazed or burnt and have promptly turned into woodland'.

2.8.3 Given that climate and surface geology prove suitable for heathland, then the following are important for the maintenance of lowland heath:

- conditions that are not in themselves inimical to heathland plants (either as seedlings or after establishment);
- conditions which do not favour plants that might out-compete heathland plants, especially trees and grasses.

2.8.4 In general, this implies maintaining certain conditions of **stress** and **disturbance**, and in particular those listed below:

- soils with sufficiently low pH (acid soils), a form of **stress**;
- soils with very low nutrient status, a form of **stress**;
- the intermittent removal of plant material (usually by cutting, burning or grazing), a form of **disturbance** and, to a lesser extent, **stress** (ie by removing nutrients).

At the same time it is necessary to maintain freedom from some forms of stress (especially shading) and disturbance (eg ploughing) which are specifically harmful to lowland heath vegetation.

2.8.5 The levels of macronutrients (ie nitrogen, phosphorus and potassium) in lowland heath soils are extremely low. In a lowland heath ecosystem a significant proportion of available nutrients is sequestrated within the plant material. Heaths are sensitive to tiny increases in the amount of nutrients available, and they are especially sensitive to increased nitrogen. Heath may deteriorate where the nutrient balance and dynamics of the soil system are altered, for example through increased cycling of nitrogen and phosphorus in soils under moor-grass (*Molinia*) due to increased litter production (Aerts 1993a).

2.8.6 In Britain the phosphorus adsorption capacity of the soil may also be an important factor in determining whether lowland heath is liable to eutrophication. In consequence, open heath tends to persist where the phosphorus adsorption maximum is less than about 70 mg P g^{-1} of soil (as in the Dorset heaths); gorse invasion is likely on heaths with adsorption maxima between 70 and 700 mg P g^{-1} of soil; and woodland development is likely on heaths with higher adsorption maxima. Sites where heath has persisted on soils with adsorption maxima above 300 mg P g^{-1} are all actively grazed or managed (Chapman, Rose & Basanta 1989).

2.8.7 In the absence of suitable management, heather will enter a degenerative phase, and heathland will deteriorate in one of two principal ways.

- In the absence of **disturbance**, tree seedlings will become established and, in time, the heath will turn into woodland. Many trees are stress-tolerant (especially birch and pine), so lack of disturbance alone may be enough to bring about this change. Furthermore, short periods without disturbance may be sufficient, because once trees become established they become self-sustaining.

- In the absence of **stress**, more competitive plants will tend to become established, especially grasses. Where stress declines (eg due to increased nutrient input) but disturbance (eg grazing) is maintained, change from heathland to grassland is likely.

2.8.8 On many heaths bracken (*Pteridium aquilinum*) is present. Though naturally present on many heaths, its vigour is limited by cutting and grazing, and it does not out-compete heather in the 'building' phase. Once out of control, bracken can rapidly form a dense litter cover which smothers all other species.

2.8.9 Where all forms of management are relaxed, it is likely that there will be complex changes to habitats containing mosaics of bracken, grassland and woodland. Successional relationships among the vegetational elements of post-heath grassland and woodland complexes may be very involved (the grasses may facilitate woodland development, or inhibit it by preventing the establishment of tree seedlings). In addition, it should be noted that fire and over-grazing may, in certain circumstances, actually kill heather plants and the effects can be just as disastrous as under-management.

2.9 Trends for change in lowland heath

2.9.1 Lowland heath loss, deterioration and damage have been matters for concern in Britain for the greater part of this century. The main existing and potential causes of such change are landtake for development, land reclamation to agriculture and forestry, modifications in land management practice, recreational pressures, and, increasingly, atmospheric pollution and global warming. Each of these has differing effects upon the lowland heath resource. The scale, pace and significance of the various changes are reviewed below.

Landtake and land reclamation

Loss of lowland heath

2.9.2 In the 20th century lowland heath has been lost mainly to built development (particularly housing and roads), mineral extraction, arable farming and afforestation. These causes have also led to fragmentation of the lowland heath resource (eg Webb 1986).

2.9.3 Figures for lowland heath loss in Britain are affected by the definition of heath adopted. However, on any computation, the percentage losses of lowland heaths are higher than those for related vegetation types in the uplands. A review by Peterken and Hughes (1990) highlights the following points.

- The largest concentrations of lowland heath are in the New Forest, Breckland, the Suffolk Sandlings, Surrey and Hampshire, Dorset and the Lizard peninsula, as noted earlier. Most surviving lowland heaths are military land, common land or nature reserves.

- The decline of the Dorset heaths has been especially well studied. The area has dropped from around 40 000 ha in 1760 to 18 200 ha in 1934 and to 5700 ha in 1983. The most rapid decline took place during 1960–73 when 4000 ha were lost. Declines in other areas where lowland heath is concentrated have been broadly similar, though the particular causes may vary radically from one area to another.

- Outside the main concentrations of heathland listed above, the losses have been proportionately much higher than within them; for example, in Hertfordshire 83 ha in 1940 had reduced to 1.6 ha by 1984. This amounts to virtual eradication of heathland from some areas.

2.9.4 Clearly, the loss of lowland heath has direct adverse impacts upon all aspects of its conservation value. Landtake for built development has had a particularly severe impact upon the recreational resource (for instance in Surrey and Hampshire), as much of the loss has occurred in urban fringe areas where, as we saw earlier, lowland heath is of great amenity value. In more rural locations where mineral extraction, farming and forestry have been the main forces for change, there has been significant damage to the ecological, scenic and historical interest of lowland heath.

2.9.5 Percentage loss of lowland heath has been severe in other European countries as well as Britain. Farrell (1989) gives the following figures:

- 60–70% in Sweden and Denmark between 1860 and 1960;
- about 66% in western France between 1770 and 1955;
- 90% in the Belgo-Dutch Campine (period unspecified);
- 95% in The Netherlands as a whole (period unspecified).

Fragmentation

2.9.6 The fragmentation and isolation of surviving areas of lowland heath are as much a cause for concern as the overall loss. Any form of landtake or land reclamation can result in fragmentation, but road building probably causes a disproportionate amount. Fragmentation is known to be very widespread, but no national figures are available to show the magnitude of the change that has occurred, although detailed regional studies have been carried out (eg Webb 1990).

2.9.7 Fragmentation again affects all aspects of lowland heath conservation value. The integrity of the lowland heath habitat, the sense of wilderness, the wide open space for recreation, and the historic value are all reduced. Ecological values are thought to be particularly affected.

2.9.8 The principal concerns relate to loss of biodiversity which received international attention in June 1992 at the United Nations Conference on Environment and Development, when over 150 heads of state/government signed the Convention on Biological Diversity at Rio de Janerio, an initiative aimed at halting the loss of species and the associated genetic resource. The UK's *Biodiversity Action Plan* was published in January 1994 (Department of Environment 1994). Recent studies of island theory (Shafer 1990), minimum viable populations (Soulé 1987), metapopulations ('populations of populations' which constitute the presence of a species in a geographical area; each constituent population occupies a discrete 'site') (Gilpin & Hanski 1991), and 'landscape ecology' which deals with the relationship between landscape structure and living things (Forman & Godron 1986) place this issue upon a firm footing. Another important concern relates to edge effects which are related to measures of biodiversity. The more important aspects are listed below.

- Fragmentation may have long-term consequences for the maintenance of species diversity within heaths. Essentially plants and animals have a reduced chance of migrating between isolated patches of heath, and this increases the chance that species will become extinct within any given patch.

- Fragmentation may lead to a drain on populations of species in surviving fragments of heath. Emigrating individuals succumb to inhospitable environments. Wildlife corridors (eg road verges) may ameliorate this effect, but blind corridors leading out of patches of heath may exacerbate it (Selman & Doar 1992).

- There may be loss of genetic diversity within species confined to isolated habitat patches. Besides constituting loss of biodiversity in itself, this may in turn increase local extinction probabilities for species.

- Increased edge to the heathland habitats will change the relative importance of ecological processes taking place at the heathland boundary.

- Buffer zones around heathland fragments may ameliorate some effects of isolation, but Webb (1990) pointed out that, if such zones consist of vegetation at late stages in succession (especially woodland), this may actually increase the isolation of the low-growing heathland vegetation.

- Fragmentation may exacerbate conflicts in nature conservation priorities. The management required to maintain particular species may be harmful to other species. For example, burning and disturbance cycles required for conservation of the marsh gentian (*Gentiana pneumonanthe*) populations in Dorset (Chapman, Rose & Clarke 1989a) may be very harmful to herpetofauna (Corbett in Daniels 1983). In unfragmented heathlands conflicts of this kind may not be critically important because of differences in capacity, management and potential for amelioration.

Changes in land management

2.9.9 Changes in land management, notably reductions in the traditional management practices of cutting, burning and grazing, have also had adverse effects upon the ecological value and open character of lowland heath. Many surviving heaths show serious signs of deterioration, especially invasion by tree seedlings or trees and change towards grassland.

2.9.10 Deterioration is always caused primarily by lack of suitable management. Lowland heath historically was maintained by a mixed regime of agricultural practice that featured cutting for fuel, burning and grazing, typically on common land. This type of management is not part of modern farming practice, and the role of common land in most farming systems has declined.

2.9.11 Other influences may exacerbate deterioration. The large-scale planting of conifers on heaths leads to large sources of seed supply, increasing the rates of tree invasion on unplanted heaths nearby. The increase of arable in heathland areas, combined with modern fertilizer use, may inadvertently lead to increased nutrient inputs to the heaths in such areas (especially nitrogen). Spray drift and soil erosion may be associated with intensive arable farming within or around areas of surviving lowland heath.

Recreational pressures

2.9.12 Many heaths are now used for recreation, especially surviving commons, the New Forest, and land held by the National Trust. While recreational use may provide an incentive for the conservation of heath where the old agricultural regime has passed away, it may also exacerbate deterioration. Reasons for deterioration include physical disturbance and soil compaction (from parking, walking, cycling, horse riding and motorcycle scrambling), dogs (which can disturb stock and cause localised pollution), and accidental fire (which can trigger processes of habitat change). In addition, there may be public resistance to management measures, especially tree clearance.

2.9.13 Severe recreational pressures result not only in damage to lowland heath habitats, but in significant visual intrusion and degradation of the recreational resource itself. In addition, they may lead to disturbance of buried archaeological features.

Atmospheric pollution

2.9.14 Pollutants may affect soils and the overall nutrient cycle within the lowland heath ecosystem. The nitrogen status of lowland heath soils is sufficiently low for atmospheric inputs of nitrogen oxides to cause eutrophication of the most nutrient-poor heath types. In addition, lowland heath soils may be vulnerable to increased acidification from acid rain. Although they are naturally acidic, in many areas certain plant species are restricted to spots where the soil has some small buffering capacity. Ammonium deposition followed by nitrification leads to soil acidification which is inhibited in heathland soils at pH 4.1. Differences in pH accordingly disappear, and species diversity is reduced, only the most acid-tolerant species (including heather) persisting (Roelofs 1986).

2.9.15 Plants may also be affected directly. The nitrogen content of the leaves of ericaceous shrubs tends to increase under conditions of increased nitrogen supply resulting from atmospheric deposition of nitrogen, and this may both increase the palatability of ericaceous shrubs to grazing invertebrates and increase frost sensitivity in heather (Bobbink & Heil 1993). Some heathland plants, especially bryophytes and lichens, may be directly affected and often eliminated by acid deposition, especially sulphur deposition.

2.9.16 The scale and significance of changes to lowland heath as a result of these factors are still unclear. The main effects will be on the ecological value of the lowland heath, although in the long term there may well be scenic and recreational effects also.

Climatic warming

2.9.17 The complex climatic changes that might potentially be associated with a rise in mean temperatures could affect different species in different ways, leading to vegetational change. Generally, raised temperatures might encourage weedy species on heaths. Associated changes in rainfall could be especially significant, causing a shift towards wetter heathland types. Increased rates of microbial activity in the soil may exacerbate problems associated with nutrient cycling on heaths, especially those related to inputs of nitrogen from agriculture and atmospheric deposition.

2.9.18 Again, the impacts of such changes are unclear, but a decline in both ecological and the scenic value of lowland heath may be expected.

2.10 Conservation and restoration of lowland heath

2.10.1 This Section considers what potential there is to conserve, restore or even re-create lowland heath, and looks at the measures needed to achieve such changes.

Conservation

2.10.2 Most lowland heath management today is carried out for nature conservation purposes, or for closely related countryside amenity purposes in which nature conservation is almost always an element. Lowland heath loss has been widely identified as a significant issue, especially in the south of England. Ambitious schemes and strategies for management are therefore rather common (Harrison 1976). Often they are backed and operated by consortia of local government, English Nature, and voluntary nature conservation organisations (eg Hampshire County Council, undated). However, such existing management schemes are quite localised in relation to the national resource. They focus upon the best-surviving areas of heathland, which are generally the subject of nature conservation designations.

2.10.3 To a large extent, conservation management consists of re-establishing the old management practices of cutting, burning and grazing, albeit in modified forms.

Features of modern conservation management include:

- burning which is often used deliberately as a management tool;
- cutting, often by machine, especially flails and forage harvesters (Andrews 1990), which is carried out simply to remove biomass, not to obtain a useful harvest;
- grazing which is being used successfully in heathland conservation in some places;
- herbicides which may be used to control invasive species, especially bracken (azulam sprays) and tree saplings; they may have some effects on other heathland species;
- turf stripping which may be used to effect nutrient removal (Dolman & Sutherland 1991); cutting shallow sods is deemed to be the most effective way of removing nitrogen from heathlands (Heil & Aerts 1993).

Restoration and re-creation

2.10.4 Heathland restoration and indeed re-creation are both possible, and potentially could be used to extend or re-introduce lowland heath in areas where it has been lost to arable cropping, forestry and abandonment. Unlike simple conservation measures, such action could bring real benefits to the scenic, recreational and historical resource.

2.10.5 For instance, heathland restoration within the urban fringe could be an effective way of enhancing degraded landscapes, providing new areas for recreation, and preserving and presenting ancient monuments to the public. Such an approach is currently being adopted under the Countryside Stewardship Scheme, but is not a feature of many other heathland management programmes at present.

2.10.6 Most work so far has focused upon remedial management to retrieve the situation on heaths where deterioration is under way. Situations where nutrients have accumulated leading to the conversion of lowland heath into grassland require more drastic action, such as stripping of vegetation and topsoil followed by seeding with heather (Putwain 1983).

2.10.7 The dominant ericaceous shrubs commonly produce large soil seed banks, though these tend to be localised in the organic (surface) layers of the soil. The seeds are long-lived, and annual losses are low, so that large seed banks remain under grass heaths where the cover of ericaceous shrubs had been lost for more than ten years (Bruggink 1993). The surface layers of heathland soils may also contain bud banks for some species, eg bilberry (*Vaccinium myrtillus*), which are important for regeneration of some species if heath is disturbed (Putwain & Gilham 1990).

2.10.8 This evidence implies that it is possible to restore or re-create lowland heath on former heath areas. Ericaceous shrubs sometimes re-appear in sites through changes in management carried out for other reasons, and Willems (1988) reported the re-appearance of heather on a site cleared of trees after 50 years. In trials upon grass-dominated former heathlands in The Netherlands (Diemont & Linthorst Homan 1989), a range of conventional management treatments including burning, mowing and ploughing failed to cause recovery of ericaceous shrubs, but shallow sod cutting did succeed (provided that the top layers of the mineral soil were not disturbed), without the need for other intervention (such as sowing or planting heather).

2.10.9 More ambitious schemes for restoring arable land to heath depend primarily on removing nutrients from the soil, by soil stripping and nutrient depletion using crops (Marrs 1986; Marrs & Gough 1989). The existence of a heath seed bank will then be critical to any re-establishment of heather. If the seed bank no longer exists, then the area would have to be sown initially. This could be carried out using cuttings from other managed areas locally. This kind of restoration is considerably more complicated than restoration of modified or degraded heath.

2.11 Summary

2.11.1 Lowland heaths are ancient landscapes created and shaped by human activity. They are recognised not only for their ecological value, but also for their scenic, recreational and historical importance. This wider importance relies not just on the rarity of lowland heath habitats, flora and fauna, but on the wider environmental context, which is also quite unusual. Key qualities are wilderness character; open space in close proximity to large urban populations; and an exceptionally well-preserved archaeological resource. As Britain holds approximately 18% of European lowland heath, these resources are of European if not global importance.

2.11.2 An understanding of the evolution and dynamics of lowland heath systems is essential to their conservation and enhancement. Concern over their continuing loss, fragmentation and deterioration has led to a range of studies related to the impacts of land use and environmental agents of change, and to research into how lowland heath can be conserved, restored and re-created. Management schemes so far have concentrated on conservation of the best-surviving areas of lowland heath habitat. However, in terms of future policy formulation, restoration and re-creation of lowland heath may be equally relevant, because of the potential to generate wider scenic, recreational and historical benefits.

2.11.3 This Chapter describes the background to the present study. The remainder of the Report attempts for the first time to create a national definition of existing and potential lowland heath, to assess its extent and quality, and hence to inform policy-making.

Chapter 3 DEFINING THE LOWLAND HEATH MASK

3.1 Introduction

3.1.1 Although a widely used description of lowland heath has been derived (Section 2.2), data have not been collected in a consistent manner to allow the definitive national distribution of lowland heath to be mapped. A small-scale map has been drawn by Webb (pers. comm.) indicating areas in the south-west, south and east of England. Some of the data compilations of English Nature may also provide sufficient information to map distributions across England; for example, a 10 km map of SSSI grade 1 sites has been presented in the *Nature conservation review*. At the outset of this project, little else had been done to bring together more detailed mapped information. However, the information available forms a useful check against the geographical information system (GIS) procedures described below.

3.2 Defining the lowland heath mask

3.2.1 The lowland heath mask (see Box 1.1) was based on a database of 1 km squares in England containing existing and potential areas of lowland heath landscape. This database was constructed by combining data on soils and altitude and used in a GIS to create a map showing the distribution of these heathland areas. The database also provided the population from which a stratified random sample of 1 km squares was subsequently taken for field survey. The rationale and methodology behind the derivation of the lowland heath database and mask are described in this Section.

3.2.2 In constructing the database and map of the lowland heath mask, the aim was to include only those 1 km squares which had, or had the potential for, heathland cover at a landscape scale, defined as squares with potential to contain lowland heath as a dominant or subdominant vegetation type. The map was not intended to cover squares with small areas of lowland heath.

3.2.3 Areas of potential heathland were included because the study needed to examine changes in land use and heathland re-creation schemes which may lead an increase in heathland cover in the future. Although only one sixth of the area of lowland heath present in England in 1800 now remains (Farrell 1993), it is possible that this decrease may not continue and that the area of heathland in England could begin to increase. Vestiges of heathland vegetation can still be found in other land cover types such as grasslands and woodlands, and with changes in land use and agricultural practice some of these areas may revert to heathland. Heathland re-creation schemes such as Countryside Stewardship, Environmentally Sensitive Areas and English Nature's national lowland heath programme provide the financial incentives for direct re-creation of heathlands, even in areas which are currently arable or improved grassland and which have no remaining heathland species.

3.2.4 The steps taken to define the 1 km map of lowland heath landscape areas ('the lowland heath mask') were to:

i. agree a working definition of lowland heath;
ii. develop criteria for identifying areas of potential lowland heath;
iii. obtain the datasets, and use GIS technology to identify and map 1 km squares in England which already support or have some potential to support the lowland heath vegetation types defined in (i);
iv. validate the lowland heath mask and, if necessary, modify procedures (i)–(iii);
v. produce a map and database of potential lowland heath landscape areas for use in other parts of the project and for inclusion in the DOE's Countryside Information System.

3.3 Lowland heath potential

3.3.1 Soil types characteristic of lowland heath vegetation and landscapes were used to define a population of 1 km squares having potential for heath. For this work a 1 km database of the Soil Survey and Land Research Centre (SSLRC) was used which provided data in digital form on dominant and subdominant soils within 1 km grid squares. Soil types (Table 3.1) most likely to support heathland vegetation were identified and their distribution mapped. Comparison with known areas of heathland provided information for further soil categories to be added to the map; some of these were combinations of dominant and subdominant soil types to avoid mapping areas which did not contain lowland heath. Peat soils were also included as these have a potential for heathland, especially in the vicinity of existing heathlands.

3.3.2 Soils data alone cannot be used to differentiate between upland and lowland heaths. This differentiation is to some extent subjective as there is considerable overlap between their species compositions, and the same NVC classes (see para 2.3.3) may occur in areas traditionally considered as either. Lowland heath cannot simply be defined in terms of altitude because climate varies in different parts of England such that what might be considered as 'upland' vegetation may occur at relatively low altitudes in harsher environments. Thus, whereas the lowland/upland vegetation interface may be considered to occur somewhere in the region of 200–300 m in the south of England, in the north characteristically 'upland' vegetation may occur in areas about at sea level. In order to overcome these regional differences, use has been made of the ITE Land Classification database. Land classes 17–24 and 27–32 which are characteristically 'upland' in nature have been used to exclude areas of England unlikely to contain lowland heath landscape areas. This definition of uplands departs from that used in the Countryside Survey 1990 project and in the separate Report on uplands (Part 3), in both of which land class 27 has not been included in the uplands.

3.3.3 Coastal heathlands are poorly covered by this mask because they tend to be small and difficult to associate with soil types marked on the 1:250 000 map. Attempts were made to identify soils in areas of known coastal heathlands so that they could be incorporated into the map of potential lowland heath defined above. Unfortunately, the soils identified were not specific to coastal heathland areas and no procedure could be devised to limit the soil types to those areas. Even the addition of a buffer zone along the coastline was unable to separate coastal habitats including heathlands from other areas. However, coastal heathlands are also part of the current project and are reported separately (Part 4).

Table 3.1 Soil types used to indicate potential lowland heath landscape (typology from Soil Survey of England and Wales 1983)

1. Where the following soil types are dominant in a 1 km square

Brown calcareous sands (series 5.21)
Brown sands (series 5.51, 5.52, 5.54, 5.55)
Typical brown podzolic soils (series 6.11)
Paleo argillic podzols (series 6.34)
Humo-ferric podzols (series 6.31)
Ferric podzols (series 6.33)
Gley podzols (series 6.41, 6.43)
Soils on ultra-basic rock (Lizard area) (series 7.17)
Typical humic gley soils (series 8.71)
Peat soils (series 10.11, 10.13)
" " (series 10.21, 10.22, 10.24, 10.25)

2. Where the following dominant and subdominant soil types occur together in particular regions

Dominant soil type		*With subdominant*		*Region*
Brown rendzinas	3.43	Brown calc. sands	5.21	Thetford
Brown rendzinas	3.43	Brown sands	5.54	"
Brown rendzinas	3.43	Brown sands	5.51	"
Brown earths	5.41	Humic gleys	8.71	Lyme Bay
Argillic brown earths	5.71	Humic gleys	8.71	"
Argillic brown earths	5.72	Humic gleys	8.71	"
Humic alluvial gleys	8.61	Gley podzols	6.41	Dorset
Stagnogleys	7.11	Stagnogley podzols	6.43	New Forest

Figure 3.1 The lowland heathland mask, showing areas of England with potential for supporting heathland vegetation. Areas with some designation status are shown in green and areas without designation status are shown in black

Figure 3.2 Areas of lowland England with more than 10% cover of dwarf shrub land cover types on the Land Cover Map which fall outside the heathland mask

3.3.4 Work has been carried out to validate the lowland heath mask through comparisons with other information. A description of this work is given in Appendix 1; the overall conclusion is that, although there are some mismatches between the lowland heath mask and other datasets, the fit was judged to be acceptable for the purposes of this project.

3.5 The lowland heath mask – outputs

3.5.1 The lowland heath mask covers 8538 1 km squares in lowland England (Figure 3.1). The National Grid references of these squares are available as a dataset, eg for use in the DOE's Countryside Information System.

3.5.2 These data have been used as the framework for the field survey programme described in Chapter 4 and the modelling of atmospheric inputs described in Chapter 6.

Chapter 4 ECOLOGICAL CHARACTERISTICS OF THE LOWLAND HEATH MASK

4.1 Introduction

4.1.1 The methods used to define the lowland heath mask are described in Chapter 3. This Chapter goes on to describe the field survey which was completed in order to characterise the mask in terms of ecological components such as land cover, landscape features and vegetation.

4.2 Sampling strategy

4.2.1 The lowland heath mask was stratified to ensure that the sample of surveyed squares was representative, and to allow comparison between lowland heath landscapes in different parts of the country, and between heathland types in designated and non-designated areas. The four strata are:

i. designated arable
ii. designated pastural
iii. non-designated arable
iv. non-designated pastural

4.2.2 'Arable' and 'pastural' refer to the land class groups derived from the ITE Land Classification, as used in Countryside Survey 1990 (Barr *et al.* 1993) (but see para 3.3.2 re class 27). The arable land class group covers areas where arable farming is a dominant land use, together with intensively managed grassland; it is concentrated in East Anglia and the eastern Midlands (land classes 2, 3, 4, 9, 11, 12, 14, 25 and 26). The pastural land class group represents areas mainly in the west of lowland England, where grassland used for livestock farming is the dominant land use (land classes 1, 5, 6, 7, 8, 10, 13, 15, 16 and 27). This regional division has been used to distinguish the different land cover patterns found across lowland England. In general, the wet heath and bogs are more often found in the wetter pastural landscapes, with only dry heath present in the more continental climate of the east.

4.2.3 'Designated' refers to the presence in all or part of a 1 km square of one of the following designations, according to databases assembled by ITE in 1988:

- Site of Special Scientific Interest (SSSI),
- National Nature Reserve (NNR),
- National Park (NP),
- Area of Outstanding National Beauty (AONB),
- Heritage Coast (HC),
- Green Belt (G Belt),
- Environmentally Sensitive Area (ESA).

These designations have varied objectives and were defined on the basis of different criteria, ranging from the conservation of rare species to landscape value. Some cover small homogeneous areas such as NNRs, whilst others are large and varied, like National Parks. They are administered by a range of bodies including English Nature, the Countryside Commission, the Ministry of

Agriculture, Fisheries and Food, wildlife conservation trusts and local authorities.

4.2.4 The inclusion of a 1 km square in the designated strata indicates that some part of the square has at least one designation – in interpreting the following results it should be remembered that not all of the square is necessarily designated, so the area of the designated strata and areas of land cover types within it may be over-estimates. This point is mainly relevant to designations which affect small areas, eg SSSIs. Further the designation may not be related to the 'heathy' nature of the vegetation.

4.2.5 The sampling unit, as for Countryside Survey 1990, is a 1 km square. Within each stratum, 1 km squares were chosen at random for field survey. As in CS1990, squares which were more than 75% built-up were excluded from the sample. A total of 80 squares were surveyed in 1992, plus a further nine in 1993 (Table 4.1). In addition, 16 squares which were surveyed in Countryside Survey 1990 fell within the lowland heath landscape; data from these squares have been extracted and added to the database.

4.2.6 The results from the sample squares have been used to calculate estimates for the lowland heath landscape as a whole. The relationship between the survey squares and the size of each stratum is shown in Table 4.2. The decision to use CS1990 squares and the targeting of pastural strata in 1993, to increase the likelihood of surveying core heathland vegetation, mean that the final sample numbers are not directly proportional to the area of each stratum.

Table 4.1 Squares surveyed in the lowland heath mask

	Number of 1 km squares surveyed			
Strata	1990	1992	1993	Total
Designated arable	6	20	0	26
Designated pastural	6	21	5	32
Non-designated arable	1	20	0	21
Non-designated pastural	3	19	4	26
Total	*16*	*80*	*9*	*105*

Table 4.2 The lowland heath mask stratification

	Stratum size		Sample size	
Strata	km²	%	km²	%
Designated arable	2758	32	26	25
Designated pastural	2002	23	32	30
Non-designated arable	1838	22	21	20
Non-designated pastural	1940	23	26	25
Total	*8538*	*100*	*105*	*100*

However, because averaged and weighted stratum results are used in the overall calculation of ecological characteristics, this sampling strategy has no inherent bias.

4.3 Field survey

4.3.1 Land cover was recorded at 25 points on a grid within each field survey square, rather than mapping the whole square as in Countryside Survey 1990 (Barr *et al.* 1993). Each grid point was accurately located on the ground and the land cover of the parcel of land (ie area of relatively homogeneous land cover) in which each point fell was recorded (code numbers were described in a field handbook). The nearest field boundary (within 100 m of each grid point) was also recorded.

4.3.2 For the 16 squares which had already been recorded as part of the CS1990 survey, the same approach was used, ie a grid of 25 points was placed over a map of each square and relevant data were extracted from associated databases.

4.3.3 Quadrats were recorded to provide quantitative botanical information about the areas within the sample squares that support, or could support, lowland heath. Quadrats (2 m x 2 m) were recorded at each grid point where the vegetation was indicative of acid soils, ie on heathland and associated habitats, including scrub, bracken-dominated areas, acid grassland, and in woodland where 'heath' species were present, mainly conifer plantations but also in some deciduous woodland where purple moor-grass, bilberry, heather or bell heather (*Erica cinerea*) and cross-leaved heath (*Erica tetralix*) were a component of the ground flora. Arable fields and fertilized, sown or neutral grasslands were excluded. In each quadrat, all species were recorded, and cover was estimated to the nearest 5%. All quadrats were permanently marked to allow future monitoring.

4.3.4 Considerable care was given to maintaining quality in field recording and to minimising variation between surveyors. Quality measures included the use of a field handbook, a training course for surveyors and constant supervision. During the field survey, independent ecological consultants revisited a sample of the survey squares, and repeated quadrats and land cover descriptions. Information from these repeat visits was given to surveyors so that consistency of recording was maintained.

4.3.5 A pilot study was carried out to assess this survey approach, which showed that the grid system was reasonably accurate at estimating the most extensive, or widely distributed, land cover types, but was poor for those with limited geographical extent.

4.4 Field survey results: land cover

4.4.1 The land cover recorded at the 25 grid points in each 1 km sample square has been used to estimate the area of each land cover type in the four strata (Figure 4.1). Full details of the land cover estimates for each stratum, and for combined strata, are given in Appendix 2.

4.4.2 Just over 5% of the heathland mask was estimated to be heathland vegetation and 74% of this fell in squares in designated strata. There was a greater overall area of heathland in the arable than in the pastural strata. Nearly all lowland bogs occurred in squares in the designated strata; 59% of the bogs were in the pastural strata.

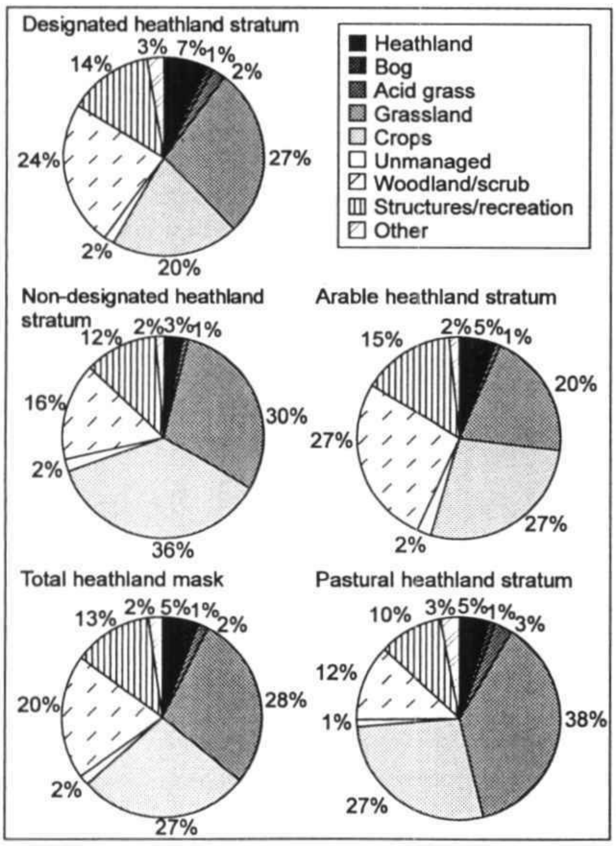


Figure 4.1 Estimates of the percentage area of each land cover type in the lowland heath mask. Based on descriptions of land cover at 25 grid points. Areas under 1% are not labelled

4.4.3 Moorland grass was recorded only in the pastural strata and 84% of the moorland grass occurred in designated squares. Acid grassland/bracken occurred predominantly in the pastural strata; 79% fell in designated strata.

4.4.4 Agricultural grassland was a major component of the heathland mask, especially in the pastural strata where it occupied 38% of the area. Crops accounted for 27% of the lowland heath mask in both the arable and pastural strata.

4.4.5 Woodland/scrub was a common feature of the heathland mask, especially in the arable strata where it occupied 27% of the total area, a much higher percentage than for the arable land class group in England as a whole (Barr *et al.* 1993). This may be because the soil types used to define potential for lowland heath were those least favourable to agriculture and, hence, more likely to have remained as woodland. This finding contrasts with the pastural strata where topography may be as, or more, important in determining the sites which have remained wooded (eg steep valley-sides which cannot be cultivated).

4.4.6 Although the heathland mask is rural (no squares more than 75% built-up are included), a combination of buildings, curtilage and recreation land occupied 15% of the arable strata. In some survey squares, lowland heath was located on the urban fringe.

4.5 Field survey results: boundaries

4.5.1 Overall, two-thirds (68%) of all grid points had a boundary within 100 m (Table 4.3). There was a clear difference between strata in the number of boundaries. The squares in designated strata had a lower proportion of field boundaries, which shows the greater areas of unenclosed land (heathland and woodland) in these designated areas. The

Table 4.3 Abundance of boundaries in the lowland heath mask

	% of points	
Stratum	Without boundaries	With boundaries
Designated arable	49.5	50.5
Designated pastural	34.6	65.4
Non-designated arable	31.2	68.8
Non-designated pastural	6.0	94.0
Total	*32.0*	*68.0*

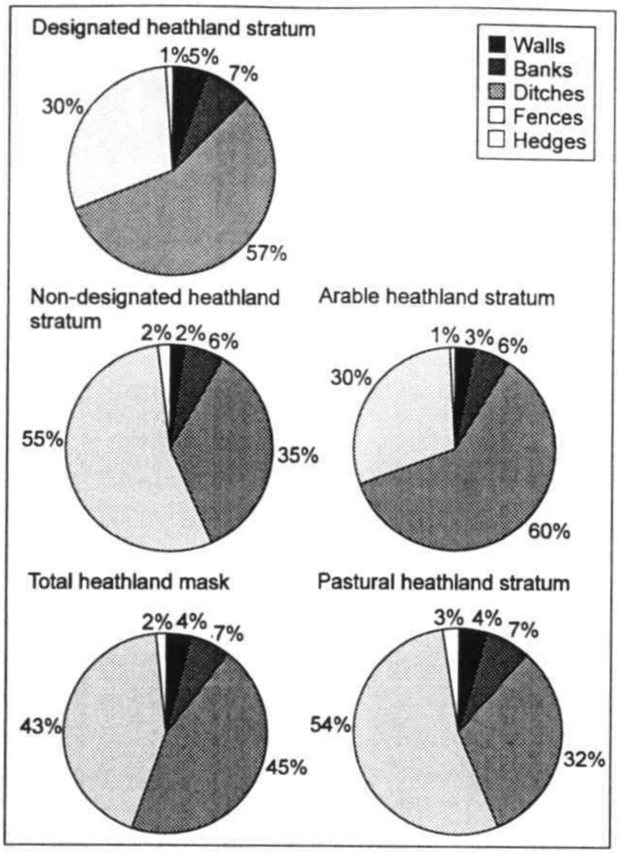


Figure 4.2 Proportion of boundary types in the lowland heath mask

arable strata have fewer boundaries than the pastural strata; this is probably related to the larger cereal fields, and greater areas of built-up land. Fences were the most common type of boundary, being twice as frequent as hedges (Figure 4.2). The ratio of fences to hedges was higher in the designated and arable strata. These results suggest that the effect of designation is to select large blocks of heathland that have not been fragmented or enclosed. Further details are given in Appendix 2.

4.6 Summary of land cover and boundary results

4.6.1 There is still a significant proportion of heathland which is not covered by any of the designations included in this study (Figure 4.3). This is also true of moorland grassland and acid grassland, which may have been heathland in the past. Heathland and bog occur in both arable and pastural strata, whilst moorland grass is restricted to the pastural areas. In terms of habitats with potential for heath vegetation, acid grassland is more common in pastural areas, but woodland and scrub are more common in arable areas. This finding suggests that these are the respective habitats that might form the focus of habitat re-creation schemes in lowland England.

4.6.2 There is above-average woodland and heath in the heathland mask compared with lowland England as a whole, and a smaller area of crops and managed grassland (Table 4.4). It is not possible to make a direct

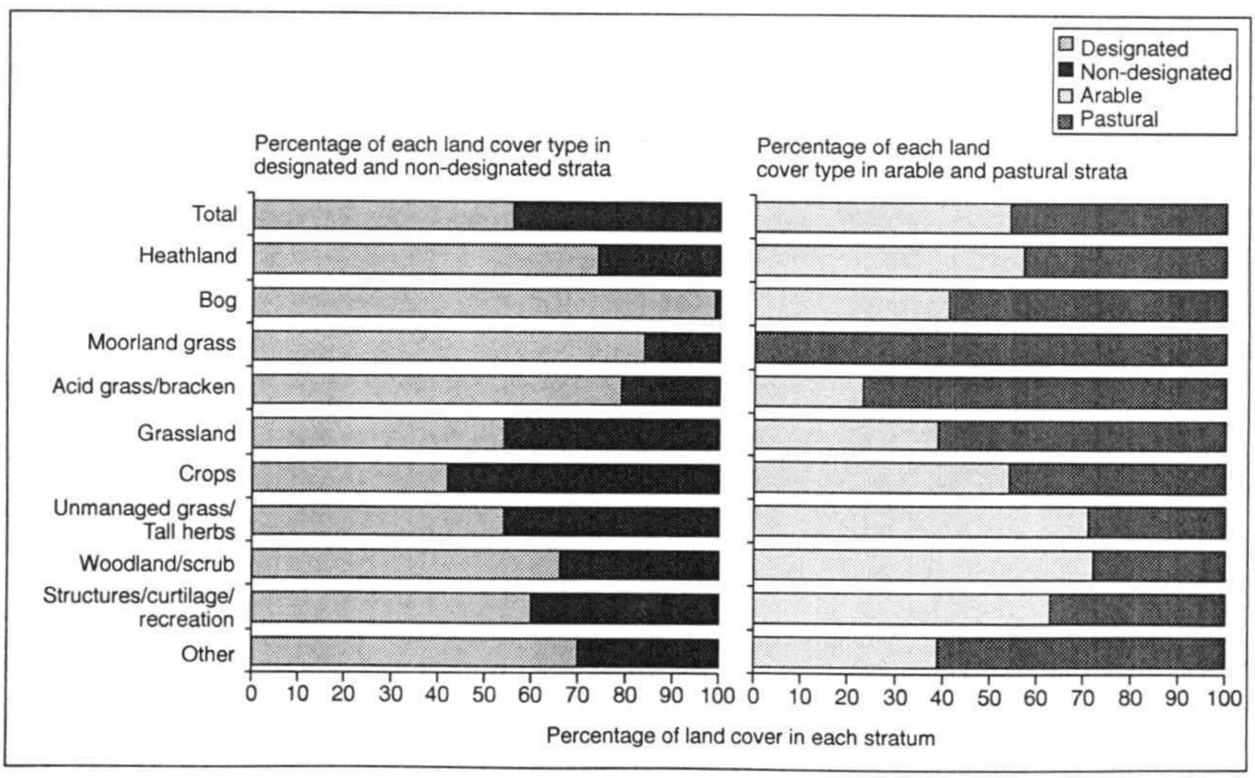


Figure 4.3 Percentage of land cover types in the lowland heath mask

Table 4.4 Comparison of land cover estimates for the lowland heath mask with those of lowland England (ie all arable and pastural land class groups)

Land cover class	Lowland heath mask[1] Area (km²)	SE	%	Lowland England[2] Area (km²)	SE	%
Heathland/bog	489	128	6	1423	630	1
Moorland grass	8	4	0	402	161	0
Acid grass/bracken	141	49	2	1072	290	1
Grassland	2421	224	28	35263	3560	32
Crops	2342	275	27	43256	6159	40
Unmanaged	147	31	2	1584	172	1
Woodland/scrub	1718	156	20	10636	1456	10
Structures/curtilage/recreation	1081	142	13	12000	1472	11
Other	190	38	2	3168	1351	3
Total	*8538*	*1047*	*100*	*108804*	*15251*	*100*

[1] Lowland heath landscape land cover estimates are based on information from 25 grid points in field survey sample km squares
[2] Land cover estimates for lowland England (all soil types) are based on habitat maps from CS1990 sample squares, for lowland land classes (1–16,25,26 as used in definition of lowland heath landscape)

comparison with the area of lowland heath, because the CS1990 results are not presented in this detail, so a comparison can only be made between the areas of combined heath (including wet heath) and bog. The area of combined 'heathland/bog' is proportionately lower for lowland England than for the heathland mask. There is also proportionately more 'moorland grass' in the area outside the lowland heath mask. Thus, the lowland heath mask appears to be relatively rich in semi-natural habitats with fewer highly managed cover types, such as agricultural crops.

4.7 Vegetation sampling and analysis

4.7.1 The land cover data (as described in Section 4.3) represent the major vegetation categories and provide a baseline against which quantitative estimates of change can be made. To examine the more subtle changes that may take place as a result of new management or changing environmental conditions, the balance of vegetation species within the major land cover types needs to be recorded. To do this, species were recorded within quadrats. Two broad types of analysis have been carried out: first, quadrats have been analysed according to the species they contain, and, second, the species have been analysed according to their frequency of occurrence in quadrats.

Analysis of quadrats: 'structural types' and 'plot classes'

4.7.2 Quadrats were recorded from 60 of the sample squares; in the other 45 sample squares the grid points did not fall on vegetation which met the criteria for recording quadrats, ie it was arable or non-acid grassland (para 4.3.3). In some of these squares lowland heath was present but was not recorded at any of the 25 grid points. The absence of lowland heath at grid points from such a high proportion of the survey squares may reflect the distribution characteristics of lowland heath which occurs in large blocks in relatively few areas of the country. A sampling scheme based on a 1 km square resolution, while appropriate for the mask as a whole, picks up few areas of lowland heath.

4.7.3 Two types of analysis have been carried out using the quadrat data: allocating the quadrats to structural vegetation types and classifying quadrats into plot classes.

4.7.4 The quadrats have been aggregated according to vegetation type, based on quadrat descriptions, into broad groups called **'structural types'**:

Dry heath
Wet heath
Bog
Bracken
Acid grassland
Scrub
Woodland edge
Woodland (deciduous)
Plantation (conifer)

4.7.5 The quadrats were classified statistically into **'plot classes'** based on species composition (using a multivariate statistical classification, TWINSPAN – see hierarchy diagram in Appendix 2). These plot classes have been given short descriptive names to aid interpretation (Table 4.5), and are ordered according to the principal gradient score (derived from the DECORANA analysis), from acid, wet conditions to less acid, drier conditions

Table 4.5 Lowland heath 'plot classes'
A classification derived from multivariate analysis of quadrat data (using TWINSPAN)

Principal gradient score	Plot class	Name
56	PCA	Bog
105	PCB	Wet heath
184	PCC	Ultra-basic wet heath
185	PCD	Very acid heath
197	PCE	Southern damp heath
219	PCF	Dry heath
220	PCG	Damp heath (incl. plantation)
231	PCH	Dry heath often planted
244	PCI	Grassy heath
247	PCJ	Southern dry heath
263	PCK	Plantation over heath
351	PCL	Plantation over bracken/heath
356	PCM	Damp acid grassland
359	PCN	Southern acid plantation (dense)
365	PCO	Plantation often open
392	PCP	Dense rhododendron
434	PCQ	Midland plantation over bracken
451	PCR	Dry mildly acid grassland
483	PCS	Plantation over grass/bracken
503	PCT	Woodland over bramble

Shaded plot classes (A–F,I,J) are those that are considered to be typical of true lowland heath = 'core' heathland. Non-shaded plot classes (G,H,K–T) are other types found within the mask = 'non-core' heath classes. The 'principal gradient score' is derived from DECORANA analysis (see para 4.7.5)

(see Figure 4.9). Further details of the plot classes are given in Appendix 2.

Analysis of species: 'habitat indicator groups' and 'species groups'

4.7.6 Species have been allocated to **'habitat indicator groups'**, based on expert knowledge, to identify the extent to which the species are associated with heathland (Box 4.1).

Box 4.1

Lowland heath specialists,
eg *Agrostis curtisii, Ulex minor*
Lowland heath generalists,
eg *Calluna vulgaris, Molinia caerulea*
Acid grassland species,
eg *Pteridium aquilinum, Deschampsia flexuosa*
Neutral grassland species,
eg *Holcus lanatus, Rumex acetosa*
Woodland species,
eg *Rubus fruticosus, Betula pendula*
Weeds and aliens,
eg *Chamerion angustifolium, Poa annua*

4.7.7 A multivariate statistical classification has been produced to group species into **'species groups'** which have similar distributions across the quadrat dataset, using DECORANA and Ward's Minimum Clustering. The rare species (frequency <2%) have been excluded from this classification, and the rest of the species have been split into two groups, and analysed independently:

i. dominant species (frequency >10%),
ii. subdominant species (frequency <10% and >2%).

These groups are shown in Table 4.6, ordered on the principal gradient.

4.7.8 Species have been identified as being sensitive to particular threats (based on expert knowledge):

i. drying out;
ii. succession, ie colonisation by trees species resulting in scrub or woodland;
iii. grazing, leading to dominance of graminaceous species;
iv. eutrophication, through runoff or deposition.

Table 4.6 Lowland heath species groups. A classification derived from multivariate analysis of quadrat data (using DECORANA)

Principal gradient score	A	Dominant species groups	B	Subdominant species groups
-5			B1	Bog species
137			B2	Wet heath species
170			B3	Moss/lichen heath species
207	A4	Moss/lichen heath species		
219	A5	Vascular heath species		
343			B6	Damp acid woodland species
353	A7	Forest tree species		
386			B8	Acid grassland species
403	A9	Acid grassland species		
414			B10	Mildly acid grassland species
437			B11	Acid woodland species
457	A12	Acid woodland species		
516			B13	Mildly acid woodland species

Shaded species groups (B1,B2,B3,A4,A5) are those which are characteristic of lowland heath = 'heath' species groups
Unshaded species groups (B6,A7,B8,A9,B10,B11,A12,B13) are also found in the heathland mask = 'non-heath' species groups

Table 4.7 Mean number of quadrats recorded per square, by strata in the lowland heath mask (indicative of area of acid semi-natural vegetation)

Strata	Mean number of quadrats km^{-2}	% of points recorded as quadrats
Designated arable	4.2	16.6
Designated pastural	4.1	16.4
Non-designated arable	2.3	9.2
Non-designated pastural	1.2	4.8
Combined designated	4.1	16.4
Combined non-designated	1.8	7.2
Combined arable	3.4	13.6
Combined pastural	2.7	10.8
Total	*3.1*	*12.4*

These figures represent the mean number of quadrats per square, including those squares where no quadrats were recorded. Figures for combined strata are weighted by strata size

The presence of species from these **'sensitivity indicator groups'** implies that the vegetation in which they occur has not been subject to these pressures.

Assessment of vegetation quality

4.7.9 These classifications of quadrats and species will be used to describe the types of vegetation in the four strata, and to compare them in terms of selected quality criteria.

4.7.10 The use of quality criteria to provide a comparative assessment of sites by other studies is discussed in Appendix 2 (Box A2.1). In this project, objective measures of vegetation have been related to quality criteria, to provide an empirical evaluation of the quality of heathland vegetation in different parts of the lowland heath landscape. Each criterion emphasises a particular aspect of quality, but they do inter-relate, and should not be considered as mutually exclusive. The following discussion of vegetation in terms of quality criteria is based on species information from quadrats, and makes use of the classifications described above (Section 4.4). The following quality criteria are considered in turn: size, diversity, naturalness, representativeness, rarity, fragility, potential value.

4.8 Vegetation quality: size/abundance

4.8.1 Large size is usually considered a benefit, for a number of reasons. Each species has a minimum area (or resource) which is necessary to maintain a viable population. There is a relationship between area and species diversity affected by population size, extinction and immigration rates. Large sites provide a buffered 'edge' between the central core of the site and adjacent land, which helps to protect the core from disturbance, runoff, spray drift, etc. Larger sites usually (but not always) contain a greater range of local environments, reflected in a greater diversity of species. In the lowlands of England, where semi-natural habitats tend to be highly fragmented, size is likely to be an

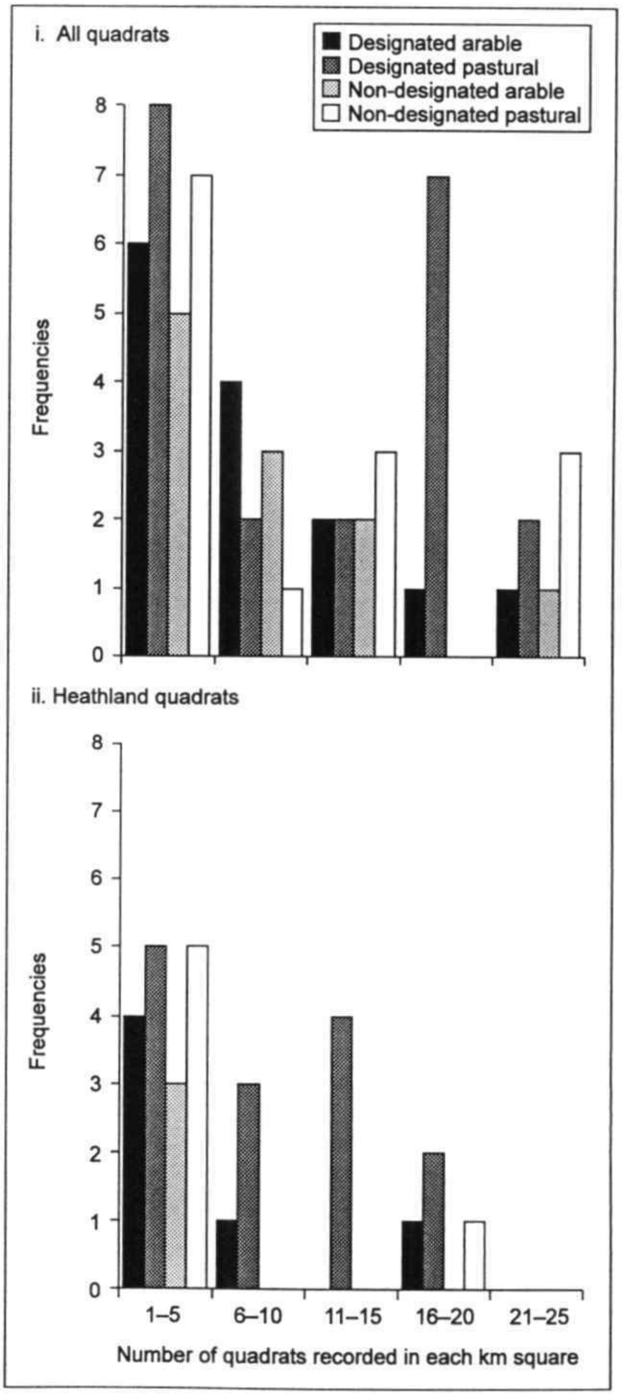


Figure 4.4 The number of quadrats recorded per km square from the lowland heath mask. Quadrats were recorded at a maximum of 25 grid points, where the vegetation met the criteria

important criterion. Not only the size of individual units of heathland needs to be considered, but also the extent of associated acid semi-natural vegetation. Size is also important in terms of landscape, in that larger areas have a greater overall visual impact and are inherently more robust and less susceptible to landscape change.

Average area of acid semi-natural vegetation per km square

4.8.2 On average, there was twice as much acid semi-natural vegetation (ie meeting the criteria for recording quadrats) in squares in the designated strata compared to those in the non-designated strata (Table 4.7).

Variation in area of acid semi-natural vegetation, and heathland, per km square

4.8.3 There was only a small proportion of squares which were dominated by acid semi-natural vegetation (Figure 4.4a). The arable strata have fewer squares overall with a large number of quadrats in each. These squares with large numbers of quadrats include both some which were dominated by heathland, eg in the New Forest, and some which were dominated by forestry plantations. Figure 4.4b shows the equivalent frequency distribution for those quadrats on existing heathland or bog (ie excluding those on acid grassland, scrub or woodland) – here the squares with large numbers of these quadrats are largely restricted to the designated pastural stratum.

Association between heathland, acid grassland and woodland

4.8.4 Figure 4.5 shows the number of squares which contained one or more of three aggregated 'structural types': woodland (including plantations and scrub), acid grassland (including bracken) and heathland (including bogs). All strata are dominated by squares containing plantation/woodland/scrub, particularly the non-designated strata. The designated pastural stratum shows the greatest proportion of squares with two or more categories, ie the greatest variety of habitats. The frequent proximity of woodland to heathland provides an abundant seed source, which, in the absence of appropriate

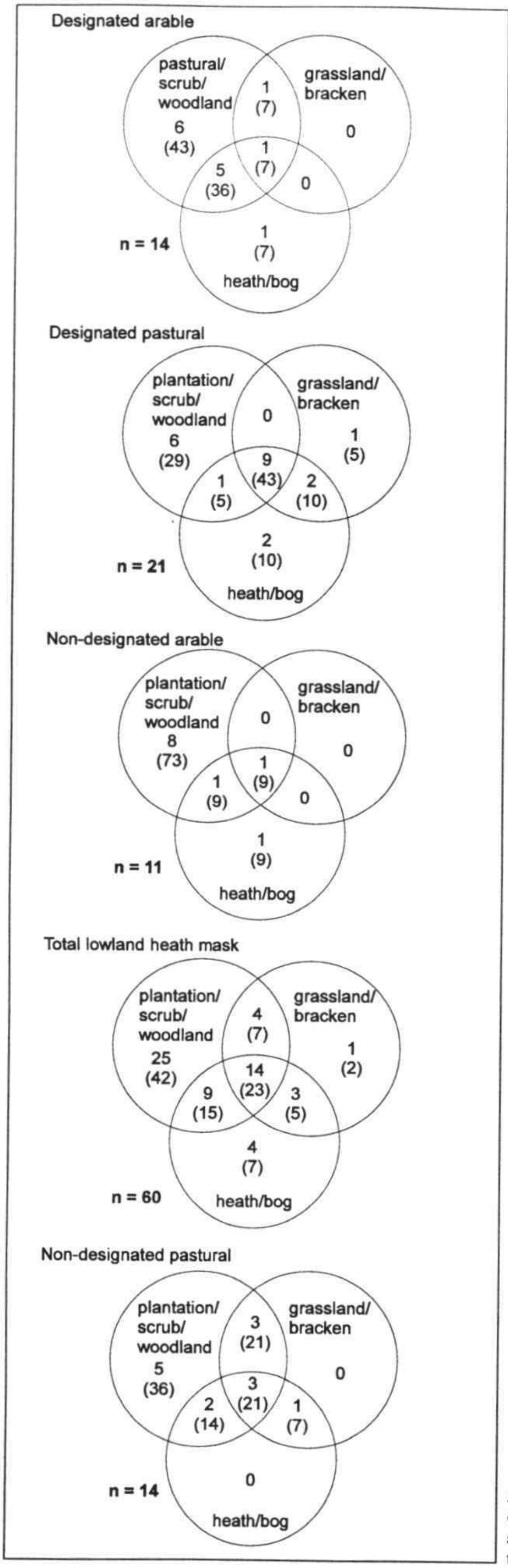


Figure 4.5 The association of heathland with acid grassland and/or woodland, shown by the number of survey squares with quadrats in one or more of these three categories in the lowland heath mask

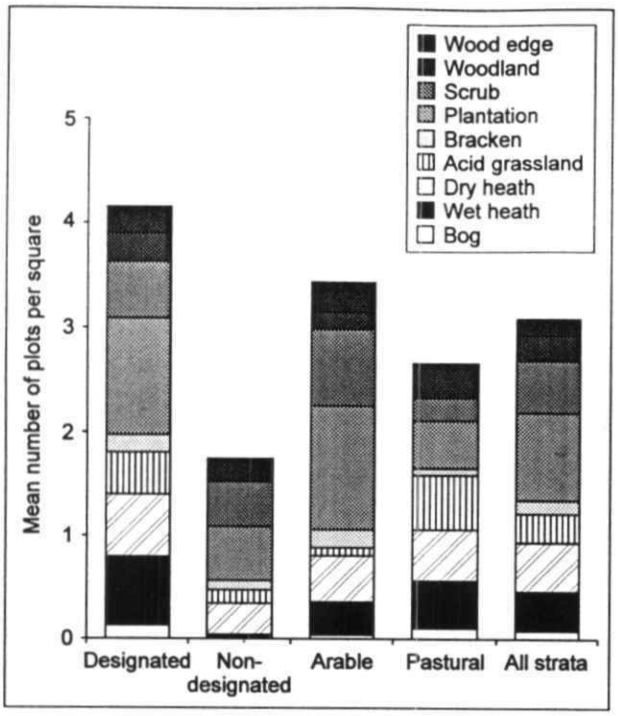


Figure 4.6 Abundance of structural types in the heathland mask based on quadrat data (no quadrats were recorded on arable land or in calcareous/neutral grasslands; the number of quadrats is related to the area of the vegetation type)

management, means that such heathlands will be vulnerable to colonisation by trees. These areas of scrub and forestry which are adjacent to existing heathland may also have potential for heathland restoration if the trees are removed.

Relative abundance of structural types

4.8.5 In terms of structural types, all of the bog quadrats and most of the wet heath quadrats were recorded in squares in the designated strata, whilst the dry heath, although predominantly in the designated strata, also occurs in significant amounts in the non-designated strata. Both bog and wet heath are more common in the pastural strata, whilst dry heath is more evenly spread (Table 4.8).

4.8.6 Most of the bracken and acid grassland occurs in the designated strata. The acid grassland is a large component of the pastural strata, contributing 22% to the pastural designated stratum. Plantations and scrub form a significant component of the arable strata, with deciduous woodland more common in the pastural strata.

4.8.7 Over the lowland heath mask as a whole, 20% of quadrats were recorded on heathland or bog, forming the core heathland component of these landscapes. Of the remaining 80%, many quadrats represent modified or relict heathland – for instance, former heathland which is being converted to grassland though grazing, or which is being colonised by birch or pine, or has been planted with conifers. The woodland and plantation quadrats also include heath species as a natural component of both broadleaf woodland flora and plantations which are on sites of former heath and broadleaf woodland. Differentiation between these situations will require analysis of species composition (see Section 4.11 for discussion of composition in terms of plot classes and species groups). The former, modified or relict heathland sites will provide the best opportunities, in an ecological sense, for restoration of heathland.

4.8.8 Of the quadrats recorded, 28% were in plantations, 16% were in scrub woodland and 9% were in acid grassland. All of these situations offer potential for heathland restoration, as discussed in Chapter 8.

Table 4.8 Mean number of quadrats per square in each structural type for each strata

									Combined									
	Designated				Non-designated						Non-		Combined					
Structural	Arable		Pastural		Arable		Pastural		Designated		designated		Arable		Pastural		All	
types	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Bog	0.07	2	0.20	5	0.00	0	0.01	0	0.13	3	0.00	0	0.04	1	0.10	4	0.07	2
Bracken	0.18	4	0.13	3	0.14	6	0.02	1	0.16	4	0.08	5	0.17	5	0.07	3	0.12	4
Acid grassland	0.04	1	0.92	22	0.15	6	0.13	11	0.41	10	0.14	8	0.08	2	0.53	20	0.29	9
Dry heath	0.56	14	0.65	16	0.28	12	0.31	27	0.60	14	0.30	17	0.45	13	0.49	18	0.47	15
Wet heath	0.48	12	0.92	22	0.07	3	0.01	1	0.67	16	0.04	2	0.32	9	0.47	18	0.39	13
Plantation	1.63	39	0.41	10	0.54	23	0.51	43	1.12	27	0.53	30	1.20	35	0.46	17	0.86	28
Scrub	0.69	17	0.33	8	0.79	34	0.09	7	0.54	13	0.43	25	0.73	21	0.21	8	0.49	16
Woodland	0.08	2	0.56	14	0.29	12	0.11	9	0.28	7	0.20	11	0.16	5	0.34	13	0.24	8
Wood edge	0.42	10	0.00	0	0.07	3	0.00	0	0.25	6	0.03	2	0.28	8	0.00	0	0.15	5
Total	*4.16*	*100*	*4.12*	*100*	*2.34*	*100*	*1.18*	*100*	*4.14*	*100*	*1.75*	*100*	*4.44*	*100*	*2.67*	*100*	*3.08*	*100*

The means for combined strata are weighted by strata size

Summary of size/abundant as a quality criterion

4.8.9 The designated strata have far more acid woodland (including scrub and plantations) and heathland than the non-designated strata (Figure 4.6). More quadrats were recorded in the arable strata, but a large proportion of these were woodland; there were more heathland and acid grassland quadrats recorded in the pastural strata. The wet heath and bog were concentrated in the designated pastural squares, whilst the dry heath was more widespread. Habitats associated with heathland which might be suitable for restoration are scrub and plantation (more common in the arable strata) and acid grassland (more common in the pastural strata).

4.8.10 The key points are that acid, semi-natural vegetation was only found at 12% of points, representing a relatively small area of the total mask. Abundance of this vegetation was greatest in already designated strata and over half of these plots were associated with woodlands, particularly in the arable strata. True heathland is scarce and fragmented.

4.9 Vegetation quality: diversity

4.9.1 Diversity can be expressed both as the variety of vegetation types and the range of plant species within a site, thus reflecting the range of variation in physical variables as well as the species richness associated with each vegetation type. The number of 'plot classes' present indicates the diversity of different vegetation types or habitats; the number of 'species groups' recorded is used to assess the species richness. The number of species recorded in quadrats is not reported because it cannot be directly related to quality, without taking account of the types of species present. For example, high species number may reflect either a 'high'-quality heathland site or one which is being invaded by grassland and/or woodland species. Dry heath tends to be poorer in species than wet heath and bog, which can be rich, particularly in lower plants. (See para 4.9.6 for discussion of species groups).

Table 4.9 Mean number of different plot classes represented per square

Stratum	All plot classes	Heath plot classes
Designated arable	1.86	0.41
Designated pastural	1.82	0.55
Non-designated arable	1.15	0.14
Non-designated pastural	0.60	0.12
Combined designated	1.84	0.47
Combined non-designated	0.87	0.13
Combined arable	1.58	0.30
Combined pastural	1.22	0.34
Total	*1.41*	*0.32*

These figures represent the mean number of plot classes per square, including those squares where no plots were recorded. Squares in which plots were recorded varied from one to ten plot classes per square

Table 4.10 Mean number of different species groups per square for each strata

Stratum	All species groups	Heath species groups
Designated arable	3.95	1.37
Designated pastural	3.70	1.43
Non-designated arable	3.86	1.02
Non-designated pastural	1.62	0.68
Combined designated	3.85	1.40
Combined non-designated	2.71	0.84
Combined arable	3.92	1.23
Combined pastural	2.68	1.06
Total	*3.34*	*1.15*

These figures represent the mean number of species groups per square,including those squares where no plots were recorded

Number of different plot classes

4.9.2 The classification of quadrats into 'plot classes' can be used to consider the average range of vegetation present in each square, ie the higher the mean number of classes present in squares in a strata, the greater the variety of acid semi-natural vegetation (Table 4.9). If all quadrats are considered, there is greater variety amongst the vegetation types sampled in the designated strata. If just the heathland plot classes (A–F,I,J) are considered, the designated strata also show greater diversity, and there is not much difference between the arable and pastural strata. (See Section 4.11 below for discussion of differences in the composition of plot classes between strata).

Number of different species groups

4.9.3 Table 4.10 uses the classification of species into 'species groups' to consider the range of different types of species present in each square. When all species groups are considered, the average number of types present is greatest in the designated and arable strata, whilst the non-designated pastural stratum is substantially less diverse. If just the heath species groups (1–5) are considered, there is a much greater difference between the designated and non-

Table 4.11 Mean number of species per plot in each habitat indicator group

Habitat indicator groups	Designated arable		Designated pastural		Non-designated arable		Non-designated pastural	
	No.	%	No.	%	No.	%	No.	%
Heath specialist species	+	1	1.0	9	0.2	2	0.3	3
Heath generalist species	3.0	40	5.5	50	1.7	21	3.7	40
Acid grassland species	2.2	30	2.4	22	3.0	37	3.1	33
Neutral grassland species	0.4	5	0.7	6	0.6	7	0.5	5
Woodland species	1.5	20	1.1	10	2.2	27	1.6	17
Weeds and alien species	0.3	4	0.2	2	0.4	5	0.1	1
Total	*7.4*	*100*	*10.9*	*100*	*8.1*	*100*	*9.3*	*100*

Habitat indicator groups	Combined designated		Combined non-designated		Combined arable		Combined pastural		All	
	No.	%	No.	%	No.	%	No.	%	No.	%
Heath specialist species	0.8	8	0.3	3	0.3	4	0.7	7	0.6	6
Heath generalist species	4.7	48	2.9	33	2.4	30	4.8	48	4.0	42
Acid grassland species	2.3	23	3.1	35	2.6	33	2.6	26	2.6	27
Neutral grassland species	0.6	6	0.6	7	0.5	6	0.6	6	0.6	6
Woodland species	1.2	12	1.8	20	1.8	23	1.3	13	1.5	16
Weeds and alien species	0.2	2	0.2	2	0.3	4	0.1	1	0.2	2
Total	*9.8*	*100*	*8.9*	*100*	*7.9*	*100*	*10.1*	*100*	*9.5*	*100*

The means for combined strata are weighted by strata size

designated areas, and relative uniformity between the arable and pastural strata. (See Section 4.11 for discussion of species group composition).

Summary of diversity as a quality criterion

4.9.4 There was a greater range of acid vegetation types in general, and heathland types in particular, in the designated compared to the non-designated strata. Relating these data to the relative abundance of structural types suggests that this was largely due to the greater frequency of wet heath and valley bog types in designated squares, whilst heathland in the non-designated squares was generally more uniform dry heath. There was a greater range of heath species groups in the designated strata; this could be because there is a greater variety of local environmental conditions or because these areas have maintained natural diversity.

4.10 Vegetation quality: naturalness

4.10.1 'Natural' is a term sometimes applied to vegetation which is considered to be unmodified by human influence – it cannot be strictly applied to any habitat in England, certainly not to a subclimax habitat such as heathland. However, in this context, naturalness is used as a measure of the extent of modification or disturbance away from the optimum required to maintain an area as heathland. Too little 'modification' will allow succession to scrub and woodland, too much will move the vegetation towards grassland or bare ground. Such modification or disturbance is indicated by the presence of species which are not normally associated with heathland, eg grassland species like rye grass, which in a heathland context might indicate eutrophication and/or over-grazing, or a woodland species, eg silver birch (*Betula pendula*), which might indicate that lack of grazing is allowing scrub development. It is clearly not only the presence of such species but their relative abundance or cover which provides useful measures of 'naturalness'.

Numbers of habitat indicator species

4.10.2 The classification of species into 'habitat indicator types' examines the extent to which vegetation recorded in quadrats is dominated by plant species associated with heathland, as opposed to those mainly found in grasslands or woodlands (Table 4.11). The proportion of heath-specialist and heath-generalist species is greater in quadrats in designated than non-designated strata and in pastural than arable strata. In quadrats in the non-designated strata, there is a greater proportion of acid grassland and woodland species. So quadrats in the designated strata have a higher proportion of 'heath' species, implying more 'natural' heathland vegetation, whilst in non-designated strata more grassland and woodland species are present. Similarly, quadrats in the pastural strata have a higher proportion of heathland species and a lower proportion of grassland and woodland species than those in the arable strata.

4.10.3 Analysis of the mean percentage cover of species (as opposed to presence) of each 'habitat indicator type' per quadrat shows the same relationships as for mean species number (see Appendix 2). So this pattern of a greater proportion of heath-specific and heath-generalist species in designated strata and a greater proportion of acid grassland and woodland species in non-designated strata applies both to the dominant species which make up most of the cover, and to the overall species composition, which includes the smaller and less common species.

Cover of dwarf shrub species

4.10.4 Heathland is characterised by the presence of dwarf shrub species, and a high cover of these species is associated with most heathland types. Heather was the most dominant of four dwarf shrub heath species. There is more heather in the designated than in the non-designated strata, and more in the pastural than arable strata. Bell heather, which is mostly associated with dry heath, is predominantly in designated quadrats, but is also present in quadrats in the non-designated arable stratum. Cross-leaved heath, which is associated with wet heath, is mostly in the designated strata, as would be expected as this is where the wet heath plot classes were located. Bilberry forms only a minor component of the quadrats sampled, and was almost all in quadrats from the designated pastural stratum. Overall cover of dwarf shrub species is greater in the designated and pastural strata (Table 4.12).

Summary of naturalness as a quality criterion

4.10.5 A higher proportion of heath specialist species were recorded in the designated pastural stratum, implying that there was more 'natural' heathland vegetation in these areas, whilst those in other strata had a higher proportion of non-heathland species, suggesting that they were more modified from the 'natural' state. This may be because dry heathland (more prevalent in the arable strata) is more vulnerable to colonisation by grassland species. It may also be because more heathland in the designated strata is receiving appropriate management.

4.10.6 Overall, dwarf shrub species provided 20% of the vegetation cover in the quadrats. This was greatest in the designated and the pastural strata. In arable strata cross-leaved heath represented less than one fifth of the shrub cover, compared with over a quarter in the pastural strata.

4.11 Vegetation quality: representativeness

4.11.1 Representativeness involves using a classification of the range of vegetation being considered to ensure that examples of the full range of types present within a region are conserved, as well as giving emphasis to those which are 'typical'. In the case of lowland heath, it may not be important that a range of types is present, as heath may be maintained only if some types are favoured. Nevertheless, the range of vegetation present is described here using the classification of quadrats into 'plot classes', and of species into 'species groups'.

Ratio of 'heath' to 'non-heath' plot classes

4.11.2 The classification of quadrats into 'plot classes' has been used to consider the range of vegetation recorded in the four strata. Table 4.13 compares the proportion of quadrats in the 'heath' plot classes, as defined in Table 4.5, compared with those in the 'non-heath' plot classes (ie the modified

Table 4.12 Mean percentage cover per quadrat of dwarf shrub species

Stratum	Heather	Bell heather	Cross-leaved heath	Bilberry	Combined
Designated arable	13.6	1.9	4.3	0.0	19.9
Designated pastural	17.0	2.2	9.4	0.4	29.0
Non-designated arable	4.6	1.5	0.1	0.0	6.1
Non-designated pastural	13.3	0.4	0.5	0.1	14.3
Combined designated	15.9	2.1	7.8	0.2	26.0
Combined non-designated	9.9	0.8	0.3	0.1	11.1
Combined arable	9.7	1.7	2.5	0.0	13.9
Combined pastural	15.6	1.6	6.1	0.3	23.5
Total	*13.5*	*1.6*	*4.8*	*0.2*	*20.1*

Cover is averaged over all plots in strata, not only those where the species was present

Table 4.13 Percentage of plots in heath *vs* non-heath plot classes

Stratum	Core heathland (PCs A-F,I,J) %	Modified heathland (PCs G,H,K,L) %	Grassland/ woodland (PCs M-T) %
Designated			
Arable	20	32	48
Pastural	36	16	48
Non-designated			
Arable	15	39	46
Pastural	16	32	53
Combined			
Designated	27	25	48
Non-designated	14	37	48
Arable	19	34	47
Pastural	31	19	49
Total	*24*	*28*	*48*

heaths which have been planted or colonised by trees, or converted to grassland, acid grasslands and woodlands). Overall, about a quarter (24%) of plots are core heathland, another quarter (28%) are modified heathland, and the remaining half (48%) are non-heathland, ie acid grassland and woodland. These proportions are discussed further in Chapter 9 in relation to habitat re-creation. In the combined pastural strata and combined designated strata, there are greater proportions of core heathland to modified heathland.

Relative abundance of plot classes

4.11.3 Nearly all the 'bog' (PCA), 'wet heath' (PCB), 'ultra-basic wet heath' (PCC), 'southern damp heath' (PCE) and 'grassy heath' (PCI) were in designated strata (Figure 4.7). The 'very acid heath' (PCD) was all in the pastural strata . Less than half of the 'dry heath' (PCF) and 'southern dry heath' (PCJ) were in designated strata, the latter being mainly in the arable strata. Of the eight heath plot classes only two were represented in the arable non-designated strata, these being the dry heath types (PCF & PCJ). In the pastural strata it was mainly the 'very acid heath' (PCD) and the 'dry heath' (PCF) which occurred in the non-designated stratum. Further details are given in Appendix 2.

4.11.4 At least 40% of each of the heathland types recorded in the survey were in designated strata, and a much higher proportion of the bogs and wet heaths, suggesting that designation has been effective in covering the range of heath vegetation. There was still dry heathland in non-designated squares in both arable and pastural strata, as well as areas of disturbed or planted heath, which have potential for heathland restoration.

Relative abundance of species groups

4.11.5 The relative abundance of different types of species in quadrats in each stratum is shown in Figure 4.8. 'Bog species' (B1) and 'wet heath species' (B2) were most frequent in the designated strata. 'Moss/lichen heath species' (B3 & A4) were most abundant in the pastural and non-designated strata. The dominant 'vascular heath species' (A5) were more evenly spread, though still more abundant in the designated strata. Further details are given in Appendix 2.

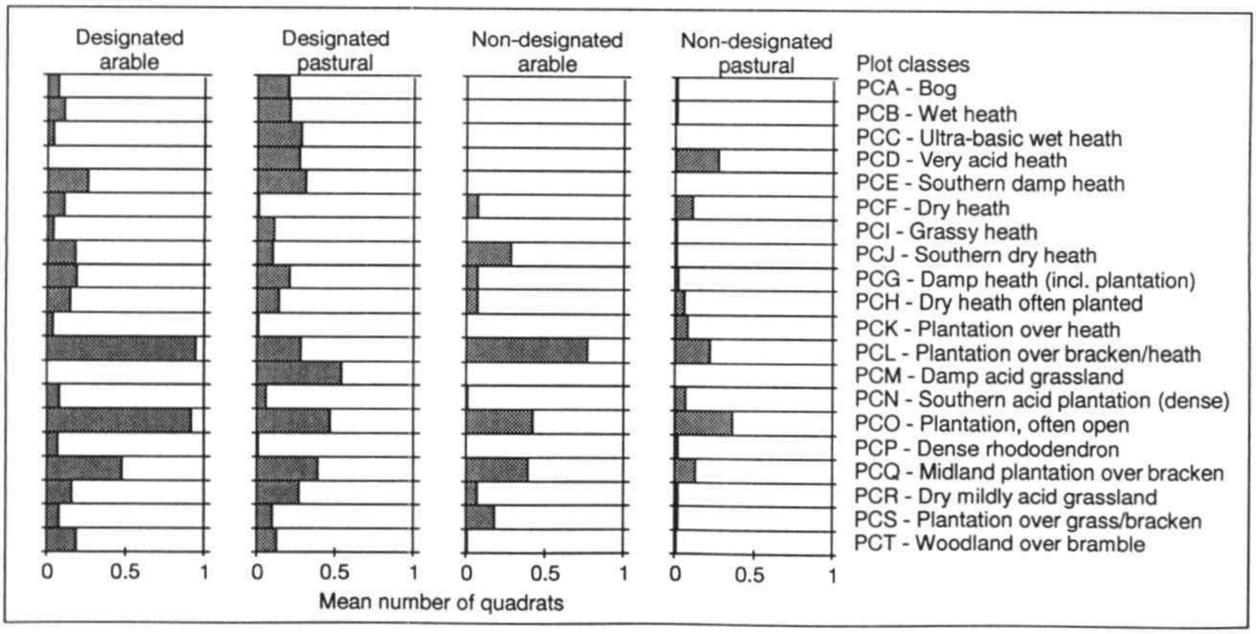


Figure 4.7 The mean number of quadrats in each plot class recorded in the four heathland landscape strata

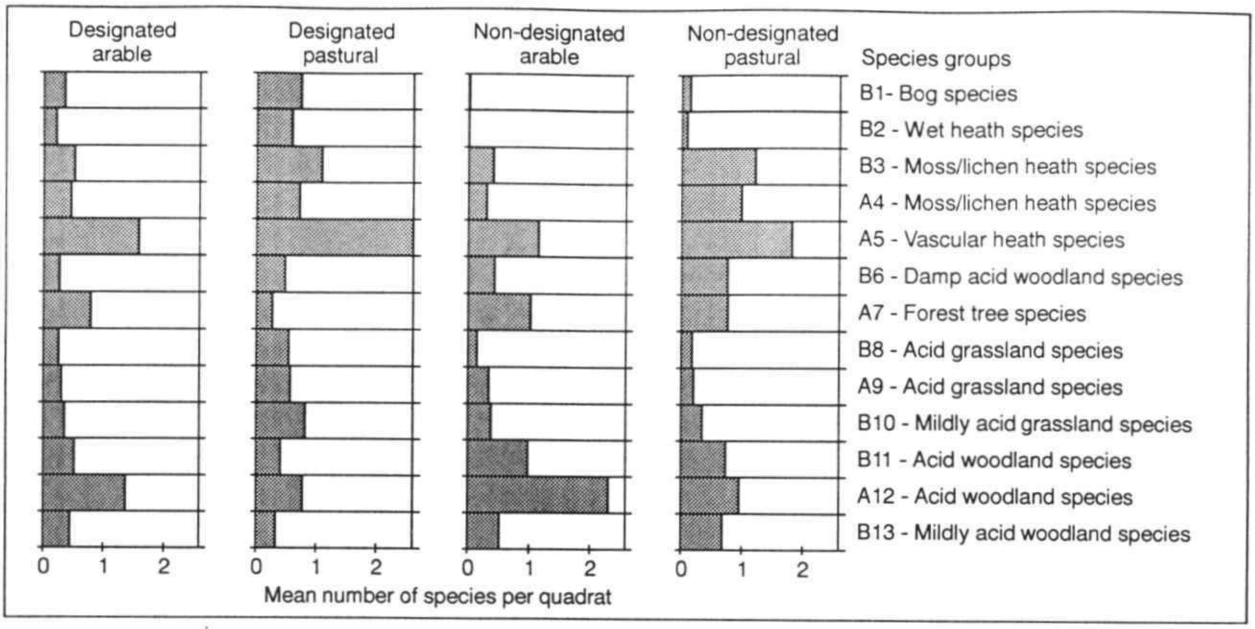


Figure 4.8 The mean number of species per quadrat, in each species group, recorded in the four heathland landscape strata

4.11.6 The 'damp acid woodland species' (B6) and the 'forest tree species' (A7), as well as the 'acid woodland species' (B11, A12, B13) were all more abundant in the non-designated strata. In contrast, the 'acid grassland species' (B8, A9) were more frequent in the designated strata.

Summary of representativeness as a quality criterion

4.11.7 Analysis of the quadrats recorded in heathland has identified eight types of core heathland plot classes which have different distributions across the four strata. The bog and wet heath types were mainly found in designated squares, and more often in the pastural strata. Dry heath types were more evenly distributed geographically and in terms of designation status. This was also reflected by the distribution of species groups. Bog and wet heath species were most strongly represented in the designated strata, whilst the vascular heath species were more widely spread. The designated strata include examples of the whole range of heathland plot classes and species groups.

4.11.8 Using TWINSPAN analysis, about one quarter of the plots are defined as core heathland, another quarter is modified heathland, and the remainder is either grassland or woodland. The modified heathland plots are likely to have the greatest potential for restoration of heath and are more frequent in the arable and in non-designated strata.

4.12 Rarity

4.12.1 The survey strategy employed for this project is designed to record representative examples of heath, not rare types or rare species; although they may occur within the sample, it is not possible to make any general statements about their abundance or distribution.

4.12.2 The vascular species recorded have been checked against the *Red Data Book* (RDB) list of species, and against the 'Nationally scarce' species list defined *in Guidelines for selection of biological SSSIs* (NCC 1989). The only species recorded which occurs on these lists is Cornish heath (*Erica vagans*) – an RDB species, recorded from several quadrats on one sample square on the Lizard peninsula in Cornwall. Non-vascular species were checked against nationally scarce species listed in *Guidelines for the selection of biological SSSIs: non-vascular plants* (Hodgetts 1992). The only species which occurred was *Sphagnum pulchrum.*

4.13 Fragility

4.13.1 Fragility reflects the degree of sensitivity of vegetation types and species to environmental change. Four types of change have been considered which may adversely affect heathland:

- drying out;
- succession;
- grazing;
- eutrophication (see Chapter 2).

4.13.2 Heath species which are sensitive to each of these four processes have been identified;

Table 4.14 Mean number of species per plot of each fragility type

Strata	Drying out	Succession	Grazing	Eutrophication
Designated				
Arable	0.53	1.51	0.93	1.35
Pastural	1.71	3.19	1.78	2.56
Non-designated				
Arable	0.14	0.87	0.37	0.74
Pastural	0.35	1.99	0.90	1.80
Combined				
Designated	1.32	2.65	1.50	2.17
Non-designated	0.27	1.56	0.70	1.39
Arable	0.36	1.23	0.68	1.08
Pastural	1.20	2.75	1.45	2.28
Total	*0.91*	*2.22*	*1.19*	*1.86*

their presence implies that an area remains unaffected, therefore the relative abundance of these species can be used as a measure of quality. There is a similar pattern for all four types of change (Table 4.14). In each case, quadrats in the designated strata have higher proportions of sensitive species than in the non-designated strata, and quadrats in the pastural strata also have more sensitive species than those in the arable strata. However, for the process of succession, quadrats in the non-designated pastural stratum have more sensitive species than the designated arable stratum, suggesting that sites in arable-dominated areas are more vulnerable to this process. It is not possible to determine whether the higher proportions of sensitive species in the designated strata reflect a designation policy targeted at fragile vegetation, or whether they are present because they have been protected by the designation.

4.14 Vegetation quality: potential value

4.14.1 The value of heathland, and areas which have potential to become heathland, depends on the current vegetation type, and on the potential for enhancement and restoration, the latter being affected by all the criteria discussed above.

4.14.2 Existing heathland depends for its maintenance on appropriate management. It can be enhanced by increasing the patch size, incorporating associated habitats, linking patches and providing buffer zones.

4.14.3 Non-heathland elements of the lowland heath landscape can be divided into two types.

i. Land cover types which have received high management inputs and whose vegetation no longer contains any heath species (eg arable fields, improved grassland); although heathland creation may be possible in these situations, the current vegetation and seed bank will not influence the resulting vegetation. The areas of these land cover types available for such heathland creation schemes are shown in Table 4.3.

ii. Habitats which are derived from heathland or include heath species – if these are on appropriate soils, then heathland restoration is feasible, and the process will incorporate the heath species present both above-ground and in the seed bank. The effort required to achieve this will depend on the current vegetation, as well as on soil type, past management, and the length of time since heath vegetation was dominant.

4.14.4 The classification of quadrats into 'plot classes' can be used to separate existing heathland from the 'modified' heathland and grassland/woodland vegetation. (Figure 4.9) By plotting the position of each quadrat on the first and second gradients, the relationship between plot classes can be shown. The left side of the graph represents the most acid vegetation (bogs) moving down the first gradient to the more neutral vegetation on the right side. The second gradient separates the grasslands (top) from the woodlands (bottom). The diagram shows three discrete groups of plot classes: the core heathland (blue and turquoise), the grasslands (yellow) and the woodlands (green), with small amounts of overlap between them (mainly PCO – plantation often open). The position of the modified heathland types (red and purple) in relation to these three groups gives an indication of the degree of similarity of their species composition.

4.14.5 The core heathland plot classes (PCA–PCF, PCI, PCJ) fall on the left side of the graph – a ring has been drawn round them to indicate a 'heathland zone'. Within this area, the bogs and wet heaths are concentrated on the left, the drier heaths to the right. In this same area of the graph are many quadrats from the 'modified' heathland plot classes (PCG, PCH, PCK); this implies that the quadrats in these plot classes still have a

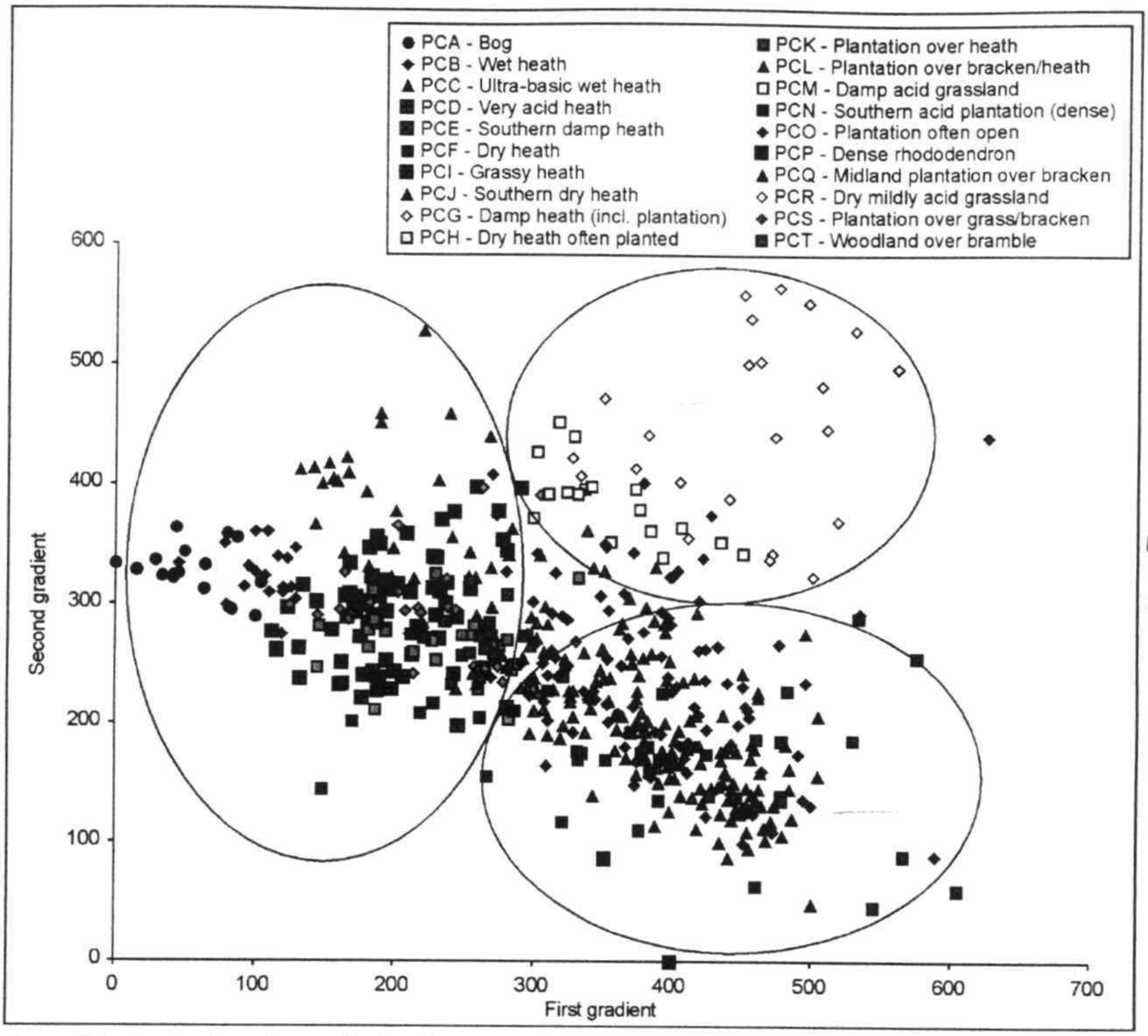


Figure 4.9 Lowland heath quadrats - ordination diagram using DECORANA scores

table missing

significant component of a heathland flora, but within this group, plot classes PCG (damp heath including plantation) and PCH (dry heath often planted) are near to the centre, whilst PCK (plantation over heath) is on the right-hand edge, ie on the boundary with the woodland classes. PCL (plantation over bracken/heath) overlaps with both the heathland and the woodland groups, although most plots fall in the woodland area of the graph. Thus, the positions of quadrats on this graph can be used to assess, in a quantitative way, the relative quality (in terms of similarity in species composition with core heathland) of vegetation, both within and between plot classes. The quality of the existing vegetation is directly related to the potential for heathland restoration, ie restoration of 'modified' heathland similar to plots on the left of the graph will be more successful and will require less management input than restoration of vegetation represented by plots on the right side of the graph.

4.14.6 The spread of points from quadrats in the woodland plot classes (PCN–PCQ, PCS, PCT) distinguishes those which are furthest from heathland (PCS, PCT – associated with the more neutral soils), from those which include some heath species (PCN–PCQ). PCO (plantation often open) has a wide distribution, and borders both the heathland and grassland groups; further division of this class might separate out those types nearest to heathland, with the best potential for restoration.

4.14.7 The two grassland plot classes (PCM, PCR) occupy a distinct area of the graph, but PCM (damp acid grassland) is clearly closer to heathland, and has more potential for restoration, than PCR (dry mildly acid grassland).

Table 4.15 Summary of heathland strata ranked by quality criteria

Quality measures	Designated arable	Designated pastural	Non-designated arable	Non-designated pastural
Size				
Estimate of heathland area	1	2	3	4
Number of quadrats recorded on heathland	2	1	4	3
Proportion of survey squares with existing heathland	2	1	3	4
Diversity				
Mean number of heath plot classes per square	2	1	3	4
Mean number of species groups per square	2	1	3	4
Naturalness				
Mean species number in heathland habitat indicator groups	2	1	4	3
Mean species cover in heathland habitat indicator groups	2	1	4	3
Cover of ericoid species	2	1	4	3
Representativeness				
Proportion of quadrats in heath plot classes	2	1	3	4
Number of species in heath species groups	3	1	4	2
Fragility				
Mean number of fragile species	3	1	4	2
Number of criteria ranked first	1	10	0	0
Number of criteria ranked second	8	1	0	2
Number of criteria ranked third	2	0	5	4
Number of criteria ranked fourth	0	0	6	5

4.14.8 Plot classes PCG (damp heath including plantation), and PCH (dry heath often planted) represent heaths which show signs of recent modification whether from succession or disturbance resulting from planting of conifers, over-grazing or excessive recreational use. PCM (damp acid grassland), although not classed as heath, may also represent recent change from heathland due to over-grazing. Restoration of these types may require considerable management input (eg removal of trees, scrub control, controlled grazing) but may use fewer resources, and be more successful, than habitat creation schemes. The heath species already present in the ground flora and the seed bank will contribute to the resulting vegetation.

4.14.9 PCK (plantation over heath) and PCL (plantation over bracken/heath) largely represent secondary planting (usually first generation) on to heathland sites, where heath species are still a significant component of the ground flora. Restoration is likely to take longer than for classes PCG and PCH, but is still feasible, although the heathland produced may take a long period of time to become of good quality.

4.14.10 Plot classes PCN (southern acid plantation (dense)), PCO (plantation often open), PCP (dense rhododendron) and PCQ (midland plantation over bracken) represent sites of more doubtful potential, where heath species are poorly represented. Many are sites which have not been heathland for a considerable time. Removal of trees would not necessarily result in heathland vegetation, but might instead be dominated by bracken or grasses.

4.14.11 The remaining classes, PCR (dry mildly acid grassland), PCS (plantation over grass/bracken) and PCT (woodland over bramble), are at the opposite end of the first gradient to the heath plot classes, and are probably on soils which are only marginally suitable for heathland development. The latter class is mainly composed of deciduous woodland sites which include one or two heath species as natural components of their ground flora, but are unlikely to have ever been heathland.

Table 4.16 Number of km squares including designations in the lowland heath mask

Designation	Designated arable No.	Designated arable % of stratum	Designated pastural No.	Designated pastural % of stratum	Lowland heath mask No.	Lowland heath mask % of mask
SSSI	1024	37	591	30	1615	19
NNR	103	4	77	4	180	2
ESA	1232	45	111	6	1343	16
NP	79	3	452	23	531	6
AONB	826	30	615	31	1441	17
HC	99	4	164	8	263	3
G Belt	601	22	660	33	1261	15
Any design	2758	100	2002	100	4760	56

Squares may contain more than one designation, so the last row is not the sum of the above

Table 4.17 Number of survey squares including designations

	Designated arable		Designated pastural		Lowland heath mask	
Designation	No.	% of stratum	No.	% of stratum	No.	% of mask
SSSI	6	23	15	47	21	20
NNR	0	0	2	6	2	2
ESA	10	38	2	6	12	11
NP	1	4	3	9	4	4
AONB	9	35	11	34	20	19
HC	1	4	2	6	3	3
G Belt	7	27	16	50	23	22
Any design	26	100	32	100	58	55

4.15 Quality criteria – ranking of heathland strata

4.15.1 Table 4.15 shows the results of ranking the four strata in terms of the quality measures discussed above. It shows quite clearly that heathland in the designated pastural stratum ranks highest both on the basis of area and abundance, and in terms of integrity or lack of disturbance. The designated arable stratum consistently ranks second in terms of some estimates of size, species diversity, naturalness and aspects of representativeness.

4.15.2 The non-designated strata have lower-quality rankings than the designated, except in terms of fragility where the non-designated pastural stratum ranks higher than the designated arable. The arable non-designated stratum tends to rank higher with respect to diversity than the pastural non-designated stratum which has higher values for naturalness and fragility.

4.15.3 This form of non-parametric comparison is useful in terms of identifying the priorities for further lowland heath protection, although it does not, by definition, give measures of the relative importance of each stratum in terms of quality.

Table 4.18 Overlap between designations for sample squares

Designation combinations							% of designated squares
		ESA		AONB			2
		ESA		AONB	HC		3
				AONB		G Belt	3
SSSI				AONB	HC	G Belt	2
SSSI	NNR			AONB			3
SSSI				AONB			7
SSSI							9
SSSI						G Belt	16
				AONB			14
			NP				7
		ESA					16
						G Belt	19

4.16 Designations

4.16.1 The above discussion has considered designations as a whole, but clearly different types of designation have different purposes. Within the lowland heath landscape, ESAs cover the largest area in the arable strata, while National Parks are mainly restricted to the pastural strata. AONBs and Green Belts are significant in both, as are SSSIs – see Table 4.16.

4.16.2 Analysis of individual designations was not an objective of the project, and was not incorporated into the sampling strategy. The number of sample squares available for each designation allows only limited analysis (Table 4.17). It will be noted that some categories are over-represented in the sample (SSSIs and Green Belts in pastural strata), whilst others are under-represented (SSSIs in the arable strata and National Parks in the pastural strata). This is because the sample was not stratified by designation type, and was not large enough to be fully representative; this needs to be considered in interpreting the results.

4.16.3 In addition, the situation is complicated by the overlap between designations (Table 4.18). Of the sample squares in the designated strata, 45% have more than one designation.

4.17 Conclusions

4.17.1 The lowland heath mask (ie lowland England on acid soils) was defined as an area of 8538 km^2; 56% of these km squares contained one or more of the specified designations. Of this landscape, just 5% (440 km^2) was estimated to be lowland heath habitat (dwarf shrub heath and associated vegetation types), 75% of which occurred in designated strata. Analysis of the quadrat data showed that this lowland heath habitat included a range of vegetation types, from bogs and wet heath, through dry heath, to vegetation becoming dominated by grasses or scrub. The core heathland vegetation types (defined in terms of TWINSPAN plot classes) were estimated at just 361 km^2. Of this, the wet heath and bogs occurred almost entirely in designated strata, whilst some dry heath occurred in areas which were not designated.

4.17.2 In addition to the core heathland, modified heathland vegetation types were identified which had been colonised or planted with trees but still contained a recognisable heathland flora; these were estimated at 674 km^2, nearly twice the area of existing heathland. These modified heathland areas occurred throughout the lowland heath landscape, though they were more common in designated areas and on drier soils. These areas provide the best opportunity for heathland restoration.

Chapter 5 HISTORICAL CHARACTERISTICS OF THE LOWLAND HEATH MASK

5.1 Introduction

5.1.1 The archaeological study was designed to provide an 'evaluation of distribution of historic (archaeological) features in the lowland heath landscapes and of the effectiveness of the designations in protecting these features'. In conjunction with this, the study was intended to examine the task of developing 'recommendations for modification/enhancement of policies to improve protection of historic features'.

5.1.2 There were three specific aims of the archaeological study:

i. to examine the distribution of archaeological features in the lowland heath landscape;
ii. to assess the relationship between features and designations in the lowland heath landscape;
iii. to develop recommendations for modifying designations to improve the protection of features.

5.2 Methodology

5.2.1 In order to achieve the aims of the project, it was necessary to obtain a list of archaeological sites occurring in each of the ITE sample squares. In practice, the extent of this resource is unknown and no reliable estimate/ projection of its size exists. For this reason, two distinct types of archaeological data gathering were carried out: information from archives and from new survey work. The 'extended national archaeological database' (see below) constitutes the recorded archaeological resource in England and extraction of data from it constituted the major part of the work. Survey work was designed to assess the viability of estimating the percentage of the archaeological resource examined in the sample squares. Within the current project, work was restricted to three sources:

- fieldwork by ITE staff (non-archaeologists);
- selective aerial photography (AP) analysis; and
- map interpretation of recent edition Ordnance Survey map extracts supplied by ITE, County Sites and Monuments Records (SMRs) and the National Monuments Record (NMR).

5.2.2 No national standard was known to exist for recording the condition of archaeological monuments. It was therefore anticipated that local information, if available, would be difficult to use. However, information was collated within this project and its value was assessed. A work programme is shown in Appendix 3, together with a description of the available archaeological data.

5.3 Analysis and results

The distribution of archaeological sites in the lowland heath mask

5.3.1 The quantity of archaeological monuments is presented in Table 5.1 (with further details in Appendix 3). These data suggest that lowland heath is characterised as follows.

- Prehistoric periods are mainly represented by 'find' sites (ie where objects have been found) together with hut circles and Bronze Age barrows.
- The Roman period is also dominated by find sites, although with a scattering of other site types, particularly roads.
- Representation of the Early Medieval period is sparse, the only notable features being barrows and burials.
- The Medieval period retains a religious, ritual and funerary grouping (here mainly churches and crosses), but there is a notable increase in settlement sites together with farms and field systems.
- In the Post Medieval period, the settlements included many villages and some small towns (reflected in the entries under domestic, civil, and garden and parks classes). In addition, there is a surge of industrial (mainly extraction) and transport (especially railway) sites.

Table 5.1 Quantity of features in the lowland heath mask – RCHME* classes by period

	Pre-historic	Palaeo	Meso-lithic	Neolithic	Bronze Age	Iron Age	Roman	Early Medi-eval	Medieval	Post Medi-eval	Modern	Un-known
Agriculture and subsistence	2				2	1			8	12		110
Domestic	9		1	1	2	5	2		17	11		46
Civil							1			11		6
Recreation												2
Garden and parks										4		
Commemorative										1		
Religious, ritual and funerary	6				38	3		6	13	4		28
Commercial												8
Industrial			1				2			44	1	53
Transport							7	1		31	2	13
Water & drainage										5		19
Maritime												
Defence						1			3		1	6
Object	23	6	21	24	23	10	25	2	9			2
Unassigned	5						1	1	1	6		43

* Royal Commission on the Historical Monuments of England

Many of the unspecified sites almost certainly belong to the Post Medieval period, and this group follows the same pattern as the Post Medieval distribution.

5.3.2 Although some reference to the current condition of monuments is present in some SMR/NMR entries, it is widely variable and the only option is to examine the recorded 'form' of monuments. However, this examination can only give an indication of the form which monuments currently take. Some monuments of a given form may be stable (eg henges as 'ruins', barrows as 'earthworks'); others of the same form may be rapidly deteriorating (eg many industrial structures as 'ruins').

5.3.3 The number of sites within form groups (aggregations of 20 'forms' into 11 groups – see Appendix 3, Table A3.3) for different archaeological periods (Table 5.2) shows a broad pattern as might be expected. Structures and ruins are generally of recent date (the Prehistoric sites are standing stones). Amongst earthworks, Bronze Age barrows form a large group (many undated barrows may also be Bronze Age in origin). Crop/soil sites and AP sites appear to be relatively uncommon. Finds as identifiers of sites are plentiful and occur throughout the periods, although they are most important for Prehistoric and Roman sites. Sites identified from documentary sources are also plentiful, although artificially boosted within this dataset by the procedure employed to identify new sites (fieldwork would enable re-allocation by both form group and period of the bulk of these sites). The number of excavated/removed sites appears small, but the unrecorded removal of sites is unquantified.

Table 5.2 Quality of features – form groups by period for lowland heath

Form group	Pre-historic	Palaeo	Meso-lithic	Neo-lithic	Bronze Age	Iron Age	Roman	Early Medi-eval	Medi-eval	Post Medi-eval	Mod-ern	Un-known
A-Structure									12	31	2	36
B-Ruin	3				1				7	9		1
C-Underground										1		
D-Feature							1		1	11		9
E-Earthwork	9				30	4	1	5	7	16	1	83
F-Crop/soil					1					1		6
G-AP	6				1							7
H-Find	22	6	23	24	23	13	27	3	9	1		5
I-Doc/oral	5				4	2	8	1	15	57	1	189
J-Exc/rem				1	5	1	1	1		2		
Unspecified												

Table 5.3 Designations – number and mean number of sites per km square by data source and designation

Data source	Designation	Total no. of sites	Mean km^{-2}
SMR/NMR	Yes	320	7.0
	No	163	3.4
Field survey	Yes	147	3.2
	No	122	2.8
Combined sources	Yes	467	10.2
	No	285	6.6

Designations and archaeological features

5.3.4 Of the 752 sites recorded in the 89 sample field survey squares, 467 occur in 46 designated squares (10.2 km^2), with 285 in 43 non-designated squares (6.6 km^2) (see Tables 5.3 & 5.4). This distribution is due almost entirely to sites derived from SMR/NMR registers and with predominantly prehistoric origins. In the historic period, Roman and Post Medieval sites show no differentiation. The Early Medieval and Medieval periods together repeat the prehistory correlation.

5.3.5 Sites which are Scheduled Ancient Monuments (SAMs) number 50. This is 6.1% of the total number of sites in the lowland heath dataset and constitutes 10.4% of SMR/NMR registered heath sites; 96% of lowland heath SAMs (all but two) occur in or near other designations (see Table 5.5). In particular, AONBs include 38 (76%) of the SAMs, 17 of these being associated with other designations (12 of these include SSSIs), and 21 with AONBs only. This implies a strong correlation between SAM designation and other forms of designation, particularly AONBs.

5.3.6 That a correlation might exist is not surprising, as part of the reasoning behind the choice of three of the designations examined (AONB, NP, HC) is that they include areas rich in historic landscape features, but the degree of correlation is surprisingly high. However, a breakdown of SAMs by site type and period shows that barrows constitute 37 (74%) of the 50 lowland heath SAMs (19 Bronze Age, 4 Early Medieval, 12 unknown) and 28 (also 74%) of the 38 AONB SAMs (12 Bronze Age, 4 Early Medieval, 12 unknown).

Table 5.4 Number of sites per square for each designation for lowland heath

Designation	No. of sites	No. of squares	Sites km^{-2}
G Belt	119	18	6.6
AONB	203	19	10.7
SSSI	135	17	7.9
NP	50	3	16.7
HC	28	3	9.3
NNR	37	2	18.5
ESA	129	10	12.9

5.3.7 That there are no SAMs of Roman date presumably reflects the relative scarcity of sites of this period in the lowland heath landscape. There are also no Post Medieval SAMs. In this case, the under-representation of the period in the Schedule of Ancient Monuments is well known.

5.3.8 The available dataset does not identify the cause of the higher site density on designated squares but this may be a question of survival. Those areas of high 'quality', deemed worthy of designation, are likely to be those with least change, and therefore those where archaeological sites have survived best. As well as designation causing better preservation of the monuments, other factors may be at work. The original choice of which areas to designate may have favoured areas already rich in archaeology. In addition, archaeological studies may have focused on these areas for that same richness. It may also be relevant that the main types of sites (barrows, woodland banks) will have originated at times when the areas were already heath.

5.3.9 Condition information was, as expected, severely limited. Of the 752 sites, only 116 have any information relating to the condition of the site. The location of this information within SMR structures is very variable and there is no standard either within or between SMRs. Virtually no

Table 5.5 Correlation of SAMs with other designations for lowland heath

G Belt	AONB	SSSI	NP	HC	NNR	ESA	No. of sites
							2
						•	3
			•				1
		•					2
	•						21
	•			•		•	5
	•	•					6
	•	•			•		5
•		•					4
•	•	•		•			1
5	38	18	1	6	5	8	50

information was available on the changing condition of the monuments.

5.4 Discussion

5.4.1 The results of the archaeological study are limited by the inadequacies of the available data. There is clearly a need to review the way in which information about archaeological site condition is recorded, such that recording over future decades will allow such analyses to be undertaken. Indeed, English Heritage is currently funding the Monuments at Risk Survey (MARS) project to compile precisely this type of information for a 5% sample area of England, looking at current condition and attempting to gauge changes over the past 50 years (Darvill, Fulton & Bell 1993).

5.4.2 Factors behind the inadequacy of the compiled data include the following.

- The expected variability of SMR data has been confirmed. There is particular variation in the terms used for 'site type' and 'form'. Entries for these fields required standardisation (often difficult to achieve objectively) at the data entry stage. The range in number and types of site represented also varies widely according to the sources used in the creation and enhancement of each SMR.
- A further problem is the absence of any standards in recorded information about management history of archaeological sites, even though all SMRs have database fields for this information.
- The analysis of aerial photography and the fieldwork carried out as part of the current project were too limited to be of much use in estimating the percentage of the total archaeological resource that has been recorded.
- The lack of location data for designations is a problem – the only designations for which we have consistent specific locations are the SAMs.

5.4.3 It is suggested that any attempt at this stage at useful comment on the effects of designations on archaeological sites might be provided by a combination of case studies with a programme of more detailed site identification and subsequent site inspection by experienced archaeologists.

5.4.4 However, the current project has shown that the lowland heath mask contains features from all historic periods, although representation of the Early Medieval period is sparse. The frequency of features was higher in designated than in non-designated strata. There appears to be a strong correlation between SAM designation and other types of designation, particularly AONBs. It is not possible to say whether designation status has helped to preserve sites or whether, by contrast, designated sites have been subject to more intensive examination.

5.4.5 From the conclusions of Chapter 4 and the above discussion, it is apparent that designated areas are richer in both 'core' vegetation types and historic features than non-designated sites.

Chapter 6 PRESSURES FOR CHANGE: ATMOSPHERIC POLUTION

6.1 Introduction

6.1.1 In Chapter 2 the existing and potential causes of change in lowland heath are summarised, including the effects of atmospheric pollution (para 2.9.14). Atmospheric pollution is considered here in terms of acid deposition and nitrogen enrichment.

6.2 Acid deposition

Critical loads

6.2.1 Areas of lowland heath likely to be affected by excessive atmospheric acid deposition have been mapped using the 'critical loads' approach developed by the Critical Loads Advisory Group (CLAG) under contract to the Department of the Environment (CLAG 1994).

6.2.2 A critical load is defined as a deposition threshold (in this case an atmospheric pollutant) below which long-term damage will not occur. Critical loads maps for soils, which reflect the weathering rate of the soil to acid deposition, using a 1 km grid for GB, have been produced (Hornung *et al.* 1995). Maps of total sulphur deposition are based on measurements of wet and dry deposited sulphur compounds and are displayed on a 20 km grid of GB. The map of 'current' deposition is based on data collected from 1989 to 1991, which when overlaid on the critical loads map gives an exceedance map showing areas where the deposition exceeds the weathering rate of the soil. This map indicates areas of GB most likely to be affected by current sulphur emissions.

6.2.3 The effects of future emission scenarios on sulphur deposition and exceedance can be predicted using a computer model – the Hull Acid Rain Model (HARM). As part of the UNECE Convention on Long-Range Transboundary Pollution (CLRTAP), Britain has agreed to a 70% reduction in sulphur emissions between 1980 and 2005 and an 80% reduction by 2010. The effects of these scenarios compared to the 1989–91 baseline have been evaluated in terms of the proportion of the heathland mask in areas where the soils' critical loads are exceeded.

Results

6.2.4 As stated in Chapter 3, lowland heaths are usually found on acidic soils with a low weathering rate which are particularly vulnerable to the acidifying effects of acid deposition (Figure 6.1). During the period 1989–91, 93% of all areas within the lowland heath mask was in exceeded areas, with only a few areas of the Brecklands and the Lizard peninsula in unexceeded areas. In comparison, in lowland England (as defined in Chapter 3), the soil acidity critical load was exceeded in only 57% of the total area.

6.2.5 The emissions reduction scenarios, as derived by HARM, appear to be relatively ineffective at protecting the lowland heathland areas of England (Table 6.1). Although the 70% UNECE emissions reduction scenario would reduce the exceeded areas to 11% of lowland England, 65% of heathland areas are still estimated to be at risk. An emission reduction of 80% would leave 7% of lowland England and 42% of lowland heathland areas at risk. The

Table 6.1 Areas within the lowland heath mask and lowland England affected by acid deposition
Figures show the percentage of 1 km squares in each area in which acid deposition exceeds the soils' critical loads

Scenario	Lowland heath mask: Desig-nated	Undesig-nated	Total	Lowland England
Baseline: 1989–91 emissions	91%	96%	93%	57%
70% reduction from 1989–91 baseline	67%	62%	65%	11%
80% reduction from 1989–91 baseline	49%	43%	46%	7%
Total no. of 1 km squares	*4760*	*3778*	*8538*	*115759*

Figure 6.2 Areas within the lowland heath mask where acid deposition (total sulphur) exceeds the critical load of heather under the 1989–91 baseline. Black = exceeded areas, green = unexceeded areas (source: CLAG Soils Sub-Group)

Figure 6.3 Areas receiving over 20 kg atmospheric nitrogen ha^{-1} yr^{-1} (in black) in relation to the lowland heath mask (source: CLAG Soils Sub-Group)

deposition in reduced and oxidised forms) for 1989–91, interpolated to a 20 km x 20 km grid of Great Britain.

Results

6.3.2 Average atmospheric deposition of nitrogen (eg from nitrogenous gases such as NO_x and NH_x) in heathland areas is 17 kg nitrogen ha^{-1} yr^{-1}, which is similar to that received by other parts of lowland England (18 kg nitrogen ha^{-1} yr^{-1}). Over 99% of heathland areas receive more than 10 kg N ha^{-1} yr^{-1} and 20% receive over 20 kg N ha^{-1} yr^{-1} (Table 6.3). Areas with high N deposition (>20 kg) occur mainly in the west Midlands, the north-west, Hampshire and Surrey (Figure 6.2).

6.3.3 Heathlands in designated squares are more likely (26%) to be receiving over 20 kg nitrogen ha^{-1} yr^{-1} than those in undesignated squares (16%) (Table 6.3).

6.3.4 These rates of atmospheric N deposition are low compared to average agricultural inputs, and there is no experimental information describing the long-term effects of these rates on lowland heathlands in England. However, although not strictly comparable, experimental results from grasslands on peat soils in the Somerset Levels (Mountford, Lakhani & Holland 1994) show that the cumulative effect of N rates as low as 25 kg N ha^{-1} yr^{-1} over a period of six years can cause significant changes in plant community composition. It is likely that the low rates of atmospheric N will have a significant effect on community composition in lowland heathlands, with gradual nutrient enrichment leading to a loss of plant species diversity. This is consistent with the conclusions of an international workshop held at Lokeberg, Sweden (Grennfelt & Thornelof 1992), which proposed that the critical load for nitrogen on lowland dry heathland, as indicated by a transition from heather to grass, is in the range of 15–20 kg nitrogen ha^{-1} yr^{-1}.

6.3.5 The impacts of nitrogen deposition have been modelled using TRISTAR. Results from this work are described in Chapter 7.

Table 6.3 Areas covered by the lowland heath mask receiving over 20 kg N atmospheric ha^{-1} yr^{-1}

Scenario	Lowland heath mask: Desig-nated	Undesig-nated	Total	Lowland England
Proportion of squares receiving over 20 kg N yr^{-1}	26%	14%	20%	32%
Total no. of 1 km squares	4760	3778	8538	115759

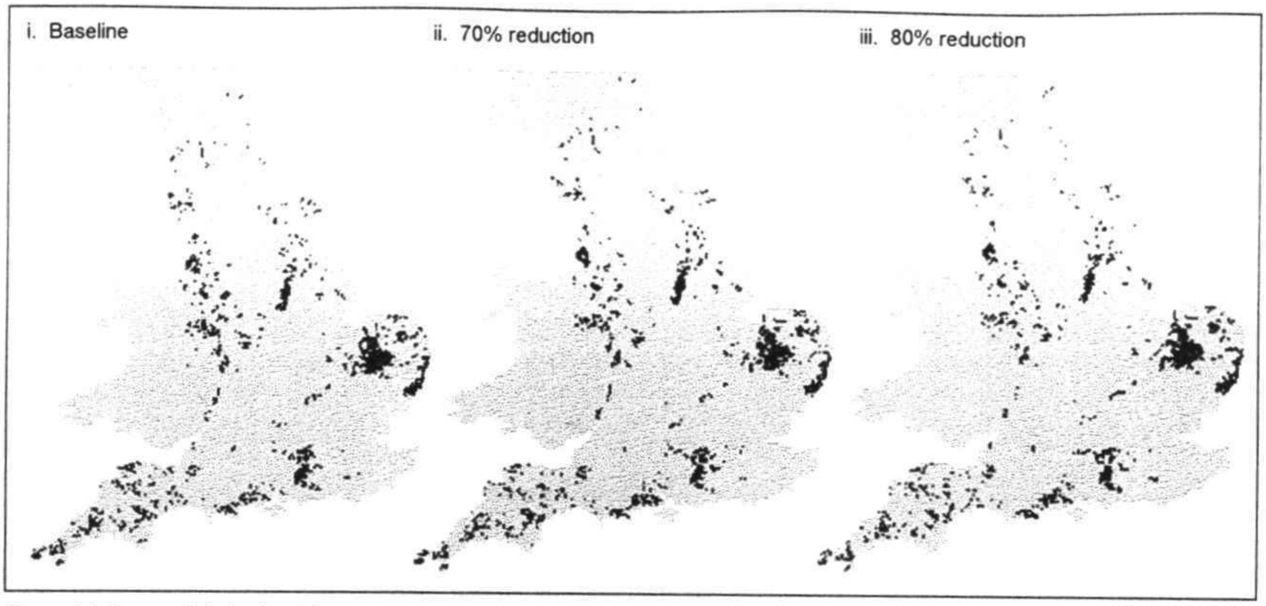


Figure 6.1 Areas within the heathland mask where acid deposition exceeds the soils' critical load under (i) 1989–91 baseline, (ii) 70% reduction by 2005 scenario and (iii) 80% reduction by 2010. Black = exceeded areas, green = unexceeded areas (source: CLAG Soils Sub-Group)

main reason is that heathland soils are often the most sensitive to acidification. The low critical loads threshold for these areas is consequently still exceeded, even though sulphur deposition may have been substantially reduced.

6.2.6 Heathlands in squares containing designations are likely to benefit least from the emissions reductions (Table 6.1). Under the 80% reduction scenario, the proportion of 1 km squares in the exceeded area fell by 42%, from 91% to 49%, compared to a fall of 53%, from 96% to 43%, in squares without designation.

6.2.7 There is insufficient experimental or field information on the effects of sulphur deposition on heath fauna and flora to be certain of how damaging these exceedances will be to lowland heath ecosystems as a whole. The critical load for individual species or assemblages may differ from the site critical load as determined from soils; for instance, many heathland species are adapted to acid soils and may not be as disadvantaged by moderate increases in the levels of acid deposition. An indication of this effect comes from current work (Hornung *et al.* 1993), where the critical loads approach is currently being developed for a range of species including heather, using a mass-balance model (CLAG 1994). Preliminary results from this model (Figure 6.1) indicate that acid deposition, under the baseline scenario, will exceed the critical load for heather in 41% of the lowland heathland area (Table 6.2).

6.2.8 The impacts of acid deposition on the lowland heathland vegetation community have also been modelled using TRISTAR (TRIangular STrAtegic Rules for British herbaceous vegetation) (Hunt *et al.* 1991). Results from this work are described in Chapter 7.

6.3 Nutrient enrichment – the effects of atmospheric nitrogen inputs

6.3.1 Preliminary data on rates of atmospheric nitrogen (N) deposition are available and have been used to identify areas of heathland where N deposition rates are particularly high. The nitrogen deposition data are derived from the National Monitoring Network run by the Warren Spring Laboratory, using adjustments for altitude effects and estimates of dry deposition (UK Review Group on Impacts of Atmospheric Nitrogen 1994). The data are for total nitrogen (including wet and dry

Table 6.2 Areas within the lowland heath mask and lowland England affected by acid deposition
Figures in the body of the Table show the percentage of 1 km squares in each area where acid deposition exceeds the critical load for heather

Scenario	Lowland heath mask Desig-nated	Undesig-nated	Total	Lowland England
Baseline: 1989–91 emissions	36%	47%	41%	9%
Total no. of 1 km squares	4760	3778	8538	115759

6.4 Summary

6.4.1 Lowland heathlands tend to be found on acid soils which are relatively sensitive to the effects of acid deposition. Under the UNECE Convention to reduce atmospheric acid deposition by 70% by 2005, soils in 65% of the lowland heath mask area will remain at risk from excessive deposition, compared to 11% in the rest of lowland England. There is, however, some uncertainty about the consequences of this scenario for lowland heathland vegetation. Lowland heathlands are also at some risk from excessive atmospheric nitrogen deposition. Preliminary data show that they are receiving an average of 17 kg of atmospheric nitrogen ha^{-1} yr^{-1} and that at this rate there may be gradual enrichment of heathland soils leading to a loss of plant species and a transition from heather to grass.

Chapter 7 PREDICTING CHANGES IN LOWLAND HEATH VEGETATION

7.1 Introduction

7.1.1 This Chapter describes the development and use of conceptual models to predict the effect of environmental changes, and changes in agricultural management, on the quality of lowland heath landscapes.

7.1.2 TRISTAR is an expert-system model which deals with the fundamental environmental and management processes controlling the composition of British herbaceous vegetation. The TRISTAR2 model, developed for this project, is a program which extends this approach specifically into the areas involving climate change scenarios.

7.1.3 TRISTAR2 takes a given specification of an initial steady-state vegetation, adopts some altered environmental and/or management scenario, and then predicts the compositions of the new steady-state vegetation in terms of its component functional types.

7.1.4 Vegetational survey data collected during this study (see Chapter 4) were processed in three distinct phases by means of the TRISTAR2 model. After the final phase, the outputs of the modelling are examined and interpreted.

7.2 Phase I – allocation of functional types

Brief description of methods

7.2.1 The initial steady-state vegetation was specified as a list of abundance of species in each of the survey plots. Each vegetation record has been classified according to both of two sets of criteria:

- the designated status, if any, of the site from which the record was taken, and
- the plant community type into which the vegetation of the quadrat falls.

The basis for the second of these classifications is a TWINSPAN analysis which divides the plots into 20 plot classes, as described in Chapter 4 (Section 4.4).

7.2.2 For each plot, one of 19 functional types (see Appendix 4) is then allocated to each of the component species using information from the databases of the Unit of Comparative Plant Ecology (UCPE) at the University of Sheffield. Briefly, two external groups of factors, called 'stress' and 'disturbance', both of which are antagonistic to plant growth, are recognised.

7.2.3 When the four permutations of high and low stress against high and low disturbance are examined, a different primary strategy type emerges in association with each of the three viable contingencies: **competitors** (C) in the case of minimum stress and minimum disturbance, **stress-tolerators** (S) in the case of maximum stress and minimum disturbance, and **ruderals** (R) in the case of minimum stress and maximum disturbance (Appendix 4, Figure B). Intermediate types of C-S-R strategy can be identified, each exploiting a different combination of intensity of external stress and disturbance. The high stress–high disturbance contingency is unlikely (Appendix 4, Figures C & D).

7.2.4 TRISTAR2 conflated the weighted abundance of up to a maximum of 19 individual functional types which may be present within each sample. This process created weighted abundance for each of seven broader groups of functional types. These seven groups represent the three extreme corners of the C-S-R triangle ordination (see Figure 7.1), its centre, and its principal intermediate positions. These seven groups were each converted into a two-part numerical code which provided a computational mechanism for representing both 'pure' and intermediate functional types.

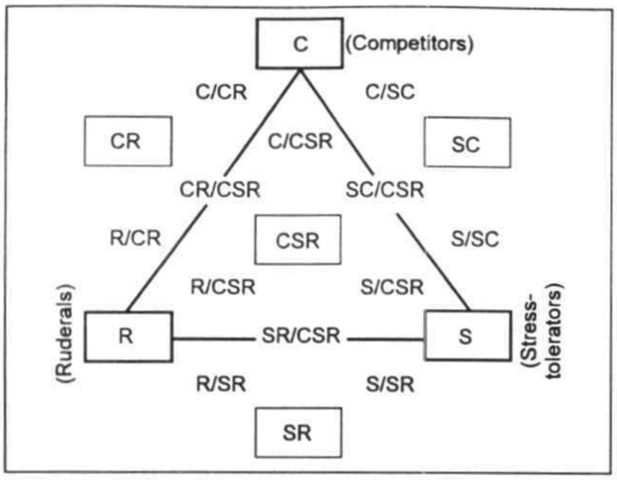


Figure 7.1 The C-S-R triangle ordination, showing the three principal functional types and intermediate positions

7.2.5 Once converted, the classifications according to functional type provided the basis for all further work on the vegetation sample by TRISTAR2. Appendix 4 provides details of the TRISTAR model and how it has been used. The presentation for each scenario consists of a divided percentage bar diagram illustrating the functional composition of all the plot classes present in the initial vegetation, with an ecological interpretation.

Results

7.2.6 As stated in Chapter 2, heaths are restricted to nutrient-poor acidic soils. The vegetation is kept in a relatively open state by grazing and, in some instances, burning. A number of dwarf shrubs, particularly heather, are characteristic of heathland as classically described. Typical functional types are stress-tolerator or stress-tolerator/competitor and, where there are bryophytes, stress-tolerator/ruderal. Thus, plot classes PCA (bog), PCB (wet heath) and PCD (very acid heath), as described in Table 4.5, are among the most 'typical' of heath in terms of functional type.

7.2.7 However, because the survey was of a broad lowland heath mask, several plot classes do not conform to 'heathland' even in strategic terms, and these have been assigned to a 'woodland' or a 'grassland' grouping, as described in Chapter 4. Woodland plot classes, particularly PCQ (Midland plantation over bracken), PCL (plantation over bracken/heath) and PCO (plantation often open) had high values for competitor type, tree species being good competitors. Increased dereliction, presumably a consequence of fire prevention, and perhaps also eutrophication, appears to be associated with forestry.

7.2.8 Grassland plot classes, PCM (damp acid grassland) and PCR (dry mildly acid grassland), had more CSR species and were often associated with grazed and with less nutritionally impoverished conditions. Plot class PCP (dense rhododendron) consisted entirely of a single species, making it unsuitable for further analysis.

7.2.9 Key species include heather, the most characteristic dominant of heathland; important invaders in derelict conditions are birch *(Betula pendula, B. pubescens)*, rhododendron *(Rhododendron ponticum)* and other trees and shrubs, bracken, and in derelict eutrophicated conditions, gorse – especially in areas which become burnt, and bramble *(Rubus fruticosus)*.

7.2.10 In summary, most of the 'core' heathland vegetation was composed of stress-tolerator and stress-tolerator/competitor species. The remaining vegetation plot types were representative of all other combinations of functional types.

7.3 Phase II – effects of change scenarios on the abundance of functional types

Brief description of methods

7.3.1 The TRISTAR2 model was populated with six scenarios comprising selected combinations of two environmental factors – disturbance and eutrophication. Each scenario can have more than one possible management or climate change interpretation, and examples of the possible causes of each scenario are given in the results. The scenarios were:

i. decreased disturbance and no change in eutrophication;
ii. decreased disturbance and increased eutrophication;
iii. no change in disturbance and decreased eutrophication;
iv. no change in disturbance and increased eutrophication;
v. increased disturbance and decreased eutrophication;
vi. increased disturbance and increased eutrophication.

It is important to note that each scenario can have more than one possible management or climate change interpretation. For example, increased eutrophication could be caused by caused by increased fertilizer application or increased deposition of atmospheric nitrogen.

7.3.2 For each factor and functional type within the six specimen scenarios, TRISTAR2 applied an appropriate numerical multiplier according to our understanding of the effects of the factor. The essence of the approach is that seven functional types are each driven by this weighting in different directions and with different gradients, according to information from UCPE's extensive survey and screening databases.

Example results

7.3.3 Full outputs from the model are given in Appendix 4. Within this Chapter, summary results for only the core heathland plot classes are described.

Scenario 1. Decreased disturbance and no change in eutrophication

7.3.4 Possible causes of this scenario, as it affects the core heathland vegetation, include reduced incidence of fires, cessation/ reduction of grazing, and less recreational pressure. Decreased disturbance is the scenario associated with abandonment or dereliction.

7.3.5 With respect to functional types, in the shorter term this scenario will have moderate but deleterious impacts on the composition of heaths and heath grassland. Losses of heathland bryophtyes of stress-tolerator/ruderal type and, to a lesser extent, vascular plants of type stress-tolerator are predicted. At the same time, there will be an increased representation of stress-tolerator/competitor species with the invasion by scrub and/or bracken.

Scenario 2. Decreased disturbance and increased eutrophication

7.3.6 Possible causes of this scenario, as it affects the core heathland vegetation, include reduced incidence of fires, cessation/ reduction of grazing, and less recreational pressure, together with increased fertilizer runoff and/or atmospheric deposition.

7.3.7 Increased eutrophication acting in combination with decreased disturbance will have a greater and more rapid impact on the distribution of functional types in core heathland vegetation than in scenario 1. There will be losses of types stress-tolerator and stress-tolerator/ruderal, two of the most typical of the habitat, and an increased representation by types competitor and stress-tolerator/competitor. Initially, species like bracken may be the first species to increase. However, eventually, heathland may become overrun with tall herbs and shrubs. Because the litter of species of functional type competitor is decomposed rapidly, there is less risk of fire than in the previous scenario.

Scenario 3. No change in disturbance and decreased eutrophication

7.3.8 Possible causes of this scenario, as it affects the core heathland vegetation, include decreased usage of or pollution from fertilizers.

7.3.9 As with scenario 2, large changes are forecast for core heathland vegetation. However, an increase in the main beneficiary, stress-tolerator type, which grows very slowly, will take considerably longer to achieve. Decreased eutrophication could have a beneficial impact on the composition with respect to functional types, with losses of competitors and the CSR type, both atypical of 'classical' heathland. Also, the decreased representation by the stress-tolerator/ competitor species is likely initially to involve a reduction in tall woody species rather than heather, to the advantage of core heath vegetation.

Scenario 4. No change in disturbance and increased eutrophication

7.3.10 Possible causes of this scenario, as it affects the core heathland vegetation, include fertilizer runoff or atmospheric deposition.

7.3.11 Increased eutrophication will have a moderate and potentially deleterious impact on the composition with respect to functional types. In 'heath' this will involve losses of stress-tolerators and the stress-tolerator/ruderal type, two of the most typical types of the habitat. In addition, an increased representation by stress-tolerator/competitor species may permit the first stages of scrub invasion. This could lead, over a prolonged period, to the formation of a rather different vegetation, or may indicate invasion by bracken.

Scenario 5. Increased disturbance and decreased eutrophication

7.3.12 Possible causes of this scenario, as it affects the core heathland vegetation, include higher incidence of fire, increased grazing, and more recreational pressure, together with less fertilizer runoff or atmospheric deposition.

7.3.13 Increased disturbance coupled with decreased eutrophication will have a major impact on the composition with respect to functional types. Impacts of increased disturbance will be rapid, with increases in stress-tolerator/ruderal and ruderal types, and a concomitant decrease in competitors and the stress-tolerator/competitor type. Any increase in stress-tolerators, the main beneficiaries of decreased eutrophication but which grow very slowly, will take considerably longer. Initially, this scenario could favour heath vegetation, with losses of competitors and CSR species, both types being atypical of 'classical' heath.

7.3.14 The decreased representation of stress-tolerator/competitor species in these more productive plot classes is likely initially to involve a reduction in tall woody species rather than in heather. Any increase in ruderals is likely to be temporary. However, changes in the less productive plot classes may be less beneficial. For example, the abundance of heather will be reduced in plot classes where it is the predominant stress-tolerator/competitor type. Other less productive classes (eg PCA – bog, PCB – wet heath) will become less fire-prone because of reduced above-ground biomass. This trend may be accentuated in these two classes by a reduction in transpirational water loss leading to a slightly increased water table.

Scenario 6. Increased disturbance and increased eutrophication

7.3.15 Possible causes of this scenario, as it affects the core heathland vegetation, include increased incidence of fires, more grazing, and more recreational pressure, together with increasing fertilizer runoff or atmospheric deposition.

7.3.16 The combination of increased eutrophication and increased disturbance will have major impacts on the composition with respect to functional types. For the heath groupings these impacts will be deleterious, involving losses of stress-tolerator type species and any low-growing variants of the stress-tolerators/competitor type (particularly heather). These are the most typical plants of the habitat. The stress-tolerator/ruderal, ruderal and, to a lesser extent, competitor types will increase. There will be fewer fires because of the reduced biomass and less persistent litter associated with this scenario.

7.4 Phase III – computation of an 'index of vulnerability'

7.4.1 For each of six scenarios, predictions for each functional type in each plot class present in the habitat (PCA, PCB, etc) are computed. An index of vulnerability is computed for each plot class. The index of vulnerability is displayed as a bar diagram for each plot class in Appendix 4 and is derived in three substages:

i. examine the original data to find the number of quadrats deviating appreciably from the typical;
ii. examine the TRISTAR2 predictions to find the new number of quadrats deviating appreciably from the original composition;
iii. find the 'index of vulnerability' for each plot class.

Summary of results

7.4.2 Full outputs from the model are given in Appendix 4 and a summary is given in Table 7.1.

7.4.3 Scenarios 1–4 all have low indices of vulnerability, even where eutrophication increases.

Table 7.1 'Indices of vulnerability' for six change scenarios

Scenario	Characteristics	Mean index of vulnerability	Impact
1	Decrease disturbance; no change in eutrophication	–0.01	Low
2	Decreased disturbance; increased eutrophication	0.05	Low
3	No change in disturbance; decreased eutrophication	0.03	Low
4	No change in disturbance; increased eutrophication	0.08	Low
5	Increased disturbance; decreased eutrophication	0.16	Medium
6	Increased disturbance; increased eutrophication	0.25	Medium

7.4.4 For scenario 5 (increased disturbance and decreased eutrophication), the low values for index of vulnerability indicate that short-term impacts on the strategic composition of the vegetation will be small in a majority of cases. Greatest vulnerability is associated both with the very unproductive classes (PCB – wet heath and PCA – bog) and with the very productive ones (PCT – woodland over bramble, PCM – damp acid grassland and PCR – dry mildly acid grassland). This scenario assumes only modest changes in disturbance and eutrophication. Under conditions both of high stress (which permits only slow growth) and of high disturbance (where recovery necessitates rapid growth) no plant species can survive. This combination of high stress and high disturbance is characteristic of many areas of 'open country' suffering problems of recreational damage.

7.4.5 For scenario 6 (increased disturbance and increased eutrophication), the highest values for index of vulnerability are associated with plot classes PCM (damp acid grassland), PCI (grassy heath) and PCF (dry heath), but long-term impacts on the composition of the vegetation with respect to both functional types and individual species will be large and difficult to reverse.

7.5 Summary of modelling results

7.5.1 The lowland heath mask includes a heterogeneous grouping of heath, grassland and woodland. However, the individual vegetation types all have one thing in common: they are relatively unproductive. Ecological theory would suggest that all the classes would be relatively unresponsive, at least in the shorter term, to minor changes in land management. This suggestion is borne out by the modelling results. However, the index of vulnerability differs markedly between scenarios. The most extreme scenario appears to be 'increased disturbance and eutrophication', with three plot classes showing high vulnerability.

7.5.2 The impact to the various scenarios can be ranked as follows.

Low/moderate impacts

- Disturbance decreased; eutrophication same (lowest impact)
- Disturbance same; eutrophication decreased
- Disturbance decreased; eutrophication increased
- Disturbance same; eutrophication increased

High impacts

- Disturbance increased: eutrophication decreased
- Disturbance increased; eutrophication increased (highest impact)

7.5.3 Although the differences between habitat groupings are relatively slight, grassland classes appear to be among the most vulnerable and woodland among the least vulnerable, with heath (both wet and dry) occupying an intermediate position. This sequence accords with expectation. Plot classes PCM (damp acid grassland) and PCI (grassy heath) have greatest average vulnerability and PCH (dry heath often planted), PCL (plantation over bracken/heath) and PCO (plantation often open) the least. However, vulnerability of individual plot classes differs markedly between scenarios. Predicted responses of particular plot classes must therefore be related to specific scenarios.

7.5.4 Lowland heath consists of a heterogeneous grouping of heath, grassland and woodland vegetation, all of which are relatively unproductive. The ecological hypothesis that such vegetation is likely to be unresponsive to changing management, at least in the short term, is supported by the results, with only one class of vegetation (damp, acid grassland) reaching even 'moderate' vulnerability. In general, grassland plot classes are among the more vulnerable, with woodland being the best protected and core heathland vegetation occupying a middle position.

7.5.5 The largest impact on the various plot classes within the lowland heath landscape would arise from an increase in disturbance combined with increased eutrophication. This scenario could arise from increased incidence of fires, more grazing or increased recreational pressures, combined with increased fertilizer runoff or atmospheric deposition. Increased grazing pressure and continued large inputs of atmospheric nitrogen is the most likely combination. The main impact of this scenario on the core heathland vegetation would be a loss of heather. Core heathland vegetation is also vulnerable to increased eutrophication with no change in the level of disturbance; again, this would lead to a loss of heather.

Chapter 8 SUMMARY OF THREATS AND POLICY RESPONSES

8.1 Introduction

8.1.1 This Chapter summarises what is known about the existing extent and quality of lowland heath, reviews existing policy instruments, and assesses threats to this landscape/habitat type.

8.1.2 Lowland heaths are ancient landscapes created and shaped by human activity. They are recognised not only for their ecological value, but also for their scenic, recreational and historical importance. Lowland heath landscapes are particularly valued for their wilderness characteristics and their accessibility, as they frequently offer open space near urban areas.

8.2 Key findings of the survey

Field survey

8.2.1 Table 8.1 summarises key findings from the field survey. The results extend the existing body of knowledge on the extent and nature of the lowland heath landscape and the presence of heath habitats within it. The survey shows that, of the 8538 km^2 comprising the heathland lowland heath mask, only 36 100 ha is still core heath (including valley bogs and wet heath). Over 80% of the total area (710 000 ha) is 'potential' heathland which has either been recently modified through planting (67 400 ha) or significantly altered for arable use or permanent pasture (642 200 ha). This area offers some potential for restoration or re-creation to its former heathland character. Finally, more than 12.5% of the total lowland heath mask comprises roads, buildings and other forms of development. The estimate from the field survey for core heath corresponds to English Nature's estimates of 32 000 ha of ericaceous heath in lowland England and 58 000 ha throughout the UK. It also compares with estimates made by Farrell (1989) of 60 000 ha of core heath in the UK.

8.2.2 The field survey presents an England-wide baseline survey. English Nature figures suggest that 40 000 ha of lowland heath have been lost since 1940 (the Grassland Inventory Project). The work of Webb and Haskins (1980) suggests that there has been a dramatic fall in lowland heath area in Dorset, from 40 000 ha in 1760 to 18 200 ha in 1934 and to 5700 ha by 1983. The Royal Society for the Protection of Birds (RSPB) reports continuing pressures on Dorset heaths (RSPB 1993). Similar declines appear to have occurred in other areas based on time-series data (Farrell 1993).

Table 8.1 Estimates of existing heathlands in England by category (area in ha)

	Field survey estimates	Other estimates
Core lowland heaths [1]	36 100	32 000 [5]
Recently modified, potential for restoration [2]	67 400	22 000 [6]
Never heathland, significantly modified, some potential for (re)-creation [3]	642 200	N/a
Unavailable, no potential [4]	108 100	N/a
Total lowland heath mask	853 800	N/a

[1] Plot classes A–F, I, J, includes valley bogs and wet heath
[2] Plot classes G, H, K, L, scrub and recent plantation over heath and bracken
[3] Remaining plot classes (M-T), crops and non-acid grassland
[4] Buildings, curtilages, urban land
[5] English Nature (areas with presence of dwarf shrubs)
[6] English Nature, wood-covered former heath

Table 8.2 Summary of UCPE scenario findings

Potential threat	Possible causes	Interpretation of results
Scenarios which would threaten heathland quality		
Decreased disturbance and no change in eutrophication	Reduced fire, reduced grazing levels and reduced grazing pressures	Large increases in competitive strategies (ie species of lower nature conservation interest such as bracken) and loss of species of interest are likely. Among the core heath, plot classes, F (dry heath – Cumbria, Hampshire and Dorset) and C (ultra-basic wet heath – Cornwall, Devon and Dorset) show the greatest response and would be most at risk of degradation
Decreased disturbance and increased eutrophication	Reduced burning, reduced grazing, less recreational pressure but increased fertilizer runoff and/or atmospheric deposition (nitrogen or sulphur)	Increases in competitive strategies with resulting loss of nature conservation interest; initial increases in bracken followed by increases in tall competitive herbs and grasses. The dry heaths may be particularly sensitive
No change in disturbance and increased eutrophication	Increased fertilizer runoff or atmospheric deposition (nitrogen or sulphur)	A move away from heathland vegetation types towards types dominated by tall competitive herbs and grasses. Alternatively, bracken might increase; again, dry heaths may be particularly sensitive
Increased disturbance and increased eutrophication	Increased use of burning and grazing with increased runoff and atmospheric deposition	This scenario has the greatest impact on vulnerable species (especially heather) with increased dominance of tall competitive herbs and grasses or bracken. The dry heaths may be particularly sensitive
Scenarios which would improve heathland quality		
No change in disturbance and decreased eutrophication	Decreased usage of/pollution from fertilizers	This will generally mean a move back towards heathland vegetation types, and some of the more important species from a nature conservation point of view may increase in existing heathlands. Wet heath classes may benefit particularly. In plot classes O–T where heath species are most poorly represented, the change in favour of stress-tolerant species is even more marked. However, although beneficial for the lowland heath landscape, these may not be heathland species. Grassy heath might become less grassy
Increased disturbance and decreased eutrophication	Increased use of burning and grazing; less fertilizer runoff and atmospheric deposition	This is a positive scenario for lowland heath: a large reduction in species of least nature conservation interest in lowland heath and greatest improvement in core heath plot classes A–F and I and J. Grassy heath (I) might respond very strongly to increased management/grazing

Threats

8.2.3 The remaining areas of lowland heath are under threat to their existence and to their quality. The key threats were identified by a meeting of experts (convened as part of this project), where key exogeneous threats were said to include:

- **landtake for urban expansion,** arable use, afforestation (now largely from local woodland expansion), mineral extraction and road building – the latter two are localised in impact, but road building is still having a major impact in the south of England, despite the high percentage of lowland heath which is protected by designations;
- **fragmentation** as a result of encroachment associated with all of the above and particularly road building, which continues to threaten undesignated heaths;
- **changes to land use** and practices on adjoining lands, particularly afforestation (which increases risks of tree invasion) and agricultural intensification (with high fertilizer use leading to a build-up in nutrient levels, particularly nitrogen, with negative impacts on core heath vegetation, see Table 8.2);

- **atmospheric pollution,** with both atmospheric nitrogen and sulphur leading to increased eutrophication which is likely to reduce conservation interest but may encourage stress-tolerators (see Table 8.2);

- **water abstraction,** which will have impacts on wet heath, with loss of wetland species to commoner species.

8.2.4 The major threats, however, are endogeneous and relate to land use and management. In descending order of importance, these include the following.

- **Agricultural use.** Table 8.2 shows several scenarios relating to agriculture; the greatest threats for core heath come from reduced grazing and burning regimes accompanied by increased nutrient build-up (from fertilizer use or runoff from adjoining land). Table 8.1 illustrates the long-term impact of this scenario; some 95% of the lowland heath mask is no longer core heath; furthermore, according to one source, some 85% of remaining lowland heath in specific areas is threatened by scrub encroachment or bracken invasion as a result of falling stocking rates, pasture improvement and nutrient build-up (Countryside Commission, pers. comm., regional offices). The most positive scenario in Table 8.2 relates to a reversal of these trends and suggests that an improvement in management offers great opportunities for increasing the nature conservation interest of lowland heath.

- **Recreational use** of surviving commons, the New Forest and National Trust land. While creating positive incentives for preservation of heaths, such use will create pressures from compaction (with stress-tolerators doing better), risk of fire (which could have some beneficial effects in areas where burning is not already part of the management system), disturbance to livestock, and resistance to necessary remediation measures such as removal of trees.

- **Military use.** In general, core heath species will benefit from increased trampling (which would lead to a general shift towards more ruderal strategies, away from competitors); proactive management of military-owned areas (grazing and burning) would also greatly increase conservation value.

- **Afforestation.** The UCPE data do not have a single scenario which represents afforestation, but several scenarios relate to different although not all effects. One conclusion may be that niches for heathland species may persist within afforested areas, and the UCPE predictions suggest that some of the more interesting species may even benefit.

Conservation objectives

8.2.5 The survey does not provide information on the ownership of heathlands or how past and current policies have affected their extent and quality. Information from other sources including non-departmental public bodies and non-governmental organisations has been collected to assist in the assessment of existing policies. As a starting point it was necessary to establish policy objectives for lowland heath against which policies could be assessed. Three objectives were defined.

- The first priority is to protect and enhance management of the relatively limited area of existing good-quality lowland heath.

- The second priority is to restore recently modified 'near' heath (both in terms of succession and spatial distribution), particularly where this is close to well-managed core heath.

- The final priority is to re-create or create heathlands in key areas linking with and between existing heath, on land which is distant from a heathland past or was never heathland (established woodland, improved agricultural land). This objective will be more costly than the other options.

8.2.6 This hierarchy of objectives was derived by an expert group working from the draft objectives of the UK *Biodiversity Action Plan* (DOE 1994) as a starting point. Based on the results of the survey, these objectives may be expressed in terms of the following targets:

- management of the estimated 36 000 ha of remaining core heath (compared to the 32 000 ha identified in the *Biodiversity Action Plan*;
- restoration/re-creation focusing on about 10% of the 67 400 ha of 'near' heath.

8.2.7 Applying these targets to the estimates from the current study would translate into management of the estimated 36 000 ha of core heath, and restoration/re-creation focusing on about 10% of the 67 400 ha of 'near' heath.

8.2.8 In order to meet these policy objectives a number of key issues have to be addressed.

- **Ownership and management.** A high, but unknown, proportion of lowland heath land is owned by local authorities, the Ministry of Defence (MOD) (up to 60% in some areas such as Surrey and perhaps 2000 ha in total on the Aldershot, Camberley and Breckland heaths) or commoners (who are custodians of large areas in Dorset). These groups do not have a direct economic incentive for long-term management or conservation activities. The MOD is required to exercise environmental care over its holdings, but the Countryside Commission argues that environmental issues should have a much higher priority. Each of these owners require different incentives in order to encourage them to commit to good management.

- **Economic viability.** Long-term management of heathlands, even through grazing, is not expected to be immediately financially viable in the current regime of agricultural subsidies.

- **Fragmentation.** Small sites are less likely to have protective designations, are more vulnerable to development pressures, and tend to be below the critical threshold for economic management.

- **Low levels of awareness.** Countryside agencies report that:
  - the public generally does not understand how heath has to be managed to sustain it;
  - farmers are not fully aware of its importance nationally;
  - there is a lack of appreciation that heath is a culturally formed landscape;
  - there are possible conflicts between use, public access and quality, and there are few means to resolve these conflicts at present, especially on common land.

8.2.9 It is important to note that the strategic objective of increasing the extent of heathland will need to be met through local targeting and, for archaeological sites and historic features, the tactical selection will be highly important. The best options for ecological targeting may not be the best archaeological features and *vice versa*. From the archaeological viewpoint, heath will normally be a more beneficial land use than arable or forest, and the choice of heathland expansion schemes should wherever possible take account of opportunities for improving the condition and accessibility of archaeological sites.

8.3 Impacts of current policies

8.3.1 Available policy instruments fall into a number of categories which may be summarised as follows:

- regulations to provide protection against deleterious activities, planning proposals or to encourage good management practices;
- economic instruments, such as the European Union's Common Agricultural Policy and packages of grants and subsidies aimed specifically at lowland heath management;
- measures to provide information and advice and to demonstrate and disseminate lessons about the sustainable management of heaths.

Policies to protect heathlands

8.3.2 International and UK legislation provides a complex framework of designations for the protection of lowland heath habitats and of important grassland species, such as rare flora and fauna. A hierarchy of designations exists.

- NNR and SSSI and Scheduled Monument status are protective designations which also prevent deleterious actions.

- AONB and Green Belt simply provide protection against planning permission for the change of use of the site.

- ESA designation is not protective but delineates an area where incentives for positive management practices are available.

8.3.3 Of the 8538 km squares covered by the ITE survey, some 4760 (55%) have one or more designations within the square (SSSI, NNR, AONB, ESA and G Belt) and in many areas multiple designations apply, with SSSIs coinciding with NNRs, National Parks, AONBs and Heritage Coasts. Some 19% of the squares have SSSI designation.

8.3.4 However, the survey does not provide estimates of the actual areas within each square covered by one or more designation; neither is it possible to define whether the designation is applied for the purpose of conserving heathland habitat within the square, or for some wider objective, as in the case of Greenbelt and Heritage Coast designations.

8.3.5 English Nature estimates that there is currently some 23 000 ha of core heathland in England protected by SSSI designation (English Nature and Lowland Heath Programme Project Officers, pers. comm.), which corresponds with the estimate that two main areas – Dorset and Thames Basin/Wealden (including north Hampshire, Surrey, Berkshire and west Sussex) – contain 19 500 ha of SSSI heathland.

8.3.6 An estimated 20 000 ha of this area is under Section 15 management agreements or the Wildlife Enhancement Scheme (WES) which is discussed below. These figures may involve some over-counting, as some 'near' heath or significantly altered areas (eg those under forest cover in the New Forest) are included. For instance, in Dorset, English Nature reports some 5700 ha of existing lowland heath (defined in terms of presence of dwarf shrubs), but 7500 ha of SSSIs defined as lowland heath. The available figures therefore suggest that some 65% of total core heath is SSSI, but that in some areas such as the south-west up to 80% is covered.

8.3.7 The survey suggests that heathland within squares covered by designations is in better ecological condition than that outside designations. Informal evidence suggests that SSSI designation has been effective in recent years in protecting heathland habitat; however, this may be a feature as much of the lack of development pressure over that period as of designation. As development pressures increase, much heathland habitat which is in proximity to existing settlements may come again under threat. Designation of some SSSIs as Special Protection Areas (EU Birds Directive 79/409/EEC) or Special Areas of Conservation (EU Habitats and Species Directive 92/43/EEC) will offer greater protection for priority habitats or species. This is likely to include designation of areas of Cornish heath (*Erica vagans*) around the Lizard peninsula, some wet heaths in Dorset, and duneland dry heaths in other areas.

8.3.8 It is estimated that 35% of core heath, most of which is fragmented, close to urban areas and vulnerable to development pressures is not covered by SSSI designation (RSPB 1993). Additional policies have been devised to provide incentives for landowners to undertake remedial or sustainable management, thereby targeting positive management.

Incentives for positive management and restoration

8.3.9 There are currently three main grant schemes to provide incentives for positive

Box 8.1 Wildlife Enhancement Scheme

The Wildlife Enhancement Scheme (WES) provides grants for positive management to landowners and tenants of valued habitats. In two areas – Dorset and Thames Basin/Wealden – the WES is being targeted directly at lowland heath management and restoration through positive management agreements for existing heathland SSSI. A total budget of £240,000 has been set to bring 1100-1500 ha under positive management. Fixed-rate payments are available at two levels:

- Payments of £15 ha^{-1} yr^{-1} are made for entry of land into the scheme, which then entitles landowners to apply for fixed grants for different types of capital expenditure (fencing, cattle grids) or one-off mechanical clearing (scrub clearance, mowing of gorse or firebreaks)
- Additional payments up to a total of £70 ha^{-1} yr^{-1} for sustainable management involving the re-introduction of grazing [1]

All areas other than those covered by ESA or the Countryside Stewardship Scheme or under ownership of Forestry Commission or MOD (unless land has been licensed or rented to NGOs or private farmers) are eligible. The response rate in the first months of the scheme has been high.

[1] Stocking rates are agreed between the adviser and owner on the basis of type of heath and stock but are typically 0.5 head of cattle or ponies ha^{-1} or 2–2.5 sheep ha^{-1}. In the first few years, stocking rates of up to twice this level are encouraged, particularly on areas which have been wooded

Box 8.2 Countryside Stewardship Scheme

The Countryside Stewardship Scheme was introduced in 1991 and covers five different landscape types. It has the following objectives for lowland heath:

- to support and re-introduce management to sustain and restore heathlands and the wildlife they support;
- to restore, protect and manage characteristic landscape features and archaeological features;
- to create and improve opportunities for people to enjoy the landscape and its wildlife (particularly rich archaeological and historical landscapes and areas offering new access potential).

The scheme is targeted at:

- existing heathland;
- heathland that requires the re-introduction of management to sustain it, eg where heath is threatened by invasive shrubs and bracken;
- areas of arable or ley grassland that were once heath, particularly land that will link or extend fragmented heaths.

The landowner enters into a ten-year agreement selecting a combination of measures from a menu of management options and capital works. Payments are made annually in arrears, and reviewed on a three-year cycle. Payments vary with management criteria including conservation, regeneration and re-creation to be achieved according to established guidelines. In the first year 2745 ha of lowland heath were entered into the scheme, with an additional 5099 ha, 3540 ha and 877 ha in each of the following three years respectively. By April 1996 some 10 578 ha of lowland heath were covered by management agreements.

management of existing core heath and restoration of 'near' heath.

- The Wildlife Enhancement Scheme (WES) is targeted at improving management of SSSIs in specific areas (see Box 8.1).
- The Countryside Stewardship Scheme (CSS) is focused on areas not covered by either WES or other schemes such as Environmentally Sensitive Areas. It may complement WES by targeting both SSSI and non-SSSI land as it may be more appropriate for land holdings which include large areas of non-SSSI, or where there are other objectives in addition to nature conservation. CSS applies to both core heath and restoration of 'near' heath (see Box 8.2).
- The MAFF Environmentally Sensitive Areas (ESA) scheme is providing support to the maintenance and improvement of lowland heath in the West Penwith (2000 ha) and Breckland (3900 ha) ESAs.

8.3.10 WES and CSS are discretionary and focused on areas with the greatest potential for environmental improvement and public benefit. Average grant payments are in the range of £160–220 ha^{-1}, including initial capital costs of clearance or remedial management and an annual grant for ongoing management. The target for the WES in the first year is 1100–1500 ha, or 6–7% of the total lowland heath SSSI in its two regions of operation, and take-up so far has been high. The Countryside Stewardship Scheme now covers 10 578 ha after five years of operation. Not all of this area is core heath, but it is not currently possible to determine how much of the land within the scheme is modified heath being restored to core heath.

8.3.11 These figures suggest a coverage of up to 30% of the total core heath, but only 10% of the combined core and recently modified heath resources being covered by incentive schemes.

8.3.12 Both WES and CSS appear to offer attractive and cost-effective means of encouraging private landowners and voluntary organisations into long-term management agreements: on the one hand, they cover capital costs, providing a real incentive for investment; on the other hand, they have reduced administrative costs from an estimated 25% across all SSSI Section 15 payments to 10–15% for the current schemes by using a standard menu of grant rates for specific activities.

8.3.13 However, the schemes do not apply to public land owned by central government (including MOD and Forestry Commission), which may account for some 20 000 ha of core heathland (including the New Forest), much of which is also SSSI. Furthermore, WES and Countryside Stewardship cannot (and are not intended to) compete with agricultural support on the most productive arable land. However, grants do apply to land owned by local authorities, and on private arable land at the margin (where frequently there is benefit to be derived from reversion to heath) grant rates can be attractive to some owners. Indeed, between 1991 and 1993 the CSS attracted some 584 ha for conversion of arable land to lowland heaths on private land. There is, therefore, considerable scope to extend these schemes further to cover core heath and forest heath.

8.3.14 Both MOD and the Forestry Commission endorse policies to improve management of existing core heath and transition zones (modified heath) on their own land, in so far as this coincides with their other key management objectives. However, neither department is eligible for capital grants and, particularly in the case of MOD which disposes of no conservation budget, this is a constraint to using remedial management techniques or to investing in fencing for longer-term grazing.

Incentives for re-creation

8.3.15 Although the Countryside Stewardship Scheme can be used for re-creation of heathland on arable land, in general the conversion of arable land to heath would be costly and none of the current grants would be sufficiently attractive to encourage farmers to undertake such actions on prime agricultural land. Thus, the major opportunity for heathland restoration appear to be in areas of forest heath and recent plantations, and this is currently being addressed in a number of ways.

8.3.16 As part of its contribution to the *Biodiversity Action Plan*, the Forestry Commission is actively considering re-creating heathland on its own estate where timber is approaching maturity and space could be restructured at reasonable cost to convey considerable conservation benefits. In some areas, such measures would coincide with Commission targets for creating up to 20% open space within forests. In these cases the net costs of clearance may be negative, being offset in the short term by revenue from timber sales. In other areas (where there has been invasion by other species or where timber is not yet mature), the cost of clearance is estimated at approximately £1000 ha^{-1}. This cost is lower than could probably be achieved by other heathland owners, reflecting economies of scale. In the longer term, the conversion of forest to heath has an opportunity cost in lost timber revenues and will lead to ongoing management costs. This means that the Forestry Commission would only be prepared to consider restoration of a small area, and in the context of clearly established priorities for heathland conservation in each area.

Awareness raising and information dissemination

8.3.17 A very wide range of factors have to be taken into account in determining the appropriate sustainable management regime for lowland heath. These include physical factors (vegetation, moisture and climate), economic factors, the size and location of the heath in relation to other heathlands, and social factors, such as land tenure and existing use of heathlands. Research is being carried out into lowland heath management and restoration, for example, through MAFF-funded projects related to the ESAs. Management guidance is available from publications such as English Nature's *Lowland heathland management handbook*. However, there is still limited experience of successful long-term management, making it difficult to disseminate prescriptive good-practice messages to prospective heath managers.

8.3.18 Guidelines are beginning to develop for larger heathland areas. For instance, cattle and pony ratios of 0.5 ha^{-1} may be suitable on wet bog and heath, and sheep at 2–3 ha^{-1} may be suitable for dry heaths. However, in practice, variables such as climate will mean that sustainable management will involve an element of trial and error in every area. Viable regimes for fragmented areas and common lands are not yet proven. In order to address this information gap the English Nature Lowland Heath Programme, local authority partners and a number of voluntary organisations, including the RSPB, are involved in specific projects to:

- demonstrate mechanisms for improved management in different settings;
- test and disseminate technical approaches;
- raise the awareness of the public and commoners and involve them in long-term management of heaths.

8.3.19 The findings to date are summarised in Box 8.3. In late 1994, English Nature sponsored a lowland heath conference which is the first major initiative to co-ordinate efforts and compare results and success to date.

8.4 Policy development

8.4.1 Future policies to meet lowland heath objectives need to focus on three main areas.

i. **Incentives for extending management and restoration.** Practical targets for

Box 8.3 Summary of knowledge of existing best practice

Based on interviews carried out during this study, the most viable management options for large open spaces appear to be:

- free grazing of flocks supervised by a shepherd. Based on stocking rates currently being used and costs of shepherding based on headage rates, the average costs of this form of management are estimated at £30–60 ha^{-1} yr^{-1} for sheep and £20 ha^{-1} yr^{-1} for cows and ponies.
- fixed fencing and cattle grids. English Nature grants are expected to cover the complete costs of this type of investment, but, as noted earlier, these grants only apply to non-public land and therefore would not be available for MOD land. Because the size of MOD holdings is generally large, the investment costs for fixed fencing are thought to be prohibitive.

For smaller areas of common land, a number of other options may be suitable as follows:

- movable electric fencing enclosures, estimated at an initial cost of approximately £100 ha^{-1} for sheep and £80 ha^{-1} for cattle and ponies.
- free grazing with shepherding shared with other smallholders. This option would only be suitable in areas where there are a relatively large number of parcels in close proximity.
- tethering of goats. No cost data are available but the major cost of this option is the time for moving livestock each day to avoid over-grazing or nutrient build-up. Goats may be suitable for some vegetation types (for instance controlling pine invasion) but unsuitable for others as they are non-discriminatory browsers.

extending current WES/Countryside Stewardship Scheme would imply:

- bringing the core heath which is outside public ownership and not covered by CSS or WES under good management – this is likely to include at least a further 4000–6000 ha;
- encouraging the restoration of modified heath – a target of 6000 ha would represent some 10% of existing modified heath.

These targets would broadly coincide with initial proposals by the Countryside Stewardship Review for the CSS successor scheme to be implemented by MAFF over the period 1996–2005.

ii. **Setting targets for the re-creation of heathland** from forest heath and recent plantation which would create linkages between existing areas of heathland; a notional short-term target (see para 8.4.2) might be 0.1% of the total significantly modified heathland area, a target of 1000 ha by the year 2000. This is comparable to what has already been included in the CS Scheme in the first three years (ie an average of 200 ha^{-1} yr^{-1}). In the longer term, initial agency proposals during the Countryside Stewardship review were for a target of 10 000 ha (1.5% of the total) by the year 2005.

iii. **Raising awareness and providing advice.** It is important to foster interest among all heathland managers/owners in particular, and the public in general, to increase understanding of the importance of heathland, the techniques available for long-term management, and the implications in relation to other objectives such as public access. Providing advice, training, offers of voluntary help, and an analysis of how good management can be viable within a broader estate or land use management plan is recommended.

8.4.2 It is important that public sector owners of substantial areas of heathland, such as the MOD, continue to be targeted for improved management through better guidance on management options and inclusion in partnership approaches to long-term management. The *Biodiversity Action Plan* (DOE 1994) proposes that MOD and the Forestry Commission should prepare action plans with specific targets for heathland management sites in their ownership with the statutory nature conservation agencies by the end of 2000. As this would require a major undertaking, policy-makers should consider setting targets for priority areas and planning to provide the necessary assistance for the preparation of environmental management plans for these priority heathlands.

8.5 Increasing the body of knowledge and potential for further work

8.5.1 In the longer term there are no guarantees that resources will be available to cover ongoing management costs. Thus, it is imperative that new approaches to sustainable (economically viable) long-term management of heathlands are developed and publicised. More work is needed to evaluate and extend existing experience and develop guidelines for landowners and managers (particularly of MOD and common land) on the most suitable and economically viable regime for their circumstances, and to assist in the establishment of arrangements/partnerships which will encourage managers to implement these practices. Guidelines need to reflect the type of heath, the level of invasive species, the climatic conditions, and size and location in relation to other heathland.

8.6 Conclusions

8.6.1 Heathland is a valuable landscape, dominated by a non-climax vegetation type. Because the vegetation is non-climax, intervention is required to prevent heathland turning into scrub/woodland; heathland therefore requires management to maintain its condition. The survey results indicate that, of the area within the lowland heath landscape (8500 km^2),

- about 36 000 ha is good-quality 'core' heath habitat,
- about 7000 ha is relatively recently modified from heathland (modified heath),
- about 650 000 ha may at one time have been heath, is still in a land use which could revert (eg forestry or agriculture), but has been long modified, and
- the remainder has no potential (eg built-up areas).

8.6.2 Working from the *Biodiversity Action Plan* draft objectives as a starting point, it would appear feasible to establish the following objectives:

- to bring 4000–6000 ha of core heath in private ownership and not covered by existing enhancement schemes under good management;
- to restore 6000 ha of 'near' heathland and maintain this under good management, focusing on expansion and linking between existing core heath sites;
- to re-create heathland habitat on about 1000 ha of long-modified lowland heath landscape to provide priority linkages between core heath sites.

8.6.3 The present study helps to define the lowland heath landscape type, in its broadest sense, and to describe its characteristics. To capitalise on the baseline study that has been completed, monitoring needs to be carried out at agreed intervals (eg at the time of the next Countryside Survey). Results from this baseline study and subsequent monitoring need to be analysed in the context of the success of the Countryside Stewardship Scheme and related work (eg Environmentally Sensitive Area monitoring).

8.6.4 If further work indicates that these targets are justifiable, it is recommended that they are achieved by extending existing schemes offering incentives for restoration and management on private land and implementing re-creation on Forestry Commission land.

8.6.5 To ensure that the benefits of these measures are retained in the long term, and transferred to other areas, it is also essential that effective management approaches are identified and publicised and that awareness of the value of lowland heath habitats is raised.

Chapter 9 SUMMARY AND CONCLUSIONS

9.1 Introduction

9.1.1 This Chapter summarises the Report in terms of the original project objectives (as described in Chapter 1), briefly summarises the advantages and disadvantages of the approach, and discusses future research needs.

9.2 Summary in relation to the original project objectives

Objective 1: To determine the distribution of the landscape type in England

9.2.1 The objective was to identify and map 1 km squares in England which support, or have some potential to support, lowland heathland vegetation types. This objective was achieved in terms of two factors: soil type and altitude. Soil types characteristic of lowland heathland vegetation and landscapes were used to define a population of 1 km squares having heathland potential, based on a 1 km database of the Soil Survey and Land Research Centre. This map was constrained in order to distinguish upland and lowland heaths using the ITE Land Classification.

9.2.2 Given the need to include a representative sample of existing and potential heathland areas and the constraint on the overall size of the lowland heath mask, comparisons with external data suggested that the fit of the mask was acceptable for the purposes of this project. The area identified for the field sampling programme does not cover the whole lowland heath resource in England, but provides an adequate sampling framework for assessing the current status of the heathland resource in the core heathland areas. The methodology described above is also sufficiently flexible to be adapted to include additional soil types or changed definitions of 'heathlands' and 'lowlands' if this adaptation is necessary for future work with different objectives.

Objective 2: To survey the habitats (including major land cover types and ecological features such as hedgerows) and historic features within each landscape type

9.2.3 For the field survey of habitats, the sampling unit was a 1 km square; 80 squares were surveyed in 1992, plus a further nine in 1993 and, in addition, data from 16 squares surveyed in Countryside Survey 1990 have been used, to give a total sample of 105. The results were extrapolated from the sample squares to the lowland heath landscape as a whole.

9.2.4 Land cover was recorded at points on a 25-position grid within each field survey square, and the nearest field boundary (within 100 m) was described. To provide 'quality' information, 2 m x 2 m quadrats were recorded at each grid point where the vegetation was indicative of acid soils, thus excluding most arable fields and fertilized, sown or neutral grasslands.

9.2.5 For each of the field sample 1 km squares, data on historic features collected in the field (by ITE surveyors) were supplemented by selective analysis of aerial photographs and map interpretation of recent edition Ordnance Survey map extracts, and examination of County Sites and Monuments Records (SMRs) and the National Monuments Record (NMR).

9.2.6 Archaeological data were compiled for 752 archaeological sites in 89 sample squares drawn from 22 counties. A breakdown by county shows considerable variation in the mean density of identified monuments.

Objective 3: To determine, on a regional basis and in relation to current designations, the composition of the landscape type in terms of the quantity and quality of the surveyed features

9.2.7 Quantitative estimates of land cover and boundaries have been made for the lowland heath mask and for strata within it.

Just 5% (440 km²) was estimated to be lowland heath habitat (dwarf shrub heath and associated vegetation types), 75% of which occurred in designated 1 km squares. The lowland heath habitat included a range of vegetation types, from bogs and wet heath, through dry heath, to vegetation becoming dominated by grasses or scrub. The core heathland vegetation types were estimated at just 361 km², of which the wet heath and bogs occurred almost entirely in designated squares, whilst some dry heath occurred in areas which were not designated.

9.2.8 In addition to the core heathland, modified heathland vegetation types were identified, which had been colonised or planted with trees, but still contained a recognisable heathland flora; these were estimated at 674 km². These modified heathland areas occurred throughout the lowland heath landscape, though they were more common in designated areas and on drier soils. They provide the best opportunity for heathland restoration. In terms of habitats with potential for heath vegetation, acid grassland is more common in pastural areas, but woodland and scrub are more common in arable areas.

9.2.9 Objective measures of vegetation have been related to quality criteria, to provide an empirical evaluation of the quality of heathland vegetation in different parts of the lowland heath landscape: size, diversity, naturalness, representativeness, rarity, fragility, potential value.

9.2.10 Using at least two separate measures of each of the quality criteria, the four strata were ranked. Based on quadrat information, heathland in the designated pastural stratum ranked highest for all measures, and the designated arable was the next highest, except for one measure of representativeness and one of fragility (where non-designated pastural land was higher). This finding confirms the relationship between designated land and 'good-quality' heath.

Historical aspects

9.2.11 Prehistoric periods are mainly represented by 'find' sites (ie where objects have been found) together with hut circles and Bronze Age barrows. The Roman period is also dominated by find sites, although with a scattering of other site types, particularly roads. Representation of the Early Medieval period is sparse, with only a few barrows and burials. The Medieval period retains a religious, ritual and funerary grouping, but there is a notable increase in settlement sites, together with farms and field systems. Both these groups occur in the Post Medieval period, with the settlements including many villages and some small towns. In addition, there is a surge of industrial and transport sites. Many of the unspecified sites almost certainly belong to the Post Medieval period, and this group follows the same pattern as the Post Medieval distribution.

Designation

9.2.12 It was recognised that, without time-series data, it was difficult to assess the effect of designation. It was not known, for example, whether correlations between 'good' areas of lowland heath and some form of designation were because the designation had been effective, or whether the designation was made because of the quality of the heath. The approach adopted in this study was to stratify the field sample according to designation status.

9.2.13 Results related to designation are included in Section 8.3, but clearly different types of designation may have different purposes. Within the lowland heath landscape, ESAs cover the largest area in the arable stratum, while National Parks are mainly restricted to the pastural stratum. AONBs and Green Belts are significant in both, as are SSSIs.

Objective 4: To develop models to predict the effect of environmental and management changes on the distribution and quality of the landscape types and their constituent habitats

9.2.14 Areas of lowland heathland likely to be affected by excessive atmospheric acid deposition have been mapped using the 'critical loads' approach. The map of 'current' deposition is based on data collected from 1989 to 1991, which when overlaid on the critical loads map gives an exceedance map showing areas. The effects of various change scenarios, compared to the 1989–91 baseline, have been evaluated in terms of the proportion of heathland in areas where the soils' critical loads are exceeded. During the period 1989–91, 93% of all areas within the lowland heath mask was in exceeded areas (ie where the pollutant deposition exceeds the weathering rate of the soil), with only a few areas of the Brecklands and the Lizard peninsula in unexceeded areas. In lowland England, the soil acidity critical load was exceeded in 57% of the total area.

9.2.15 Current emissions reduction scenarios appear to be relatively ineffective at protecting the lowland heathland areas of England. Although the 70% UNECE emissions reduction scenario would reduce the exceeded areas to 11% of lowland England, 65% of heathland areas are estimated to be at risk. An emission reduction of 80% would leave 7% of lowland England and 42% of lowland heathland areas at risk. Heathlands in squares containing designations were shown to be likely to benefit least from the emissions reductions.

9.2.16 Average atmospheric deposition of nitrogen (NO_x and NH_x) in heathland areas is 17 kg nitrogen ha^{-1} yr^{-1}, which is similar to that received by other parts of lowland England (18 kg nitrogen ha^{-1} yr^{-1}). Over 99% of heathland areas receive more than 10 kg N ha^{-1} yr^{-1} and 20% receive over 20 kg N ha^{-1} yr^{-1}. Areas with high N deposition (>20 kg) occur mainly in the west Midlands, the north-west, Hampshire and Surrey. Heathlands in designated squares are more likely (26%) to be receiving over 20 kg nitrogen ha^{-1} yr^{-1} than those in undesignated squares (16%).

9.2.17 These rates of atmospheric N deposition are low compared to average agricultural inputs, and there is no experimental information describing the long-term effects of these rates on lowland heathlands in Britain. However, it is likely that the low rates of atmospheric N will have a significant effect on community composition in lowland heathlands, with gradual nutrient enrichment leading to a loss of plant species diversity.

9.2.18 The study has made use of the C-S-R classification of functional types and of the TRISTAR2 model which takes a given specification of an initial steady-state vegetation, adopts some altered environmental and/or management scenario, and predicts the composition of the new steady-state vegetation in terms of its component functional types. Most of the 'core' heathland vegetation is composed of stress-tolerator and stress-tolerator/competitor species. The remaining vegetation plot types are representative of all other combinations of functional types.

9.2.19 The TRISTAR2 model calculated the predicted change in abundance of the functional types, under each of six specimen change scenarios, and an index of vulnerability was produced. Lowland heath consists of a heterogeneous grouping of heath, grassland and woodland vegetation, all of which are relatively unproductive. In general, grasssland plot classes are among the more vulnerable, with woodland being the best protected and heathland vegetation occupying a middle position.

Objective 5: To make recommendations on ways in which policy instruments may be refined to further protect, enhance or re-establish habitats which characterise the landscape type

9.2.20 The results from the field survey and the outputs from the vegetation change and atmospheric impact models have been considered in the light of current policy measures.

9.2.21 Heathland is a valuable landscape, dominated by a non-climax vegetation type. Because the vegetation is non-climax, intervention is required to prevent heathland turning into scrub/woodland; heathland therefore requires management to maintain its condition. The survey results indicate that, of the area within the lowland heath landscape (8500 km^2):

- about 36 000 ha is good-quality 'core' heath habitat,
- about 70 000 ha is relatively recently modified from heathland (modified heath),
- about 650 000 ha may at one time have been heath and is still in a land use which could revert (eg forestry or agriculture), but has been long modified, and
- the remainder has no potential (eg built-up areas).

9.2.22 Working from the *Biodiversity Action Plan* draft objectives as a starting point, it would appear feasible to establish the following objectives:

- to bring 5400 ha of core heath in private ownership and not covered by existing enhancement schemes under good management;

- to restore 6000 ha of 'near' heathland and maintain this under good management, focusing on expansion and linking between existing core heath sites;
- to re-create heathland habitat on about 600 ha of former heathland (with potential for restoration) to provide priority linkages between core heath sites.

9.2.23 If further work indicates that these targets are justifiable, it is recommended that they are achieved by extending existing schemes offering incentives for restoration and management on private land and implementing re-creation on Forestry Commission land.

9.2.24 To ensure that the benefits of these measures are retained in the long term, and transferred to other areas, it is also essential that effective management approaches are identified and publicised and that awareness of the value of lowland heath habitats is raised.

Objective 6: To develop a methodology for measuring change in these habitats which is sufficiently robust and precise to assess the effectiveness of policies at a national (England) scale

9.2.25 In designing the field survey, future measurement of change was a major consideration. Methods were developed from the Countryside Survey 1990 approach (which has as a major objective the establishment of a high-quality baseline against which future change can be measured). The potential and chosen approaches for measuring change are reported separately from these landscape reports (Bunce in prep.).

9.3 Advantages and disadvantages of the research approach

9.3.1 The basic approach used to address the objectives given above is shown in para 1.4.2 The advantages and disadvantages of the approach are considered under a range of headings.

Use of available, spatial data to define the lowland heath mask

9.3.2 At the start of the study there was no national map of lowland heath. Because change was a major consideration, the potential areas of lowland heath were important as a basis for monitoring the extent of the lowland heath resource. However, the use of objective criteria to define the lowland heath mask (basically soil types by land type) did not take into account the idiosyncrasies of vegetation: there was no perfect correlation between certain soil types and present or potential areas of lowland heath. The quality of the source data is unknown and it may be that some of the mismatch may be due to spatial differences in soil mapping.

Use of a 1 km square as a sampling unit

9.3.3 To be compatible with Countryside Survey 1990, the sampling unit was a 1 km square. This is said to represent a good balance between an area which contains enough information for it to be classified as a particular land type and one which is not too large to be field-surveyed. Apart from the well-known tracts of remaining lowland heath, much existing heath, as well as areas of relevant soil types which might support heath, are fragmented and spatially dispersed. Thus, by surveying whole 1 km squares, instead of smaller units, there was some inefficiency and wasted effort. In particular, there was poor representation of 'higher-quality' sites, meaning that less could be deduced about potential change in 'core' lowland heath than in the areas of potential heath. The approach did allow the calculation of national estimates but, for reasons of scale, these estimates are not highly accurate (see calculation of statistical errors in Chapter 4).

The choice of strata

9.3.4 Part of the sampling strategy was to stratify the field sample so that differences in vegetation change between different land types, and between designated and non-designated areas, could be identified. The relatively small number of samples meant that only four strata were appropriate and, further, all designation types had to be aggregated to allow any comparisons to be made at all: no results are available in relation to any one designation type. The choice of 'arable' and 'pastural' strata proved revealing, but more samples in a wider range of land types would have given clear indications as to where threats were greatest and most change was likely to occur.

Modelling vegetation change

9.3.5 The modelling of atmospheric inputs achieved its aims in that it identified the broad geographical areas where lowland heath was under threat. However, the spatial overlaying approach did not lend itself to forming inputs to the vegetation change modelling as readily as might have been expected.

9.3.6 Although not as conceptual in approach as had originally been specified, the UCPE approach to modelling was shown to be valuable in terms of identifying vulnerability to likely threats under a range of scenarios. However, the links between suggested scenarios and policy implementation were not spelled out and might form the focus of further work.

9.4 Future research needs

9.4.1 Research of the type undertaken in this ambitious project cannot answer every question and inevitably leads to more questions. Some of the areas for future research are listed below.

Monitoring

9.4.2 As stated above, the present project has laid a baseline against which further survey results may be measured and compared. It will be important to monitor the land cover changes and the quadrats which have already been recorded and to link these monitoring results with information on take-up from Countryside Stewardship Scheme monitoring. Links should be made explicitly with other environmental monitoring schemes, including any future Countryside Surveys and the Environmentally Sensitive Area monitoring. Only in this way can change be objectively determined and links with policy instruments properly understood.

Interpretation of modelling results

9.4.3 There is scope for further analysis of the modelling results, especially in identifying both the spatial and vegetational characteristics of areas likely to undergo change.

Integration of data

9.4.4 As stated above, opportunities to link the results of this study with work elsewhere should be sought so that links between change, habitat management/creation and policy may be better understood.

Experimental work

9.4.5 Some of the assumptions made in the interpretation of the change analyses are less well researched than others. For example, the effects of atmospheric nitrogen on lowland heaths have not been well studied in Britain. Experimental work, of the type undertaken in continental Europe and elsewhere, is timely.

Landscape ecology

9.4.6 The spatial characteristics of lowland heath are interesting in terms of fragmentation and connectedness. If habitat creation (and management) is to lead to maximum heathland quality, then the spatial characteristics of potential areas of heath need to be known. Will increasing the areas of existing heath be adequate or are there crucial links or 'stepping stones' that need to be made? The landscape ecology of lowland heaths needs further investigation, especially in relation to areas of potential heath as defined within this project.

ACKNOWLEDGMENTS

The authors are grateful to the following members of the DOE's project Steering Group for their guidance during the project and for the comments on drafts of this Report:

Mrs Enid Barron, DOE
Dr Janet Dwyer, Countryside Commission
Mr Graham Fairclough, English Heritage
Dr Mark Felton, English Nature
Mr Alan Hooper, ADAS
Dr Richard Jefferson, English Nature
Dr Gy Ovenden, DOE
Dr Andrew Stott, DOE
Dr Sarah Webster, DOE

Dr Richard Keymer, English Nature, and Dr Nigel Webb, ITE, are gratefully acknowledged for their contributions during the Expert Review meeting.

We are also grateful to Dr Nick Michaels, English Nature, for comments on early drafts of this Report.

Soil Survey and Land Research Centre (Silsoe) kindly gave permission for use of soils data to help determine the lowland heath mask.

Mr Richard Bridges, Mr Malcolm Harrison, Mr Richard Newman, Mr Adrian Oliver and Mr Jason Wood all contributed to the work reported in Chapter 5 (Historical characteristics of the lowland heath mask). Mr Mark Bell and Mr Andy Fulton provided information on the MARS project.

The authors are particularly indebted to the following field surveyors who spent long and arduous hours of toil in the field, collecting valuable information which has gone to form a unique and irreplaceable database:

Henry Adams
Tanya Barden
Liz Biron
Roger Cummins
John Davis
John Day
Richard Hewison
Jill Hobbs
Chris Kanefsky
Gabby Levine
Mandy Marler
Doug McCutcheon
Liz McDonnell
Karen Pollock
Sam Walters
Mike Webb

Finally, grateful acknowledgment is made of the contribution of Chris Benefield in creating the artwork for the front cover, and of Penny Ward and Karen Goodsir in preparing the final copy.

REFERENCES AND BIBLIOGRAPHY

References cited in the text are given, together with a select bibliography of recent references directly relevant to the subject matter of this Report. Various categories of literature are largely not included, as follows.

- The extensive pre-1980 literature on lowland heaths.
- The extensive literature on upland heaths, much of which could be relevant.
- Purely scientific literature on ecological processes in heathland.
- Phytosociological literature on lowland heath.
- Literature dealing with the practical detail of heathland management (for conservation).
- Amenity management and amenity issues in lowland heath.
- Agricultural use of lowland heath (ie the agri-science side of the literature).

Aerts, R. 1993a. Biomass and nutrient dynamics of dominant plant species from heathlands. In: *Heathlands: patterns and processes in a changing environment*, edited by R.Aerts & G.W.Heil, 51–84. Dordrecht: Kluwer.

Aerts, R. 1993b. Competition between dominant plant species in heathlands. In: *Heathlands: patterns and processes in a changing environment*, edited by R.Aerts & G.W.Heil, 125–151. Dordrecht: Kluwer.

Aerts, R. & Berendse, F. 1988. The effects of increased nutrient availability on vegetation dynamics in wet heathlands *Vegetatio*, **76**, 63–69.

Aerts, R .& Berendse, F. 1989. Above-ground nutrient turnover and net primary production of an evergreen and a deciduous species in a heathland ecosystem. *Journal of Ecology*, **77**, 343–356.

Andrews, J. 1990. Management of lowland heath for wildlife. *British Wildlife*, **1**, 336–346.

Armstrong, P. & Milne, A.A. 1973. Changes in the land use of the Suffolk Sandlings: a study in the disintegration of an ecosystem. *Geography*, **58**, 1–8.

Auld, M.H.D., Davies, S. & Pickess, B.P. 1992. *Restoration of lowland heathland in Dorset.* Sandy: Royal Society for the Protection of Birds.

Auld, M.H.D., Pickess, B.P. & Burgess, N.D. 1991. *History and management of southern lowland heathlands.* Sandy: Royal Society for the Protection of Birds.

Austin, M.P. & Heyligers, P.C. 1989. Vegetation survey design for conservation: gradsect sampling of forests in north-eastern New South Wales. *Biological Conservation*, **50**, 13–32.

Bakker, J.P., De Bie, S., Dallinga, J.H., Tjaden, P. & De Vries, Y. 1983. Sheep-grazing as a management tool for heathland conservation and regeneration in the Netherlands. *Journal of Applied Ecology*, **20**, 541–560.

Barr, C.J., Bunce, R.G.H., Clarke, R.T., Fuller, R.M., Furse, M.T., Gillespie, M.K., Groom, G.B., Hallam, C.J., Hornung, M., Howard, D.C. & Ness, M.J. 1993. *Countryside Survey 1990: main report.* London: HMSO.

Berdowski, J.J.M. 1993. The effect of external stress and disturbance factors on *Calluna*-dominated vegetation. In: *Heathlands: patterns and processes in a changing environment*, edited by R.Aerts & G.W.Heil, 85–124. Dordrecht: Kluwer.

Berdowski, J.J.M. & Zeilinga, R. 1987. Transition from heathland to grassland: damaging effects of the heather beetle. *Journal of Ecology*, **75**, 159–175.

Berendse, F. 1990. Organic matter accumulation and nitrogen mineralization during secondary succession in heathland ecosystems. *Journal of Ecology*, **78**, 413–427.

Berendse, F., Oudhof, H. & Bol, J. 1987. A comparative study of nutrient cycling in wet heathland ecosystems. I. Litter production and nutrient losses from the plant. *Oecologia*, **74**, 174–184.

Berendse, F., Bobbink, R. & Rouwenhorst, G. 1989. A comparative study of nutrient cycling in wet heathland ecosystems. II. Litter decomposition and nutrient mineralization. *Oecologia*, **78**, 338–348.

Berendse, F., Beltman, B., Bobbink, R., Kwant, R. & Schmitz, M. 1987. Primary production and nutrient availability in wet heathland ecosystems. *Acta Oecologica/Oecologia Plantarum*, **8**, 256–279.

Bobbink, R. & Heil, G.W. 1993. Atmospheric deposition of sulphur and nitrogen in heathland ecosystems. In: *Heathlands: patterns and processes in a changing environment*, edited by R.Aerts & G.W.Heil, 25–50. Dordrecht: Kluwer.

Bruggink, M. 1993. Seed bank, germination, and establishment of ericaceous and graminaceous species in heathlands In: *Heathlands: patterns and processes in a changing environment*, edited by R.Aerts & G.W.Heil, 153–180. Dordrecht: Kluwer.

Bunce, R.G.H. 1981. The scientific basis of evaluation. (Values and Evaluation, University College, London.) *Discussion Papers in Conservation*, **36**, 22–27.

Bunce, R.G.H. 1989. *Heather in England and Wales.* (ITE research publication no. 3.) London: HMSO.

Bunce, R.G.H. 1990. Land use and the landscape. In: *Britain's changing environment from the air*, edited by T.

Bayliss-Smith & S.Owens, 219–244. Cambridge: Cambridge University Press.

Bunce, R.G.H., Howard, D.C., Hallam, C.J., Barr, C.J. & Benefield, C.B. 1993. *Ecological consequences of land land use change.* London: Department of the Environment.

Chapman, S.B. & Webb, N.R. 1978. The productivity of a *Calluna* heathland in southern England. In: *Production ecology of British moors and montane grasslands*, edited by O.W. Heal & D.F. Perkins, 247–262. Berlin: Springer-Verlag.

Chapman, S.B. & Clarke, R T. 1980. Some relationships between soil, climate, standing crop and organic matter accumulation within a range of *Calluna* heathlands in Britain. *Bulletin d'Écologie*, **11**, 221–232.

Chapman, S.B., Clarke, R.T. & Webb, N.R. 1989. The survey and assessment of heathland in Dorset, England, for conservation. *Biological Conservation*, **47**, 137–152.

Chapman, S.B., Rose, R.J. & Basanta, M. 1989. Phosphorus adsorption by soils from heathlands in southern England in relation to successional change. *Journal of Applied Ecology*, **26**, 673–680.

Chapman, S.B., Rose, R.J. & Clarke, R.T. 1989a. The behaviour of populations of the marsh gentian (*Gentiana pneumonanthe*): a modelling approach. *Journal of Applied Ecology*, **26**, 1059–1072.

Chapman, S.B., Rose, R.J. & Clarke, R.T. 1989b. A model of the phosphorus dynamics of *Calluna* heathland. *Journal of Ecology*, **77**, 35–48.

Clément, B. & Touffet, J. 1990. Plant strategies and vegetation succession on Brittany heathlands after severe fire. *Journal of Vegetation Science*, **1**, 195–202.

Critical Loads Advisory Group. 1994. *Critical loads of acidity in the United Kingdom.* London: Department of Environment.

Crompton, G. & Sheail, J. 1975. The historical ecology of Lakenheath Warren in Suffolk, England: a case study. *Biological Conservation*, **8**, 299–313.

Crowe, T.M. 1993. Evaluation for nature conservation: principles and criteria. *South African Journal of Science*, **89**, 2–5.

Daniels, J.L. 1983. *Heathland management in amenity areas.* Cheltenham: Countryside Commission.

Darvill, T. 1987. *Ancient monuments in the countryside: an archaeological management review.* London: Historic Buildings and Monuments Commission for England.

Darvill, T., Fulton, A. & Bell, M. 1993 *Monuments at risk survey: briefing paper 1.* Bournemouth: University of Bournemouth.

Department of Environment. 1994. *Biodiversity: the UK action plan.* (Cmd 2428.) London: HMSO.

Diemont, W.H. & Heil, G. 1984. Some long-term observations on cyclical and seral processes in Dutch heathlands. *Biological Conservation*, **30**, 283–290.

Diemont, W.H. & Linthorst Homan, H.D.M. 1989. Re-establishment of dominance by dwarf shrubs on grass heaths. *Vegetatio*, **85**, 13–19.

Dolman, P. & Sutherland, W. 1991a. Historical clues to conservation. *New Scientist*, **12**, 40–43.

Dolman, P. & Sutherland, W. 1991b. The ecological changes of Breckland grass heath and the consequences of management. *Journal of Applied Ecology*, **29**, 402–413.

Ellenberg, H. 1988. *Vegetation ecology of central Europe.* 4th edn. Cambridge: Cambridge University Press.

Equihua, M. & Usher, M.B. 1993. Impact of carpets of the invasive *moss Campylopus introflexus* on *Calluna vulgaris* regeneration *Journal of Ecology*, **81**, 359–365.

Farrell, L. 1983. *Heathland management focus on nature conservation 2.* Peterborough: Nature Conservancy Council.

Farrell, L. 1989. The different types and Importance of British heaths. *Botanical Journal of the Linnean Society*, **101**, 291–299.

Farrell, L. 1993. *Lowland heathland: the extent of habitat change.* (Science no. 12.) Peterborough: English Nature.

Forman, R.T.T. & Godron, M. 1986. *Landscape ecology.* New York: Wiley.

Gilpin, M. & Hanski, I. 1991. *Metapopulation dynamics: empirical and theoretical investigations.* London: Academic Press.

Gimingham, C.H. 1972. *Ecology of heathlands.* London: Chapman & Hall.

Gimingham, C.H. 1988. A reappraisal of cyclical process in *Calluna* heath. *Vegetatio*, **77**, 61–69.

Gimingham, C.H. 1989. Heather and heathlands. *Botanical Journal of the Linnean Society*, **101**, 263–268.

Gimingham, C.H. 1993. *The lowland heath management handbook.* Peterborough: English Nature.

Gimingham, C.H. & Smidt, J.T. de. 1983. Heaths as natural and semi-natural vegetation. In: *Man's impact upon the ecosystem*, edited by W. Holzner, M.J.A. Werger & I. Ikusima, 185–199. The Hague: Junk.

Gimingham, C.H., Chapman, S.B. & Webb, N.R. 1979. European heathlands. In: *Ecosystems of the world. Volume 9A, Heathlands and related shrublands: descriptive studies*, edited by R. Specht, 365–413. Amsterdam: Elsevier.

Gloaguen, J.C. 1990. Post-burn succession on Brittany heathlands *Journal of Vegetation Science*, 1, 147–152.

Granström, A. 1988. Seed banks at six open and six afforested heathland sites in southern Sweden. *Journal of Applied Ecology*, **25**, 297–306.

Grennfelt, P. & Thornelof, E., eds. 1992 *Critical loads for nitrogen*. (Report from a workshop at Lokeberg, Sweden. Nord 1992:41.) Nordic Council of Ministers.

Grime, J.P. 1974. Vegetation classification by reference to strategies. *Nature*, **250**, 26–31.

Grime, J.P. 1979. *Plant strategies and vegetation processes*. Chichester: Wiley.

Grime, J. P., Hodgson, J. G., Hunt, R. 1988. *Comparative plant ecology : a functional approach to common British species*. London: Unwin Hyman.

Hampshire County Council. Undated. *North-east Hampshire heathlands project report*.

Harrison, C.M. 1976. Heathland management in Surrey, England. *Biological Conservation*, **10**, 211–220.

Harrison, C.M. 1983. Lowland heathland: the case for amenity and management. In: *Conservation in perspective*, edited by A Warren & F B Goldsmith, 71–82. London: Wiley.

Heil, G.W. & Aerts, R., eds. 1993. *Heathlands: patterns and processes in a changing environment*. Dordrecht: Kluwer.

Heil, G.W. & Diemont, W.H. 1983. Raised nutrient levels change heathland soils into grassland. *Vegetatio*, **53**, 113–120.

Hester, A.J. 1987. Successional vegetation change: the effect of shading on *Calluna vulgaris*. *Transactions of the Botanical Society of Edinburgh*, **45**, 121–126.

Heusden, W.R.M., van. 1983. Monitoring changes in heathland vegetation using sequential aerial photographs. *International Institute for Aerospace Survey and Earth Sciences Journal*, **2**, 160–165.

Hobbs R J. 1987. Disturbance regimes in remnants of natural vegetation. In: *Nature conservation: the role of remnants of native vegetation*, edited by D.A. Saunders, G.W. Arnold, A.A. Burbridge & A.J.M. Hopkins, 233–240. Chipping Norton: Surrey Beatty.

Hobbs, R.J. & Gimingham, C.H. 1984. Vegetation, herbivore and fire interactions in heathland. *Advances in Ecological Research*, **26**, 87–174.

Hodgetts, N.G. 1992. *Guidelines for the selection of biological SSSIs: non-vascular plants*. Peterborough: Joint Nature Conservation Committee.

Hodgson, J.G. 1991. Management for the conservation of plants with particular reference to the British flora. In: *The scientific management of temperate communities for conservation*, edited by I.F. Spellerberg, F.B. Goldsmith & M.G. Morris, 81–102. Oxford: Blackwell Scientific.

Hornung, M., Bull, K.R., Cresser, M., Hall, J., Loveland, P.J., Langan, S.J., Reynolds, B. & Robertson, W.H. 1993. Mapping critical loads for the soils of Great Britain. In: *Acid rain and its impact: the critical loads debate*, edited by R.W. Batterbee, 43–51. London: Ensis.

Hornung, M., Bull, K.R., Cresser, M., Hall, J., Langan, S.J., Loveland, P. & Smith, C. 1995. An empirical map of critical loads of acidity for soils in Great Britain. *Environmental Pollution*, **90**, 301–310.

Houdijk, A.L.F.M., Verbeek, P.J.M., Van Dijk, H.F.G. & Roelofs, J.G.M. 1993. Distribution and decline of endangered heathland species in relation to the chemical composition of the soil. *Plant and Soil*, **148**, 137–143.

Howard, D.C., Bunce, R.G.H., Jones, M. & Haines-Young, R.H. 1994. *Development of the Countryside Information System*. Ruislip: Department of the Environment.

Hunt, R., Middletone, D.A.J., Grime, J.P. & Hodgson, J.G. 1991. TRISTAR: an expert system for vegetation processses. *Expert Systems*, **8**, 219–226.

Institute of Terrestrial Ecology. 1991. *Changes in key habitat: a tender for research to the Department of the Environment*. Grange-over-Sands: ITE.

Kottman, H.J., Schwoppe, W., Willers, T. & Wittig, R. 1985. Heath conservation by sheep grazing: a cost benefit analysis. *Biological Conservation*, **31**, 67–74.

Land Use Consultants. 1986. *The New Forest landscape*. (CCP 220.) Cheltenham: Countryside Commission.

Liddle, M.J. 1977. An approach to objective collection and analysis of data for comparison of landscape character. *Regional Studies*, **10**, 173–181.

Liverpool University & British Gas. 1988. *Heath restoration: a handbook of technique*. Southampton: British Gas.

Lowday, J.E. 1984. The restoration of heathland vegetation after control of dense bracken by asulam. *Aspects of Applied Biology*, **5**, 283–290.

Lowday, J.E. 1986. *Calluna* heathland following bracken clearance. In: *Bracken: ecology, land uses, and control technology*, edited by R.T. Smith & J.A. Taylor, 233–238. Carnforth: Parthenon Press

Lowday, J.E. & Marrs, R.H. 1992a. Control of bracken and the restoration of heathland. I Control of bracken. *Journal of Applied Ecology*, **29**, 195–203.

Lowday, J.E. & Marrs, R.H. 1992b. Control of bracken and the restoration of heathland. III Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology*, **29**, 212–217.

Lowday, J.E. & Wells, T.C.E. 1977. *The management of* *grassland and heathland in country parks.* Cheltenham: Countryside Commission.

Mallik, A.U. & Gimingham, C.H. 1983. Regeneration of heathland plants following burning. *Vegetatio*, **53**, 45–58.

Margules, C.R. 1989. Introduction to some Australian developments in conservation evaluation. *Biological Conservation*, **50**, 1-11.

Margules, C.R. & Usher, M.B. 1981. Criteria used in assessing wildlife conservation potential: a review. *Biological Conservation*, **21**, 79–109.

Marrs, R.H. 1984. Birch control on lowland heaths: mechanical control and the application of herbicides by foliar spray. *Journal of Applied Ecology*, **21**, 703–716.

Marrs, R.H. 1985. The effects of potential bracken and scrub control herbicides on lowland *Calluna* and grass heath communities in East Anglia, UK. *Biological Conservation*, **32**, 13–32.

Marrs, R.H. 1986. Techniques for reducing soil fertility for nature conservation purposes; a review in relation to research at Roper's Heath, Suffolk, England. *Biological Conservation*, **34**, 307–332.

Marrs, R.H. 1987a. Studies on the conservation of lowland *Calluna* heaths. I. Control of birch and bracken and its effect on heath vegetation. *Journal of Applied Ecology*, **24**, 163–175.

Marrs, R.H. 1987b. Studies on the conservation of lowland *Calluna*. II. Regeneration of *Calluna* and its relation to bracken infestation. *Journal of Applied Ecology*, **24**, 177–189.

Marrs, R.H. & Gough, M.W. 1989. Soil fertility: a potential problem for habitat restoration. In: *Biological habitat restoration*, edited by G P Buckley, 29–44. London: Belhaven.

Marrs, R.H. & Lowday, J.E. 1983. *Management of lowland heaths.* (NERC contract report to the Nature Conservancy Council.) Cambridge: Institute of Terrestrial Ecology.

Marrs, R.H. & Lowday, J.E. 1992. Control of bracken and the restoration of heathland. II Regeneration of the heathland community. *Journal of Applied Ecology*, **29**, 204–211.

Marrs, R.H.& Procter, J. 1979, Vegetation and soil studies of the enclosed heathlands of the Lizard peninsula, Cornwall. *Vegetatio*, **41**, 121–128.

Marrs, R.H., Hicks, M.J. & Fuller, R.M. 1986. Losses of lowland heath through succession at four sites in Breckland, East Anglia. *Biological Conservation*, **36**, 19–38.

Marrs, R.H., Lowday, J.E., Jarvis, L., Gough, M.W. & Rowland, A.P. 1993. Control of bracken and the restoration of heathland. IV Effects of bracken control and heathland restoration treatments on nutrient distribution and soil chemistry. *Journal of Applied Ecology*, **29**, 218–225.

Marrs, R.H., Pakeman, R.J. & Lowday, J.E. 1993. Control of bracken and the restoration of heathland. V Effects of bracken control treatments on the rhizome and its relationship with frond performance. *Journal of Applied Ecology*, **30**, 107–118.

Miles, J. 1981. Problems in heathland and grassland dynamics. *Vegetatio*, **46**, 61–74.

Moore, N.W. 1962. The heaths of Dorset and their conservation. *Journal of Ecology*, **50**, 369–391.

Mountford, J.O., Lakhani, K.H. & Holland, R.J. 1994. *The effects of nitrogen on species diversity and agricultural production on the Somerset Moors, phase 2: (a) after seven years of fertiliser application; (b) after cessation of fertiliser input for three years.* (NERC contract report to the Department of Environment.) Abbots Ripton, Huntingdon: Institute of Terrestrial Ecology.

Nature Conservancy Council. 1989. *Guidelines for the selection of biological SSSIs. Detailed guidelines for habitats and species groups.* Peterborough: NCC.

Odgaard, B.V. 1988. Heathland history in western Jutland, Denmark. In: *The cultural landscape: past, present and future*, edited by H.H. Birks, H.J.B. Birks, P.E. Kaland & D. Moe, 311–319. Cambridge: Cambridge University Press.

Peterken, G. & Hughes, F. 1990. The changing lowlands In: *Britain's changing environment from the air*, edited by T. Bayliss-Smith & S. Owens, 48–76. Cambridge: Cambridge University Press.

Pielou, E.C. 1991. The many meanings of diversity. In: *Diversidad Biologica. Symposium international celebrado en Madrid en Noviembre y Diciembre de 1989, promovido por la Fundacion Ramon Areces, ADENA-WWF y SCOPE,* edited by F.D Pineda, M.A. Casado, J.M. de Miguel & J. Montalvo, 113–115. Madrid: Fundacion Ramon Areces.

Pons, T.L. 1989. Dormancy, germination and mortality of seeds in heathland and inland sand dunes. *Acta Botanica Neerlandica*, **38**, 327–335.

Pressey, R.L. & Nicholls, A.O. 1989. Efficiency in conservation evaluation: scoring versus iterative approaches. *Biological Conservation*, **50**, 199–218.

Putwain, P.D. 1983. The restoration of heather cover on bare areas. In: *Heathland management in amenity areas*, edited by J. Daniels. Cheltenham: Countryside Commission.

Putwain, P.D. & Gilham, D.A. 1990. The significance of the dormant viable seed bank in the restoration of heathlands. *Biological Conservation*, **52**, 1–16.

Putwain, P.D., Gilham, D.A. & Holliday, R.J. 1982. Restoration of heather moorland and lowland heathland with special reference to pipelines. *Environmental*

Conservation, **9**, 225–235.

Rackham, O. 1986. *The history of the countryside.* London: Dent.

Ratcliffe, D.A. ed. 1977. *A nature conservation review, Vols 1 and 2.* Cambridge: Cambridge University Press.

Rebolo, A.G. & Siegfried, W.R. 1990. Protection of fynbos vegetation: ideal and real-world options. *Biological Conservation*, **54**, 15–31.

Robinson, D.G., Laurie, I.C., Wager, J.F. & Traill, A.L., eds. 1976. *Landscape evaluation: the landscape evaluation research project 1970–1975.* Manchester: Centre for Urban and Regional Research, University of Manchester.

Rodwell, J.S. 1991. *British plant communities, Vol 2: Mires and heaths.* Cambridge: Cambridge University Press.

Roelofs, J.G.M. 1986. The effect of airborne sulphur and nitrogen deposition on aquatic and terrestrial heathland vegetation. *Experientia*, **42**, 372–377.

Rose, C.I., ed. 1981. *Values and evaluation.* (Discussion Papers in Conservation, 36.) London: University College.

Royal Commission on the Historical Monuments of England/English Heritage. 1992. *Thesaurus of archaeological site types.* London: RCHME/EH.

Royal Commission on the Historical Monuments of England. 1993. *Recording England's past: a review of national and local sites and monuments records in England.* London: RCHME.

Royal Society for the Protection of Birds. 1993. *Dorset heathlands – a crisis report.* Sandy: RSPB.

Selman, P. & Doar, N. 1992. Landscape ecology and rural planning. *Journal of Environmental Management*, **35**, 281–299.

Shafer, C.L. 1990. *Nature reserves: island theory and conservation practice.* Washington: Smithsonian Institution Press.

Smidt, J.T. de. 1979. Origin and destruction of northwest European heath vegetation. In: *Werden und Vergehen von Pflanzengesellschaften*, edited by O. Wilmanns & R. Tüxen. Vaduz: Cramer.

Smidt, J.T. de. 1983. Heathland management in the Netherlands, scientific and social aims. *Acta Botanica Neerlandica*, **32**, 247.

Soil Survey of England and Wales. 1983. *Legend for the 1:250,000 soil map of England and Wales.* Harpenden: Lawes Agricultural Trust (Soil Survey of England and Wales).

Soulé, M.E. 1987. *Viable populations for conservation.* Cambridge: Cambridge University Press.

Stieparaere, H. & Timmerman, C. 1983. Viable seeds in the soils of some parcels of reclaimed and unreclaimed heath in the Flemish district (northern Belgium). *Bulletin de la Societe Royale de Botanique de Belgique*, **116**, 62–73.

Summerfield, R.J. 1972. Biological inertia – an example. *Journal of Ecology*, **60**, 793–798.

Tansley, A.G. 1939. *The British islands and their vegetation.* Cambridge: Cambridge University Press.

Tansley, A.G. 1949. *Britain's green mantle.* London: Allen & Unwin.

Tansley, A.G. 1968. *Britain's green mantle.* 2nd edn. London: Allen & Unwin.

Trueman, M.R.G. & Williams, J. 1993. *Index record for industrial sites: recording the industrial heritage.* Ironbridge: Association for Industrial Archaeology.

Tubbs, C.R. 1968. *The New Forest: an ecological history.* Newton Abbot: David & Charles.

Tubbs, C.R. 1974. Heathland management in the New Forest, Hampshire. *Biological Conservation*, **6**, 303–306.

Tubbs, C.R. 1986. *The New Forest.* London: Collins.

Tubbs, C.R. 1991. Grazing the lowland heaths. *British Wildlife*, **2**, 276–289.

United Kingdom Review Group on Impacts of Atmospheric Nitrogen. 1994. *Impacts of nitrogen deposition in terrestrial ecosystems.* London: Department of Environment.

Usher, M.B., ed. 1986. *Wildlife conservation evaluation.* London: Chapman and Hall.

Usher, M.B. 1991. Biodiversity: a scientific challenge for resource managers in the 1990s. In: *Symposium international celebrado en Madrid en Noviembre y Diciembre de 1989, promovido por la Fundacion Ramon Areces, ADENA-WWF y SCOPE*, edited by F.D. Pineda, M.A. Casado, J.M. de Miguel & J. Montalvo, 113–115. Madrid: Fundacion Ramon Areces.

Webb, N.R. 1985. Habitat islands or habitat mosaic? A case study of heathlands in southern England. In: *Inselokologie – Andwendung in der Planung des landlichen Raums*, edited by W. Zielonkowski & H.J. Mader, 62–69. Laufen-Salzach: Akademie für Naturschutz and Landschaftspflege.

Webb, N.R. 1986. *Heathlands.* London: Collins.

Webb, N.R. 1990a. Changes in vegetational diversity on relict heathland fragments. *Biological Conservation*, **53**, 253–264.

Webb, N.R. 1990b. Changes on the heathlands of Dorset, England, between 1978 and 1987. *Biological Conservation*, **51**, 273–286.

Webb, N.R. & Haskins, L.L. 1980. An ecological survey of heathland in the Poole Basin, Dorset, England in 1978. *Biological Conservation,* **17**, 281–296.

Welch, D., Miller, G.R. & Legg, C.J. 1990. Plant dispersal in moorlands and heathlands in Britain. In: *Species dispersal in agricultural habitats,* edited by R.G.H. Bunce & D.C. Howard, 117–132. London: Belhaven.

Williams, P.H., Vane-Wright, R..I. & Humphries, C.J. 1993. Measuring biodiversity for choosing conservation areas. In: *Hymenoptera and biodiversity,* edited by J. La Salle & L. D. Gauld, 309–328. Wallingford: Commonwealth Agricultural Bureau International.

Willems, J.H. 1988. Soil seed bank and regeneration of a *Calluna vulgaris* community after forest clearing. *Acta Botanica Neerlandica,* **37**, 313–320.

Wyatt, B.K., Greatorex Davies, N., Hill, M.O., Parr, T.W., Bunce, R.G.H., & Fuller, R.M. 1994. *Countryside Survey 1990: comparison of land cover definitions.* London: HMSO.

Appendix 1 Technical appendix to Chapter 3 – Defining the lowland heath mask

This Appendix includes details of how the lowland heath mask was validated using two independent data sources.

A1.1 Validation procedures

A1.1.1 Figure 3.1 in Chapter 3 shows the 'lowland heath mask' identified by the above procedure. The map covers 8538 km squares in lowland England which, according to soil type or altitude, contain, or have potential to contain, lowland heathland. The extent to which this map captures the current distribution of lowland heathland would provide some validation, but this procedure is not possible because of the absence of definitive information on the current distribution of lowland heathland in England. Instead, the lowland heath mask has been compared against two national datasets, neither of which provide definitive or directly comparable data for validation purposes, but which together provide some indication of the overall accuracy and usefulness of the lowland heath mask.

A1.2 Checks against the ITE Land Cover Map

A1.2.1 Estimates of land cover in the lowland heath mask and the remainder of lowland England can be obtained from the ITE Land Cover Map of Britain. This Map is derived from Landsat remotely sensed imagery and provides information on the presence of 25 different land cover types. These data have been aggregated to provide summary data, for each 1 km square of GB, for 17 land cover classes.

A1.2.2 Land cover inside and outside the lowland heath landscape areas are compared in Table A1.1. The two Land Cover Map classes which correspond most closely to the definition of lowland heathland used in this project are dense shrub heath and open shrub heath. Squares inside the lowland heath mask tend to contain more of these heathland categories than squares outside the mask: on average, 2.7% of squares inside the mask is in these land cover types compared to 0.9% outside the mask. However, because there are far fewer squares covered by the mask, the total area of heathland classes recorded outside the mask is four times greater than within it. There are three features of the ITE Land Cover Map and its usage at the 1 km level which may contribute to the poor correspondence between the ITE Land Cover Map and the lowland heath mask.

i. The ITE Land Cover Map heathland categories do not correspond particularly well with heathland identified by field survey. From a randomly chosen sample of 25 m x 25 m pixels, the Land Cover Map recorded 15.9% of GB in the shrub heath categories compared with only 8.6% from field recording of the corresponding areas. The report on the *Comparison of land cover definitions* (Wyatt *et al.* 1994 – Table 13) gives a full explanation of the factors affecting the accuracy of the Land Cover Map.

ii. There are differences in the definition of heathland, particularly with respect to the distinction between upland and lowland categories. The Land Cover Map includes many areas of heathland which are characteristically upland in nature but which have been excluded from the lowland heath mask because they do not occur on soil types characteristic of lowland heathland.

iii. The ITE Land Cover Map and the soils data on which the lowland heath mask are based are not at the same level of resolution. The lowland heath mask does not identify 1 km squares with relatively small areas of heathland because the heathland soils on which they occur are not dominant or subdominant within the 1 km square. In contrast, the ITE Land Cover Map, in theory, identifies all squares with more than 1% heathland.

A1.2.3 Figure A1.1 shows those areas which have more than 10% heathland on the Land Cover Map but which are not covered by the lowland heath mask. It seems unlikely that the explanations given above can fully account for the discrepancies shown in this Figure. In some areas of the country, particularly in the low-lying areas of southern England, the lowland heath mask does not adequately cover all areas of lowland heath.

A1.3 Checks against English Nature records

A1.3.1 English Nature has a database which shows the location of sites containing some lowland heathland. Some of these sites may contain only small pockets of heathland on locally untypical soils and will therefore fall outside the

Table A1.1 Land cover classes from the ITE Land Cover Map in the lowland heath mask compared with land cover in the rest of lowland England

Land cover	Lowland heath mask % cover	Lowland heath mask Total area (km²)	Lowland England (not incl. mask) % cover	Lowland England (not incl. mask) Total area (km²)
Dense shrub heath	1.4	116	0.3	284
Open shrub heath	1.3	111	0.6	673
Heath grass	5.0	423	2.6	2824
Bog	0.3	26	1.0	59
Bracken	1.0		0.4	
Rough grass	2.8		1.5	
Deciduous woodland	11.0		5.8	
Coniferous woodland	5.6		1.0	
Tilled land	27.9		36.9	
Managed grassland	33.3		33.6	
Urban	0.8		2.1	
Suburban	5.8		9.7	
Inland bare	1.2		0.8	
Saltmarsh	1.0		0.3	
Coastal bare	1.0		0.6	
Inland water	0.3		0.3	
Sea/estuary	0.1		1.7	
Unclassified	2.1		1.9	
No. of 1 km squares		*8538*		*107221*

more general definition of lowland heathland landscape areas adopted in this project. The dataset has not been validated and there may be some inaccuracy in the grid references of some sites. The data were collected over an approximately 20-year period up to 1990 and therefore do not necessarily accurately reflect the current heathland status of the sites. This is not important in relation to the comparison with the lowland heath mask because the latter is designed to identify potential areas of heathland.

A1.3.2 The lowland heath mask covers only 1069 (55%) of the 1938 lowland heathland sites registered by English Nature. Most of the sites not covered by the lowland heath mask are scattered throughout England, but there is a particularly poor coverage in areas of Hampshire and Cornwall. In these areas the missing sites occur on 1 km squares with dominant or subdominant soil types which are not specific to lowland heathland, and it was not possible to improve the coverage of the lowland heath mask without greatly increasing its size to cover large areas of England with little or no heathland potential.

A1.4 Conclusions

A1.4.1 The map of lowland heathland areas derived using only soils and land class data has missed many small pockets of heathlands. However, with the exception of coastal heathlands, and areas in the New Forest and Cornwall where there are several mismatches between the ITE Land Cover Map and English Nature's reference database and the lowland heathland map, most areas of existing heathlands have been covered. The lack of resolution provided by using soils data at a 1 km scale was one of the main causes of the discrepancies between the lowland heath mask and known areas of heathland. Within the resources available to this project, there were no alternative datasets which could have improved the accuracy of the map in these problem areas.

A1.4.2 Given the need to include a representative sample of existing and potential heathland areas and the constraint on the overall size of the lowland heath mask, the fit of the mask was judged acceptable for the purposes of this project. The area we have identified for our sampling programme does not cover the whole lowland heath resource in England, but does provide an adequate sampling framework for assessing the current status of the heathland resource in the core heathland areas. The methodology described above is also sufficiently flexible to be adapted to include additional soil types or changed definitions of 'heathlands' and 'lowlands', if necessary for future work with different objectives.

Appendix 2 Tables to accompany Chapter 4 – Ecological characteristics of the lowland heath mask

This Appendix includes Tables that add detail to Chapter 4 and information on the use of quality criteria for site evaluation (Box A2.1).

Box A2.1 The use of quality criteria for site evaluation

The development of the concept of evaluation for sites originated in the post-war years when the Nature Conservancy was set up with the objective of identifying a series of National Nature Reserves. The impetus originally came from the work of Tansley (1939) on British vegetation and was encapsulated in Cmnd 7122. Whilst it was implicit that the sites should form a representative series of the 'best' examples of habitats in Britain, explicit criteria were not defined and other factors such as diversity and variety of species often determined the status of individual sites. In some regions, series were set up explicitly, eg the woodland series of sites set up by R E Hughes (unpubl) on the basis of a combination of geological and climate criteria in north Wales. The necessity to rationalise the number of sites throughout Britain led to the *Nature conservation review*, carried out in the early 1970s but eventually described by Ratcliffe (1977). That document set out the quality criteria that had been used in the selection process but these were largely *post hoc* as the large number of contributors largely worked independently.

In the early 1980s there was much discussion of the necessity for objective criteria, eg the conference at University College London (Rose 1981). Bunce (1981) laid out the necessity of prerequisites of classification to ensure that differences of quality were not inherently due to basic differences between the ecological character of sites. For example, limestone vegetation is usually species-rich whereas acid vegetation is species-poor. More recently, Usher (1991) has also pointed out that the diversification of inherently simple ecological systems represents degradation.

Usher (1986) summarised the work up to that date on evaluation and drew heavily on the work by Margules and Usher (1981). He discussed in detail the criteria laid down by Ratcliffe and showed how they had been used by various studies in different ways. He also showed how the relative weighting attached to the importance of the criteria varied widely between individuals. In this respect, conservation evaluation had paralleled that in the analogous field of landscape evaluation. Liddle (1977) laid out comparable principles and Robinson *et al.* (1976) demonstrated how objective criteria could be used for landscape assessment. The next stage for both topics was that objective criteria were virtually ignored because of the over-riding necessity for speed in the evaluation process. In landscape evaluation a decision on objective criteria could take one or even two orders of magnitude longer than on-the-spot examination, yet the outcome would, to a policy advisor, be identical.

In the case of nature conservation evaluation, the criteria had been laid down but the pressure for site safeguard meant that the majority of sites were evaluated intuitively. Within the voluntary movement this is epitomised by the recent requirement to justify the status of many sites long after they had been identified as of conservation significance.

Although there is negligible recent literature on evaluation techniques in Britain, there has been a continuing programme abroad, especially in Australia. A major meeting on systematic and conservation evaluation was held in South Africa in 1992, where most of the British speakers emphasised the need for speed in the evaluation process because of threats rather than the development of objective criteria. Crowe (1993) summarised these criteria and identified particularly the work by Margules (1989), Pressey and Nicholls (1989), Rebolo and Siegfried (1990) and Williams, Vane-Wright and Humphries (1993) in that 'together their papers embodied principles, criteria and analytical methods necessary for scientific evaluation'. They agreed that the limit of analysis should be the site and that accurate species and abundance data for the sites under consideration should be obtained. Whilst this is never completely possible, surrogate measures could be used which allow the prediction of presence or absence of individual species.

This strategy had been followed in the threatened habitats project, with measures of vegetation being used as the taxon for evaluation, partly because of the ease of consistent recording and partly because of its ready correlation with other groups. Crowe (1993) concluded that ecologists did not appreciate the severity of the conservation crisis and that short cuts were essential to identify species in crisis. Whilst this conclusion may be true on a world scale, the necessity in the present project is to develop objective measures which can determine explicitly the effects of designation in statistical terms. In this respect the methodology employed in the current project represents a combination of the criteria laid down by Margules (1989) and Pressey and Nicholls (1989), together with the vegetation survey principles of Austin and Heyligers (1989). It has also been decided as a matter of principle to rank the various scores separately and not to add them together to achieve a final 'score' – statistical considerations preclude such additions as the scale of the various measures is not known. Further, as Pielou (1991) has emphasised, and Crowe (1993) has subsequently reinforced, simple measures are more readily understood.

Table A2.1 Lowland heath landscapes – estimates of land cover types, based on descriptions of land cover at 25 grid points, in each survey square

Land cover categories for survey strata	Designated Arable Area (ha)	SE	%	Designated Pastural Area (ha)	SE	%	Non-designated Arable Area (ha)	SE	%	Non-designated Pastural Area (ha)	SE	%
Heathland	16648	7714	6.0	16145	4239	8.1	8379	5778	4.6	2868	1918	1.5
Bog	2006	2006	0.7	2864	1209	1.4	0	0	0.0	43	43	0.0
Moorland grass	0	0	0.0	679	361	0.3	0	0	0.0	129	94	0.1
Acid grass/bracken	1668	998	0.6	9461	5652	4.7	1571	826	0.9	1409	1197	0.7
Grassland	42566	10823	15.4	88029	13577	44.0	51111	8186	27.8	60441	14034	31.2
Crops	75408	17908	27.3	21866	8426	10.9	50886	11634	27.7	86045	15891	44.4
Unmanaged	5595	1846	2.0	2367	1457	1.2	4917	1795	2.7	1832	1287	0.9
Woodland/scrub	86038	13181	31.2	26904	4557	13.4	36888	5532	20.1	21956	4860	11.3
Structures/curtilage/recreation	40370	10017	14.6	24086	6867	12.0	28136	6411	15.3	15485	5426	8.0
Other	5501	1170	2.0	7789	4043	3.9	1912	744	1.0	3792	1292	2.0
Total	*275800*		*100.0*	*200200*		*100.0*	*183800*		*100.0*	*194000*		*100.0*

Land cover categories for combined strata	Designated Area (ha)	SE	%	Non-designated Area (ha)	SE	%	Arable Area (ha)	SE	%	Pastural Area (ha)	SE	%	All Area (ha)	SE	%
Heathland	32793	8802	6.9	11247	6088	3.0	25027	9638	5.4	19013	4652	4.8	44040	10525	5.2
Bog	4870	2342	1.0	43	43	0.0	2006	2006	0.4	2907	1210	0.7	4913	2314	0.6
Moorland grass	679	361	0.1	129	94	0.0	0	0	0.0	808	373	0.2	808	372	0.1
Acid grass/bracken	11129	5739	2.3	2980	1455	0.8	3239	1295	0.7	10870	5777	2.8	14109	4922	1.7
Grassland	130595	17363	27.4	111552	16247	29.5	93677	13570	20.4	148470	19527	37.7	242147	22390	28.4
Crops	97274	19791	20.4	136931	19694	36.2	126294	21355	27.5	107911	17987	27.4	234205	27463	27.4
Unmanaged	7962	2351	1.7	6749	2208	1.8	10512	2575	2.3	4199	1944	1.1	14711	3107	1.7
Woodland/scrub	112942	13946	23.7	58844	7364	15.6	122926	14295	26.7	48860	6662	12.4	171786	15587	20.1
Structures/curtilage/recreation	64456	12144	13.5	43621	8399	11.5	68506	11893	14.9	39571	8752	10.0	108077	14187	12.7
Other	13290	4209	2.8	5704	1491	1.5	7413	1386	1.6	11581	4245	2.9	19004	3764	2.2
Total	*476000*		*100.0*	*377800*		*100.0*	*459600*		*100.0*	*394200*		*100.0*	*853800*		*100.0*

Table A2.2 Lowland heath: proportion of boundary types by strata based on nearest field boundary (within 100 m) of each grid point

	Designated		Non-designated		Total		Total		
					Desig-	Non-			
	Arable	Pastural	Arable	Pastural	nated	designated	Arable	Pastural	
Boundaries	%	%	%	%	%	%	%	%	%
% of points without boundary	50	35	31	6	43	18	42	21	32
% of points with boundary	50	65	69	94	57	82	58	79	68
% of points with a boundary:									
Bank	4	7	2	2	6	2	3	4	4
Ditch only	4	11	8	5	7	6	6	7	7
Fence	65	44	54	20	54	34	59	30	43
Fence/bank	1	4	1	+	2	1	1	2	2
Hedge	20	10	16	31	15	25	18	22	20
Hedge/bank	1	10	1	12	5	8	1	11	6
Hedge/fence	6	8	16	15	7	16	11	12	12
Hedge/fence/bank		6	1	11	3	7	+	9	5
Wall		1	+	1	+	1	+	1	1
Wall/fence	1	1	+	2	1	1	+	1	1
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Table A2.3 Classification of quadrats from the lowland heath landscape (using TWINSPAN). Numbers in plain type give the numbers of quadrats at each division. Bold letters in square brackets correspond to the plot class. Numbers in italics indicate maximum score for left hand-side of division

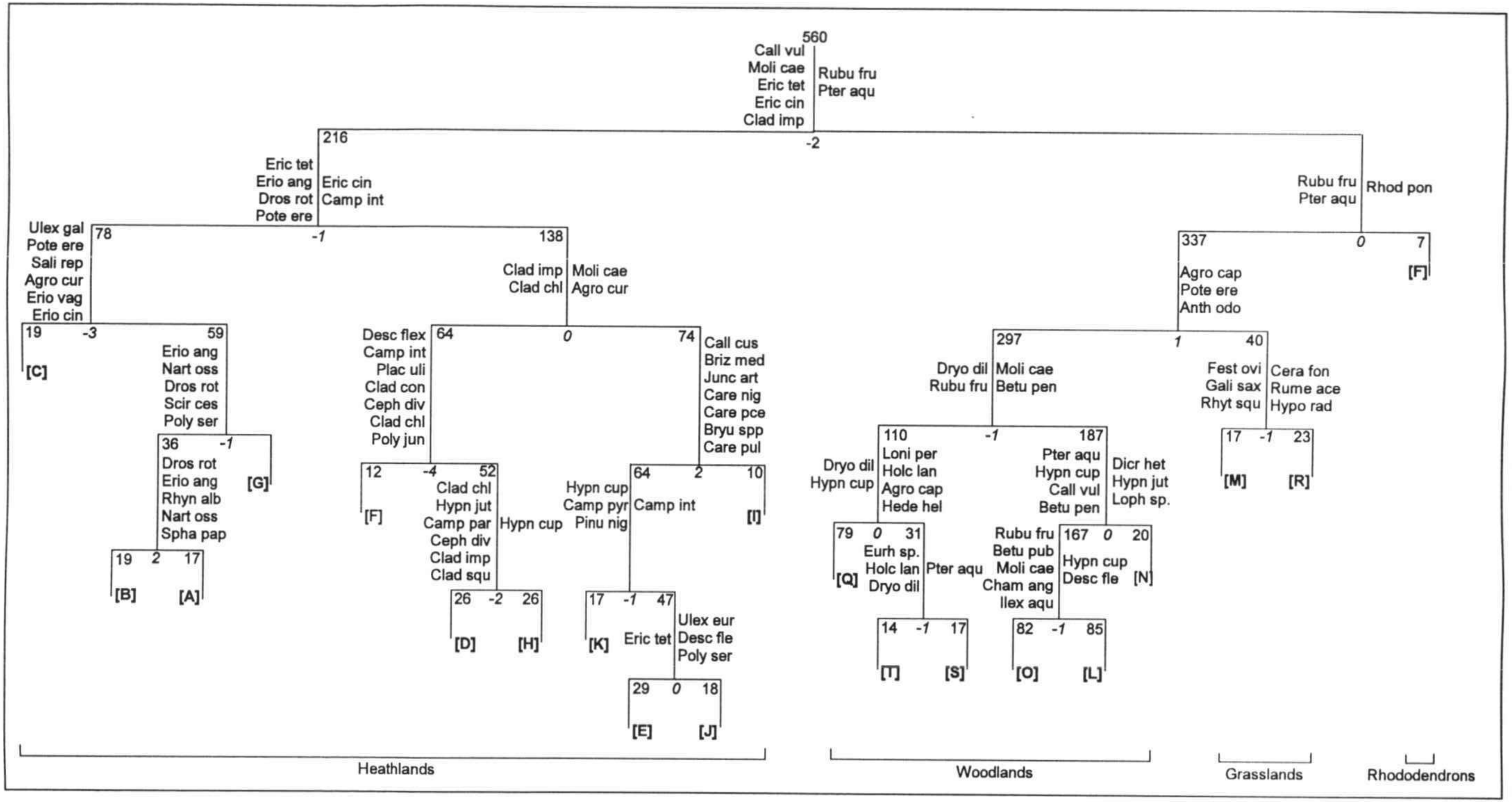


Table A2.4 Plot classes derived from multivariate analysis of species composition. from quadrats recorded in lowland heath landscapes

Plot class	Name	No. of plots	Main region	Constants	Preferentials	Dominants
PCA	Bog	17	Hants Dorset	*Drosera rotundifolia* *Eriophorum angustifolium* *Molinea caerulea* *Erica tetralix* *Narthecium ossifragum*	*Drosera rotundifolia* *Eriophorum angustifolium* *Narthecium ossifragum* *Erica tetralix*	*Sphagnum* sp *Molinea caerulea* *Erica tetralix*
PCB	Wet heath	19	Hants Dorset	*Calluna vulgaris* *Erica tetralix* *Molinea caerulea* *Trichophorum caespitosum*	*Erica tetralix* *Trichophorum caespitosum*	*Erica tetralix* *Molinea caerulea* *Calluna vulgaris* *Carex panicea*
PCC	Ultra-basic wet heath	19	Cornwall Devon Dorset	*Erica tetralix* *Molinea caerulea* *Potentilla erecta*	*Potentilla erecta* *Erica tetralix* *Ulex gallii*	*Molinea caerulea* *Salix repens* *Erica vagans* *Erica tetralix* *Calluna vulgaris* *Agrostis curtisii*
PCD	Very acid heath	26	Hants/Dorset Cumbria	*Calluna vulgaris* *Cladonia impexa*	*Cladonia impexa*	*Calluna vulgaris*
PCE	Southern damp heath	29	Hants Dorset	*Molinea caerulea* *Calluna vulgaris*		*Calluna vulgaris* *Molinea caerulea* *Erica tetralix*
PCF	Dry heath	12	Cumbria Hants Dorset	*Calluna vulgaris* *Cladonia impexa* *Cladonia chlorophaea* *Deschampsia flexuosa*	*Campylopus introflexus* *Cladonia chlorophaea*	*Calluna vulgaris* *Deschampsia flexuosa*
PCG	Damp heath (incl. plantation)	23	Dorset Hants	*Molinea caerulea* *Erica tetralix* *Calluna vulgaris*		*Molinea caerulea* *Calluna vulgaris* *Erica tetralix*
PCH	Dry heath often planted	26	Dorset Hants	*Calluna vulgaris*		*Calluna vulgaris* *Hypnum cupressiforme*
PCI	Grassy heath	10	Hants	*Molinea caerulea* *Calluna vulgaris* *Ulex europaeus*		*Molinea caerulea* *Agrostis canina* *Agrostis curtisii* *Calluna vulgaris*
PCJ	Southern dry heath	18	Hants Dorset	*Calluna vulgaris* *Molinea caerulea* *Erica cinerea* *Agrostis curtisii*		*Calluna vulgaris* *Ulex europaeus* *Agrostis curtisii* *Erica cinerea*
PCK	Plantation over heath	17	Dorset	*Hypnum cupressiforme* *Molinea caerulea* *Calluna vulgaris*		*Molinea caerulea* *Hypnum cupressiforme*
PCL	Plantation over bracken/heath	85	Hants Dorset Notts	*Pteridium aquifolium* *Hypnum cupressiforme* *Deschampsia flexuosa*		*Pteridium aquifolium* *Deschampsia flexuosa*
PCM	Damp acid grassland	17	Devon Somerset Hants	*Agrostis capillaris* *Galium saxatile* *Potentilla erecta* *Anthoxanthum odoratum*	*Agrostis capillaris*	*Agrostis capillaris* *Pteridium aquifolium*
PCN	Southern acid plant-ation (dense)	20	Berks	*Pinus sylvestris* *Dicranella heteromalla* *Hypnum jutlandicum*		*Pinus sylvestris* *Hypnum jutlandicum*
PCO	Plantation often open	82	Hants, Dorset Suffolk Surrey	*Molinea caerulea* *Rubus fruticosus* *Pteridium aquifolium*		*Pteridium aquifolium* *Molinea caerulea* *Rubus fruticosus*
PCP	Dense	7	Dorset, Hants	*Rhododendron ponticum*	*Rhododendron ponticum*	*Rhododendron ponticum*
PCQ	Midland plantation over bracken	79	Staffs Notts Linc	*Rubus fruticosus* *Pteridium aquifolium* *Dryopteris dilatatus* *Deschampsia flexuosa*		*Pteridium aquifolium* *Deschampsia flexuosa* *Rubus fruticosus*
PCR	Dry mildly acid grassland	23	Dorset, Hants Suffolk	*Agrostis capillaris* *Rumex acetocella*	*Agrostis capillaris*	*Agrostis capillaris* *Holcus lanatus*
PCS	Plantation over grass/ bracken	17	Widespread	*Rubus fruticosusicosus* *Pteridium aquifolium*		*Pteridium aquifolium*
PCT	Woodland over bramble	14	Widespread	*Eurhynchium praelongens* *Rubus fruticosus* *Holcus lanatus* *Lonicera pericylamen* *Dryopteris dilatatus*	*Eurhynchium praelongens*	*Holcus lanatus* *Rubus fruticosus*

Table A2.5 Mean percentage cover per quadrat of species in each habitat indicator type

Strata	Lowland heath specialist	Lowland heath generalist	Acid grassland	Neutral grassland	Woodland	Weeds & aliens
Designated arable	2	39	38	4	19	1
Designated pastural	7	64	28	3	12	1
Non-designated arable	1	17	49	3	27	1
Non-designated pastural	3	35	38	2	21	0
Combined designated	5	56	31	3	14	1
Combined non-designated	2	28	42	2	24	1
Combined arable	1	30	43	4	23	1
Combined pastural	5	53	31	2	15	1
All	*4*	*45*	*35*	*3*	*18*	*1*

Table A2.6 Mean number of plots per square, in each plot class

Plot classes	Designated Arable	Designated Pastural	Non-designated Arable	Non-designated Pastural	Designated	Non-desig	Arable	Pastural	All
A Bog	0.07	0.20	0.00	0.01	0.13	0.00	0.04	0.10	0.07
B Wet heath	0.11	0.21	0.00	0.01	0.15	0.00	0.07	0.10	0.09
C Ultra-basic wet heath	0.04	0.28	0.00	0.00	0.14	0.00	0.02	0.14	0.08
D Very acid heath	0.00	0.27	0.00	0.04	0.11	0.02	0.00	0.16	0.07
E Southern damp heath	0.26	0.31	0.00	0.00	0.28	0.00	0.16	0.16	0.16
F Dry heath	0.11	0.01	0.07	0.11	0.07	0.09	0.10	0.06	0.08
I Grassy heath	0.04	0.11	0.00	0.01	0.07	0.00	0.02	0.06	0.04
J Southern dry heath	0.18	0.10	0.28	0.01	0.15	0.14	0.22	0.06	0.15
'Core heathland'	0.81	1.49	0.35	0.19	1.10	0.25	0.63	0.84	0.74
G Damp heath (incl. plantation)	0.19	0.21	0.07	0.02	0.20	0.05	0.14	0.12	0.13
H Dry heath often planted	0.15	0.14	0.07	0.06	0.15	0.07	0.12	0.10	0.11
K Plantation over heath	0.04	0.01	0.00	0.08	0.03	0.04	0.02	0.05	0.03
L Plantation over bracken/heath	0.95	0.28	0.77	0.22	0.66	0.49	0.88	0.25	0.59
'Modified heathland'	1.33	0.64	0.91	0.38	1.04	0.65	1.16	0.52	0.86
M Damp acid grassland	0.00	0.54	0.00	0.00	0.23	0.00	0.00	0.28	0.13
N Southern acid plantation (dense)	0.08	0.06	0.01	0.07	0.07	0.04	0.05	0.06	0.06
O Plantation often open	0.92	0.47	0.42	0.36	0.73	0.39	0.72	0.41	0.58
P Dense rhododendron	0.07	0.01	0.00	0.02	0.05	0.01	0.04	0.02	0.03
Q Midland plantation over bracken	0.48	0.39	0.39	0.13	0.44	0.25	0.44	0.26	0.36
R Dry mildly acid grassland	0.16	0.27	0.07	0.02	0.21	0.04	0.12	0.15	0.13
S Plantation over grass/bracken	0.08	0.10	0.18	0.02	0.09	0.10	0.12	0.06	0.09
T Woodland over bramble	0.19	0.13	0.01	0.01	0.17	0.01	0.12	0.07	0.10
'Grassland/woodland'	1.98	1.97	1.08	0.63	1.99	0.84	1.61	1.31	1.48
All	*4.12*	*4.10*	*2.34*	*1.20*	*4.12*	*1.75*	*3.41*	*2.67*	*3.07*

This Table gives the mean number of plots per square, including those squares where no plots were recorded; hence the figures are low, but comparable across strata. The means for combined strata (eg subtotal for designated strata) are weighted by stratum size

Table A2.7 Mean number of species per plot in each species group

Species group	Designated Arable	Designated Pastural	Non-designated Arable	Non-designated Pastural	Combined Des	Combined Non-des	Combined Arable	Combined Pastural	All
B1 Bog species	0.36	0.74	0.02	0.15	0.62	0.10	0.21	0.52	0.42
B2 Wet heath species	0.21	0.59	0.01	0.09	0.47	0.06	0.12	0.40	0.30
B3 Moss/lichen heath species	0.52	1.09	0.41	1.22	0.90	0.91	0.47	1.14	0.89
A4 Moss/lichen heath species	0.46	0.72	0.30	0.99	0.64	0.73	0.39	0.82	0.65
A5 Vascular heath species	1.58	2.60	1.15	1.82	2.27	1.56	1.39	2.31	1.91
B6 Damp acid woodland species	0.27	0.48	0.43	0.76	0.41	0.64	0.34	0.58	0.47
A7 Forest tree species	0.79	0.27	1.02	0.77	0.44	0.87	0.89	0.45	0.48
B8 Acid grassland species	0.26	0.54	0.15	0.18	0.45	0.17	0.21	0.40	0.33
A9 Acid grassland species	0.31	0.57	0.34	0.21	0.48	0.26	0.32	0.44	0.36
B10 Mildly acid grassland species	0.36	0.82	0.38	0.35	0.67	0.36	0.37	0.64	0.53
B11 Acid woodland species	0.52	0.41	0.98	0.74	0.45	0.83	0.72	0.53	0.47
A12 Acid woodland species	1.37	0.78	2.31	0.96	0.89	0.97	1.48	1.79	0.84
B13 Mildly acid woodland species	0.45	0.33	0.52	0.68	0.37	0.62	0.48	0.46	0.42

Appendix 3 Technical appendix to Chapter 5 – Historical characteristics of the lowland heath mask

This Appendix includes:

- details of the work programme associated with characterising the lowland heath mask (A3.1)
- commentary on available data (A3.2)
- Tables which provide further, detailed results from work on historical aspects of the lowland heath mask (A3.3), not given in Chapter 5.

A3.1 Detailed work programme

A3.1.1 At the outset, a work programme was set out in a project design but this was later modified to reflect the nature of the data gathered. The resulting methodology is summarised below.

1. Review of literature and consultations with ITE
2. Survey of historic features
   - 2.1 Collation of existing data from ITE
     List of km squares for the lowland heath landscape in paper and digital form
     List of aerial photographs (APs) available at ITE
     Map overlay for each square
   - 2.2 Collation of data from County Sites and Monuments Records (SMRs) and National Archaeological Record (NAR)
     Mailing to SMRs and NAR, requesting map overlay and data printout for each square
     Data collation and map interpretation
     Computer entry of collated SMR, NAR and ITE data
     Collation of additional data on management regimes from English Heritage (EH) Register of Scheduled Monuments (RSM)
     Computer entry of EH RSM data
   - 2.3 AP work
     Examination of subsample of squares defined by AP availability at ITE
     Computer entry of AP data
   - 2.4 Data analysis
     Correlation of site type/period/form, the Royal Commission on the Historical Monuments of England (RCHME) classes and designations within the lowland heath landscape
     Quantification of management history data
3. Assessment of the effectiveness of current designations in protecting historic features within the lowland heath landscape type
4. Predictive models of the effect of environmental and policy changes – effect on historic features, including an assessment of the impact of archaeological management plans
5. Recommendations for refinement to policy instruments – to enhance protection of historic features. Based on results of 3 and 4. Formulation of proposals to minimise threats to archaeology.

A3.1.2 Physical examination of the sample squares was carried out by ITE field surveyors during the course of the ecological fieldwork between 1990 and 1993. The major part of the work was contained in stage 2, essentially a data-gathering process involving consultation with archaeological curators, together with limited AP analysis and map interpretation. This work was carried out between July 1993 and April 1994. As expected and as described below, the available data were found to be inadequate to carry out items 3–5.

A3.2 Assessment of archaeological data

Data sources

A3.2.1 The extended national archaeological database in England is composed of several distinct databases (see RCHME 1993). SMRs provide regionally co-ordinated summaries of recorded archaeological sites. The core of these records is a computerised index. The NMR is maintained by RCHME as a permanent, publicly accessible source of information in three main parts: the National Archaeological Record (NAR), the National Buildings Record (NBR), and the National Library of Air Photographs (NLAP). Together these three sections are responsible for creating a national database of information about sites and buildings of historic and architectural interest. Historically, the NAR developed in parallel with county SMRs, and it is this subset of the NMR which has been consulted.

A3.2.2 In theory, data exchange between SMRs and the NAR should enable consultation with this single central database to provide a full indication of the recorded archaeological content of each square. In practice, such exchange is in its early days and is far from standard such that, in general, the SMRs hold a great deal of information not yet indexed by the NAR. In addition, the NAR holds additional datasets not on the county SMRs. Hence, both databases were consulted. In addition, the RSM is maintained by English Heritage as a management tool for Scheduled Ancient Monuments and holds additional data on the condition of these monuments.

A3.2.3 Information on listed buildings is not yet in computerised form for the whole country. Some SMRs have computerised the lists at least in part. In 1994, the RCHME commenced central computerisation of these lists on to the NBR. Hence, for this project, the incidence of listed buildings on the project database will not reflect reality, rather the policy of individual SMRs over whether to include or exclude entries from the lists of historic buildings and, if included, to what extent this listing has been implemented.

Database structure

A3.2.4 Data compiled from the above sources were used to create a database of archaeological sites identified for the ITE sample squares. The structure of this database is outlined in Table A3.1. The information collated divides into three main groups:

- identifiers and location;
- archaeological classification; and
- management information.

A3.2.5 Identifiers and location information is routinely given in archaeological databases and was readily collated.

A3.2.6 Archaeological classification is represented by standard RCHME classes, together with archaeological 'site types'. The specification of 'site types' is supposedly standardised. In practice, there is considerable variation between SMRs. A rationalisation process was therefore undertaken to check site type against the RCHME thesaurus and modify it accordingly. However, as the data were compiled, it became apparent that the variety of site type entries was too great to be of use in the analysis process, and a further stage of simplification was carried out. For example, a wide variety of prehistoric flint implements have been found whose specific identification is of no relevance to this project. The variety of entries covering these artefacts was therefore replaced by the single entry 'flint'.

A3.2.7 The form entry is important as it provides the first indication of the condition of a monument. Very broadly, any archaeological site slowly decays from its original 'intact' state. Rates of decay vary considerably and some form of equilibrium may be achieved at any point. Once again, SMR entries are far from standard and it was necessary to impose an appropriate rationalisation as shown in Table A3.3 (based on Trueman & Williams 1993, 13). The interpretation of SMR/NMR entries which was necessary to enter this item during the course of the project made it apparent that some simplification of this system was required if any analysis of this entry were to be made. To this end the 'form group' field was added. This is structured to reflect decay from standing structures through to totally removed sites. (Note that 'features' are intended to be sites whose original form was an earthwork and which survives largely unaltered, a category which is very difficult to apply with many sites, and is probably best considered as part of 'earthworks'.)

A3.2.8 Management information was derived directly from SMR and NMR entries. A separate database of sample squares was supplied by ITE. This included designation data and in the analysis process was related to the archaeological database.

Nature and quality of archaeological data

A3.2.9 Archaeological data were compiled for 752 archaeological sites in 89 sample squares drawn from 22 counties. A breakdown by county (Table A3.5) shows considerable variation in the mean density of identified monuments. This variation is as likely to reflect the difference in details in individual SMRs as much as any real variation in the archaeological resource.

A3.2.10 One factor which is clear in the biases of the compiled data is the effect of the extent and type of site identification work undertaken by individual SMRs. For example, the importance of sites from the period of England's industrial revolution has only recently been accepted by SMRs and the NMR (following the RCHME's decision in 1990 to move the NAR entry cut-off date from 1714 to 1945). In the process of SMR/NMR enhancement that is underway, some counties are well ahead (eg Cornwall), whilst others are not (eg Shropshire).

A3.2.11 A further clear factor is the presence of particularly well-known and thoroughly investigated sites. For example, the high Suffolk figure of 115 sites is boosted by 40 entries for the kilometre square containing Sutton Hoo. This variation in the data between counties precludes any attempt to examine genuine regional variations of the archaeological resource.

A3.2.12 New sites (269) identified through ITE fieldwork, AP work and map analysis constitute 35.6% of the total number, representing an increase of 55.7% on the SMR/NMR entries (483). Reflecting the dependence on recent edition OS maps, the majority of these new sites almost certainly originated in the Post Medieval and Modern periods (although technically in most cases they are, and have been entered on the database as, 'unknown'). Site types are dominated by farms (numbering 64) as the single largest group, with a range of industrial (34) and transport (29) sites also forming a major block. These site types were already represented on archaeological registers (although in notably smaller numbers). A third major group, wood banks (31), was identified by ITE field surveyors and is not represented on the registers for this dataset.

A3.2.13 By contrast, few sites were added by the identification process to the already well-represented site types of early periods. Examples include prehistoric barrows (55 on SMRs/NMR, no new sites) and find sites (eg 57 flint sites, 42 pottery sites, no new sites). This in part reflects the very limited fieldwork (carried out by non-archaeologists), together with the limited availability of appropriate AP cover. It probably also reflects the much greater attention previously given by archaeologists to Prehistoric, Roman and Medieval archaeology, over Post Medieval and Modern archaeology.

A3.2.14 It is also apparent from the compiled data that the mean density of monuments at 8.4 sites per km^2 is notably higher than the national figure of 3–5 per km^2 quoted for the Monuments at Risk Survey (MARS) project (Darvill, Fulton & Bell 1993, 11). However, this latter figure is based on NMR data and, as Table A3.7 makes clear, NMR figures for site numbers are consistently low in the lowland heath landscape when compared to SMR entries (by a factor of between 1.5 and 3).

A3.2.15 Although this project is only dealing with a specific landscape type, these data suggest that the national mean density of monuments on existing registers is considerably higher than previously supposed. However, the number and range of new sites identified strongly suggest that the data held by SMRs and the NMR fall well short of the total archaeological resource. Establishing a figure for this shortfall is not possible with the data presented here because of the severe limitations on the identification process used. Further work to establish the specific nature and size of SMR/NMR shortfalls for different periods would require an appropriate programme of combined mapwork, AP analysis and fieldwork.

A3.3 Tables which provide further, detailed results from work on historical aspects of the lowland heath mask, not given in Chapter 5

Table A3.1 Archaeological data structure

	Field	Type	Notes
Identifiers and location	ITE no	char	As ITE
	Km grid ref	char	In one field, eg SD7534
	Qtr sht	char	In one field, eg SD73SW
	County	char	Abbreviated name
	Source	char	SMR/NMR/RSM/ITE/AP
	SMR no	char	As SMR
	Map id	char	As SMR
	NMR no	char	As NMR
	NG code	char	Eg SD
	NG east	num	Eg 7521
	NG north	num	Eg 3412
Archaeological classification	Site type	char	As SMR if confirmed by RCHME thesaurus. Enter separate records for different periods on same site
	Period	char	General period only, codify as Box 2
	Form	char	Codify as Box 3
	Formgroup	char	Codify as Box 3
	RCHME class	char	As RCHME thesaurus
Management information	Status	char	As SMR/NMR
	SAM	char	As SMR/NMR
	Land status	char	As SMR/NMR
	Area status	char	As SMR/NMR
	Condition	memo	Free text

Table A3.2 RCHME codes for period

Code	Period	Dates
PR	Prehistoric	PA–IA
PA	Palaeolithic	To 8000 BC
ME	Mesolithic	8000–3800 BC
NE	Neolithic	3600–2500 BC
BA	Bronze Age	2500–700 BC
IA	Iron Age	700 BC–43 AD
RO	Roman	43–410 AD
EM	Early Medieval	410–1066 AD
MD	Medieval	1066–1540 AD
PM	Post Medieval	1540–1901 AD
MO	Modern	1901–present
UN	Unknown	

Table A3.3 Form entry

Type	Term	Form code	Form group
Intact	Roofed building	ROOF	STRUCTURE
	Structure	STRU	
	Machinery	MACH	
	Linear feature	LIN	FEATURE
	Other feature	FEA	
	Underground feature	UFEA	UNDERGROUND
Ruinous	Roofed ruin	RRUIN	RUIN
	Ruined building	RUIN	
	Ruined structure	RSTRU	
	Foundations	FOUN	
	Earthworks	EARTH	EARTHWORK
Buried remains	Crop mark	CROP	CROP/SOIL
	Soil mark	SOIL	
	Aerial photograph	AP	AP
	Geophysical survey	GEO	Not used
	Finds spot	FIND	FIND
Unlocated remains	Documentary	DOC	DOC/ORAL
	Oral	ORAL	
Non-extant	Excavated	EXC	EXC/REM
	Removed	REM	

Table A3.4 Data source totals for lowland heath

County	All sites SMR/NMR	All sites New	Heath SMR/NMR	Heath New
Beds	13	7	13	7
Berks	16	22	16	22
Bucks	14	17		
Cambs	4	4		
Cleveland	2	4		
Cornwall	213	36	47	12
Cumbria	53	32	3	
Derbyshire	5	8		
Devon	141	29	63	22
Dorset	44	46	36	31
Durham	6	7		
Essex	9	12		
E Sussex	12	18	3	6
Gloucester	50	15	20	5
Hants	51	46	46	40
Herts	2			
Humberside	28	14		
Isle of Wight	58	27		
Kent	36	16		
Lancs	18	15		
Lincoln	3	2	3	2
Norfolk	110	47	61	32
Northants	14			
Northumberland	16	19		
Nottingham	2	5	2	5
N Yorks	65	40	6	12
Oxford	9	2		
Salop	3	16	1	3
Somerset	16	5	6	2
Staffs	20	16	12	11
Suffolk	135	21	115	11
Surrey	14	32	14	32
Tyne & Wear	8	1		
Warwick	4	5	4	5
Wiltshire	29	6		
W Midlands		4		4
Worcester	1	1	1	1
W Sussex	28	8	11	4
York Dales	77	11		
Totals	*1329*	*616*	*483*	*269*
	1945		*752*	

Table A3.5 Total number of sites and average per square km, by county for full dataset

County	No. of km squares	SMR/ NMR sites	Enhanced site totals	SMR/ NMR sites km^{-2}	Enhanced sites km^{-2}
Bedfordshire	2	13	20	6.5	10.0
Berkshire	5	16	38	3.2	7.6
Buckinghamshire	4	14	31	3.5	7.8
Cambridgeshire	1	4	8	4.0	8.0
Cleveland	2	2	6	1.0	3.0
Cornwall	13	213	249	16.4	19.2
Cumbria	23	53	85	2.3	3.7
Derbyshire	2	5	13	2.5	6.5
Devon	17	141	170	8.3	10.0
Dorset	12	44	90	3.7	7.5
Durham	4	6	13	1.5	3.3
Essex	7	9	21	1.3	3.0
East Sussex	3	12	30	4.0	10.0
Gloucestershire	6	50	65	8.3	10.8
Hampshire	17	51	97	3.0	5.7
Hertfordshire	1	2	2	2.0	2.0
Humberside	7	28	42	4.0	6.0
Isle of Wight	5	58	85	11.6	17.0
Kent	6	36	52	6.0	8.7
Lancashire	4	18	33	4.5	8.3
Lincolnshire	2	3	5	1.5	2.5
Norfolk	15	110	157	7.3	10.5
Northamptonshire	1	14	14	14	14.0
Northumberland	11	16	35	1.5	3.2
Nottinghamshire	4	2	7	0.5	1.8
North Yorkshire	10	65	105	6.5	10.5
Oxfordshire	2	9	11	4.5	5.5
Shropshire	4	3	19	0.8	4.8
Somerset	3	16	21	5.3	7.0
Staffordshire	6	20	36	3.3	6.0
Suffolk	8	135	156	16.9	19.5
Surrey	5	14	46	2.8	9.2
Tyne & Wear	1	8	9	8.0	9.0
Warwickshire	1	4	9	4.0	9.0
Wiltshire	2	29	35	14.5	17.5
West Midlands	1	0	4	0	4.0
Worcestershire	1	1	2	1.0	2.0
West Sussex	3	28	36	9.3	12.0
Yorkshire Dales	6	77	88	12.8	14.7
Totals	*224*	*1329*	*1945*	*5.9*	*8.7*

Table A3.6 Data source by period

Period	SMR/NMR sites	New sites
A-PR	111	
B-PA	10	
C-ME	32	7
D-NE	36	
E-BA	109	5
F-IA	63	
G-RO	107	3
H-EM	32	
I-MD	151	3
J-PM	384	94
K-MO	18	6
UN	276	498
Totals	*1329*	*616*

Table A3.7 Number of sites and number of sites per square

Data source	Lowland heath 89 squares Sites	km^{-2}
SMR only	407	4.6
NMR only	207	2.3
SMR/NMR	483	5.4
New survey	269	3.0
Combined sources	752	8.4

Table A3.8 Quantity of features – site types by period for lowland heath (showing site types occurring more than once in the dataset)

RCHME class	Site type	Period	No
Agriculture and subsistence	Agricultural building	J-PM	5
		UN	2
	Farm	I-MD	3
		J-PM	6
		UN	66
	Field system	E-BA	2
		I-MD	4
		UN	4
	Nursery garden	UN	2
	Rabbit warren	UN	2
	Wood bank	UN	31
Civil	Police station	J-PM	3
	Post Office	J-PM	4
	School	UN	3
Commercial	Inn	UN	5
Defence	Castle	I-MD	2
	Rifle range	UN	3
Domestic	Great house	UN	4
	House	F-IA	2
		I-MD	4
		J-PM	10
		UN	30
	Hut	A-PR	7
	Lodge	UN	9
	Round	F-IA	2
	Settlement	I-MD	10
Garden and parks	Park	J-PM	3
Industrial	Brickworks	J-PM	2
	Chalk pit	UN	3
	Clay pit	J-PM	2
	Clay pit	UN	7
	Coal mine	J-PM	5
	Forge	J-PM	3
	Gravel pit	UN	2
	Hydraulic ram	J-PM	3
	Lime kiln	J-PM	3
	Mill	UN	3
	Mill pond	UN	5
	Mine	UN	2
	Mine shaft	J-PM	2
	Pit	UN	4
	Quarry	J-PM	4
		UN	10
	Sand pit	UN	5
	Water mill	J-PM	2
	Windmill	J-PM	4
	Works	UN	3

RCHME class	Site type	Period	No
Object	Axe	C-ME	2
		D-NE	2
		E-BA	6
	Coin	F-IA	3
		G-RO	5
	Flint	A-PR	10
		B-PA	4
		C-ME	17
		D-NE	20
		E-BA	6
	Pottery	A-PR	9
		E-BA	5
		F-IA	5
		G-RO	13
		I-MD	7
	Tile	G-RO	2
	Waster	G-RO	2
Religious, ritual and funerary	Barrow	A-PR	4
		E-BA	33
		H-EM	4
		UN	14
	Burial	H-EM	2
	Burial cairn	A-PR	2
		E-BA	2
	Church	I-MD	7
		UN	4
	Cross	I-MD	5
	Cup marked stone	F-IA	2
	Human remains	UN	2
	Rectory	UN	2
Transport	Boat house	UN	2
	Ford	J-PM	2
	Railway	J-PM	12
	Railway bridge	J-PM	6
	Railway station	J-PM	5
	Road	G-RO	7
		J-PM	2
		UN	2
	Road bridge	UN	7
	Tramway	J-PM	2
Unassigned	Bank	UN	8
	Boundary	UN	4
	Ditch	UN	3
	Earthwork	J-PM	2
		UN	7
	Enclosure	A-PR	5
		UN	5
	Mound	UN	2
	Site	UN	5
	Stone	UN	2
Water and drainage	Ford	UN	2
	Pond	UN	11
	Pump house	UN	2

Appendix 4 Technical appendix to Chapter 7 – Predicting changes in lowland heathland vegetation

This Appendix includes:
- details of the TRISTAR model
- figures showing the effects of different change scenarios on vegetation within the lowland heath mask.

A4.1 Introduction

A4.1.1 The UCPE contribution to the threatened habitats project involves taking vegetational survey data, provided for the selected habitats by ITE, and processing these data in three distinct phases by means of the TRISTAR2 model. After the final phase, the outputs of the modelling are examined and interpreted by UCPE. Each phase in this process will now be described separately, with illustrations given at intervals to provide a worked example.

A4.2 Phase I – allocation of functional types

A4.2.1 The initial steady-state vegetation is specified by ITE in the form of a list of abundances of species in each of many survey samples or records. An example of such data appears in Figure A. The record labelled A1-A is the first in the series and contains 12 species, *Agrostis curtisii* to *Ulex europaeus* inclusive. Each vegetation record arrives at UCPE bearing a classification according to both of two sets of criteria:

- the designated status, if any, of the site from which the record was taken, and
- the plant community type into which the vegetation of the quadrat falls.

The basis for these two classifications is the ITE TWINSPAN analysis which is described elsewhere in this Report.

A4.2.2 For each vegetation record, one of 19 functional types is then allocated to each of the component species using information from UCPE databases. The system used, the C-S-R classification of functional types (Grime 1974, 1979; Grime Hodgson & Hunt 1988), has been explained in moderate detail by Hunt *et al.* (1991). Briefly, it recognises two external groups of factors, both of which are antagonistic to plant growth. The first group is called *stress* and consists of factors which place prior restrictions on plant production, such as shortages of light, water, carbon dioxide, mineral nutrients, or chronically non-optimal temperatures. The second group, called *disturbance*, causes the partial or total destruction of plant biomass after it has been formed, and includes management factors such as grazing, trampling, mowing and ploughing, and also phenomena such as wind damage, frosting, droughting, soil erosion, acutely non-optimal temperatures and fire.

A4.2.3 When the four permutations of high and low stress against high and low disturbance are examined (Figure B), a different primary strategy type emerges in association with each of the three viable contingencies: *competitors* in the case of minimum stress and minimum disturbance, *stress-tolerators* in the case of maximum stress and minimum disturbance, and *ruderals* in the case of minimum stress and maximum disturbance. The initials of these three 'primary' strategists give the C-S-R model its name. The fourth contingency, that of maximum stress and maximum disturbance, does not support plant life at all. The triangular diagram (Figure B) which emerges from this view of plant life gives the TRISTAR system its name.

A4.2.4 Intermediate types of C-S-R strategy can be identified, each exploiting a different combination of intensity of external stress and disturbance. The positions of any of a wide variety of species (or, by aggregating its component species, of any vegetation type) can thus be displayed on a hexagonal diagram (Figure C) which represents the central zone of the original triangle (Figure B) turned clockwise through 45°. The positions on this diagram can each be identified by means of a C, S, and R co-ordinate on a scale of 1–5 (Figure D), thus facilitating the quantitative treatment of any position within C-S-R space. This can be done for individual species, for individual samples, or for groups of samples. All play a part in the modelling conducted within the threatened habitats project. Plant strategy theory in this form is thus applicable to vegetation systems other than those from which it was derived, and does not rely upon the estimation of specific plant parameters.

A4.2.5 The TRISTAR2 conflates the weighted abundances of up to a maximum of 19 individual functional types which may be present within each sample. This process created weighted abundances for each of seven broader groups of functional types (those shown in bold type in Figure C). These seven groups represent the three extreme corners of the C-S-R triangle ordination, its centre, and its principal intermediate positions. The seven groups are each converted into a two-part numerical code (seen, for example, in the second and third columns of Figure E). The two-part code provides a computational mechanism for representing both 'pure' and intermediate functional types.

A4.2.6 Once converted, the classifications according to functional type provide the basis for all further work on the vegetation sample by TRISTAR2. The first page of the presentation for each habitat (or subhabitat, if appropriate) consists of a divided percentage bar diagram illustrating the functional composition of all the plot classes present in the initial vegetation. Ecological notes on the habitat as a whole appear at this point.

A4.3 Phase II – effects of change scenarios on the abundance of functional types

A4.3.1 The TRISTAR2 model is next provided with various climate change or management scenarios. These have various implications for vegetation because they represent possible changes in environmental stress and disturbance. Initially, eight specimen scenarios were suggested by the project team (Figure F). Although these were all of direct interest to the project, it was felt that sufficient information on habitat sensitivity and resilience could be obtained by applying a smaller number of scenarios (Figure G). These involve only certain of the possible combinations of the two variable factors, environmental disturbance and eutrophication (the latter being defined as a *relaxation* of stress).

A4.3.2 For each factor and functional type within the six specimen scenarios, TRISTAR2 applies an appropriate numerical multiplier according to our understanding of the effects of the factor. The essence of the approach is that seven functional types are each driven by this weighting in different directions and with different gradients, according to information from UCPE's extensive survey and screening databases.

A4.3.3 However, even the six simple scenarios adopted do not always have a simple environmental interpretation. Their value lies in there being a representative group of theoretical changes against which the robustness of different habitats, of different categories of designation, or of different functional types or plant community may be tested. The main difficulty here is that a single scenario condition, such as 'increased eutrophication', may have a multiplicity of meanings. For example, it may literally mean reduced stress, in the sense of a reduced presence of toxic compounds or of a movement away from chronically non-optimal temperatures, or it may mean an enrichment of the environment in the sense of an increased availability of mineral nutrients or an enhancement of CO_2 level. The term 'decreased eutrophication' may have the opposite meaning to these, and similar arguments apply to 'decreased' or 'increased' levels of disturbance factors such as grazing, trampling, mowing, ploughing, wind damage, frosting, droughting, soil erosion, acutely non-optimal temperatures and fire.

A4.3.4 For these reasons the scenarios listed in Figure G cannot be identified explicitly in terms of *all* the environmental or management changes which they may present. The total number of permutations of scenarios runs into tens of thousands, and even one of the scenario lines in the Table may have very many variants, according to which definitions of disturbance and eutrophication are adopted.

A4.3.5 Nonetheless, each scenario prompts TRISTAR2 to predict a new abundance for each functional type under the new stable state. New percentage abundances for each functional type and designation stratum are calculated for all scenarios.

A4.3.6 For each of six scenarios a Table is computed (but not presented) which groups the predictions for each functional type in each plot classes presenting the habitat (PCA, PCB, etc). TRISTAR2 calculates the predicted change in percentage abundance of each of the seven functional types C, C-R, CSR, R, S, SC and SR relative to the initial composition of each plot class in the habitat. When charted, this analysis form the top left-hand element in the display of predictions for each scenario (pages 92–98).

A4.4 Phase III – computation of an 'index of vulnerability'

A4.4.1 Next, an index of vulnerability is computed for each plot class. This is done in three substages.

i. **Examine the original data to find the number of quadrats deviating appreciably from the typical**

The mean and standard deviation (SD) of each functional type within each plot class is calculated (the type-mean and type-SD). The mean across all seven type-SDs within each plot class is also derived (the class-type-SD). Each individual quadrat is then examined and the percentage abundance of each of its functional types is compared with the type-mean from the appropriate plot class; the result is expressed as a deviation from the type-mean. The mean of all such deviations for the quadrat is then compared with the class-type-

SD to find which quadrats have mean deviations greater than one unit of SD. Such quadrats are classified as outliers and their number is noted: the remaining quadrats, those within one class-type-SD (the great majority), are classified as typical.

ii. Examine the TRISTAR2 predictions to find the new number of quadrats deviating appreciably from the original composition

In the model prediction the abundances of CSR types within each of the quadrats have often changed. The new abundances are compared with the original class- and type-means and SDs (as in substage (i)). The new counts of typical or outlying quadrats are obtained. Some plot classes may contain more outliers under the new scenario, but others may be more resistant to predicted change, or may even contain fewer outliers (ie be made more typical) in certain instances.

iii. Find the 'index of vulnerability' for each plot class

This is simply the proportional change (on a scale of −1.0 to +1.0) in the number of quadrats identified as 'outliers', in each plot class, found by comparing substages (i) and (ii).

A4.4.2 The index of vulnerability is displayed as a bar diagram for each plot class in the habitat (the top right-hand section of the presentation on pages 91–97). A value of 0.0 in this diagram indicates that no increase or decrease in number of outliers has taken place as a result of the imposition of the scenario in question. If some change has taken place, this is classified as 'decreased' (ie having fewer outlying quadrats, indicating a composition even more typically uniform than before), or 'increased' to a 'low', 'moderate' or 'high' degree (indicating an appropriate amount of departure from typicality) according to the thresholds shown on each diagram. These particular thresholds have no absolute validity in themselves and are provided only as comparative tools. The indices of vulnerability are summarised across all plot classes in a small Table below the diagram. Ecological notes on the effects of the particular scenario within the current habitat conclude the presentation of each scenario.

A4.4.3 Finally, page 99 summarises the mean index of vulnerability across all scenarios for each plot class within the current habitat. Further ecological notes are added at this point. Comparisons between different habitats (or subhabitats) will ultimately be made possible by means of such material.

Figure A. Sample of raw data as received from ITE

Quadrat identifier	Species	Cover (Inner nest)	Cover (Outer nest)
A1-A	*Agrostis curtisii*	5	0
A1-A	*Calluna vulgaris*	10	0
A1-A	*Campylopus* sp.	1	0
A1-A	*Carex pilulifera*	1	0
A1-A	*Erica cinerea*	15	0
A1-A	*Erica tetralix*	10	0
A1-A	*Hypogymnia physodes*	1	0
A1-A	*Leucobryum glaucum*	1	0
A1-A	*Molinia caerulea*	40	0
A1-A	*Potentilla erecta*	1	0
A1-A	*Pteridium aquilinum*	10	0
A1-A	*Ulex europaeus*	1	0
A1-B	*Calluna vulgaris*	95	0
A1-B	*Cladonia impexa*	1	0
A1-B	*Cladonia* sp.	1	0
A1-B	*Erica cinerea*	5	0
A1-B	*Molinia caerulea*	1	0
A1-C	*Agrostis canina canina*	1	0
A1-C	*Agrostis curtisii*	20	0
A1-C	*Molinia caerulea*	35	0
A1-C	*Polygala serpyllifolia*	1	0
A1-C	*Pteridium aquilinum*	90	0
A1-C	*Rubus fruticosus*	1	0
A1-C	*Teucrium scorodonia*	1	0
A1-C	*Ulex europaeus*	1	0
A1-D	*Calluna vulgaris*	95	0
A1-D	*Dicranum scoparium*	1	0
A1-D	*Erica cinerea*	1	0
A1-D	*Hypnum cupressiforme*	1	0
A1-E	*Agrostis curtisii*	1	0
A1-E	*Calluna vulgaris*	5	0
A1-E	*Cephalozia* sp.	1	0
A1-E	*Drosera intermedia*	1	0
A1-E	*Drosera rotundifolia*	5	0
A1-E	*Erica tetralix*	15	0
A1-E	*Eriophorum angustifolium*	1	0
A1-E	*Gymnocolea inflata*	1	0
A1-E	*Juncus bulbosus*	1	0

Figure B. The relationship between stress and disturbance factors and the C-S-R types

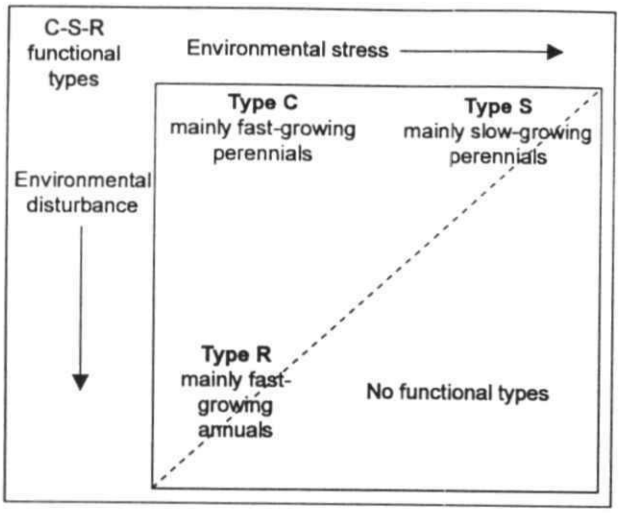


Figure C. The C-S-R triangle ordination showing the three principal functional types and intermediate positions

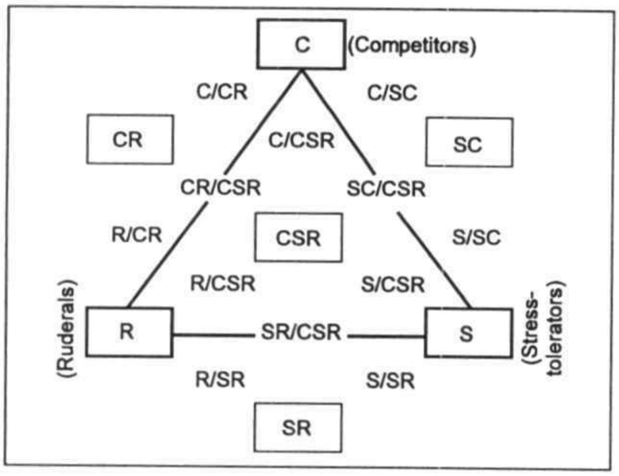


Figure D. C-S-R co-ordinates of functional types

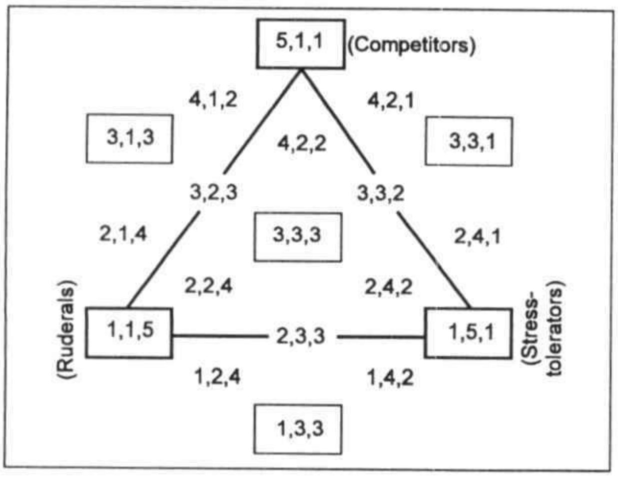


Figure E. Reclassification of species according to functional types

Quadrat identifier	Species	C-S-R classification Part 1	Part 2	Cover
A1-A	*Agrostis curtisii*	5	5	5
A1-A	*Calluna vulgaris*	6	6	10
A1-A	*Campylopus* sp.	7	7	1
A1-A	*Carex pilulifera*	5	5	1
A1-A	*Erica cinerea*	5	6	15
A1-A	*Erica tetralix*	5	6	10
A1-A	*Hypogymnia physodes*	0	0	1
A1-A	*Leucobryum glaucum*	5	5	1
A1-A	*Molinia caerulea*	6	6	40
A1-A	*Potentilla erecta*	3	5	1
A1-A	*Pteridium aquilinum*	1	1	10
A1-A	*Ulex europaeus*	6	6	1
A1-B	*Calluna vulgaris*	6	6	95
A1-B	*Cladonia impexa*	5	5	1
A1-B	*Cladonia* sp.	5	5	1
A1-B	*Erica cinerea*	5	6	5
A1-B	*Molinia caerulea*	6	6	1
A1-C	*Agrostis canina canina*	3	3	1
A1-C	*Agrostis curtisii*	5	5	20
A1-C	*Molinia caerulea*	6	6	35
A1-C	*Polygala serpyllifolia*	5	5	1
A1-C	*Pteridium aquilinum*	1	1	90
A1-C	*Rubus fruticosus*	6	6	1
A1-C	*Teucrium scorodonia*	3	4	1
A1-C	*Ulex europaeus*	6	6	1
A1-D	*Calluna vulgaris*	6	6	95
A1-D	*Dicranum scoparium*	5	5	1
A1-D	*Erica cinerea*	5	6	1
A1-D	*Hypnum cupressiforme*	5	7	1
A1-E	*Agrostis curtisii*	5	5	1
A1-E	*Calluna vulgaris*	6	6	5
A1-E	*Cephalozia* sp.	7	7	1
A1-E	*Drosera intermedia*	5	7	1
A1-E	*Drosera rotundifolia*	3	6	5
A1-E	*Erica tetralix*	5	6	15
A1-E	*Eriophorum angustifolium*	5	6	1
A1-E	*Gymnocolea inflata*	7	7	1
A1-E	*Juncus bulbosus*	3	7	1

Figure F. Eight specimen scenarios

1 An 80% reduction in sulphur emissions

2 A 40% reduction in nitrogen emissions

3 A 10% increase in nitrogen emissions

4 A 3°C increase in temperature, together with
- 10% extra precipitation
- 10% less precipitation

5 Reduction of grazing to 50% (where relevant)

6 Removal of land from arable (where relevant)

7 Removal of land from forest (where relevant)

Figure G. Six simplified scenarios used by UCPE

UCPE scenario	Disturbance factor	Eutrophication factor	Example
1	Decreased	The same	Less grazing, trampling, cutting or burning, etc, but resource levels unaltered
2	Decreased	Increased	Less grazing, trampling, cutting or burning, but more resources such as light, water or nutrients
3	The same	Decreased	No change in grazing, trampling, cutting or burning, etc, but fewer resources such as light, water or nutrients
4	The same	Increased	No change in grazing, trampling, cutting or burning, etc, but more resources such as light, water or nutrients
5	Increased	Decreased	More grazing, trampling, cutting or burning, etc, and fewer resources such as light, water or nutrients
6	Increased	Increased	More grazing, trampling, cutting or burning, etc, and more resources such as light, water or nutrients

Baseline [the intial state]

General notes on this habitat

Heaths are restricted to nutrient-poor acidic soils. The vegetation is kept in a relatively open state by burning and, in some instances, grazing. A number of small shrubs, particularly heather, are characteristic of heathland as classically described, and typical functional types are S or SC and, where there are bryophytes, SR. Thus, plot classes A, B and D are among the most 'typical' in terms of functional type. However, there are also other axes of environmental variation, namely wet/dry and shaded/unshaded, and plot class A is too wet to be considered as 'core' heath. Furthermore several classes do not conform to 'heathland' even in strategic terms, and these may be assigned to a 'woodland' or a 'grassland' grouping. Woodland plot classes, particularly Q, L and O, have high values for type C. Increased dereliction, presumably a consequence of fire prevention, and perhaps also eutrophication, appear associated with forestry land use. Grassland classes, M and R, have more CSR species. This type is often associated with grazed and with less nutritionally impoverished conditions. Plot class P consists entirely of rhododendron making it unsuitable for further analysis. Note that, especially in the most species-poor vegetation, a description solely in terms of functional types is not ideal. Success or failure is determined by **functional type** in conjunction with:

- **regenerative characteristics,** particularly if the species is not already present in the community, and
- a wide range of other **habitat features** relatively independent of strategy (eg soil moisture and pH).

Also, in the case of woodland, data for the different strata in the vegetation (tree layer, shrub layer, ground layer) should ideally be analysed separately. Any factor that reduces the dominance of and level of shading exerted by trees will increase growth in the lower strata. Hence, for example, **disturbance** to the canopy (eg tree thinning) may at the ground layer be regarded as an entirely different factor, **dereliction**, a release from shade stress.

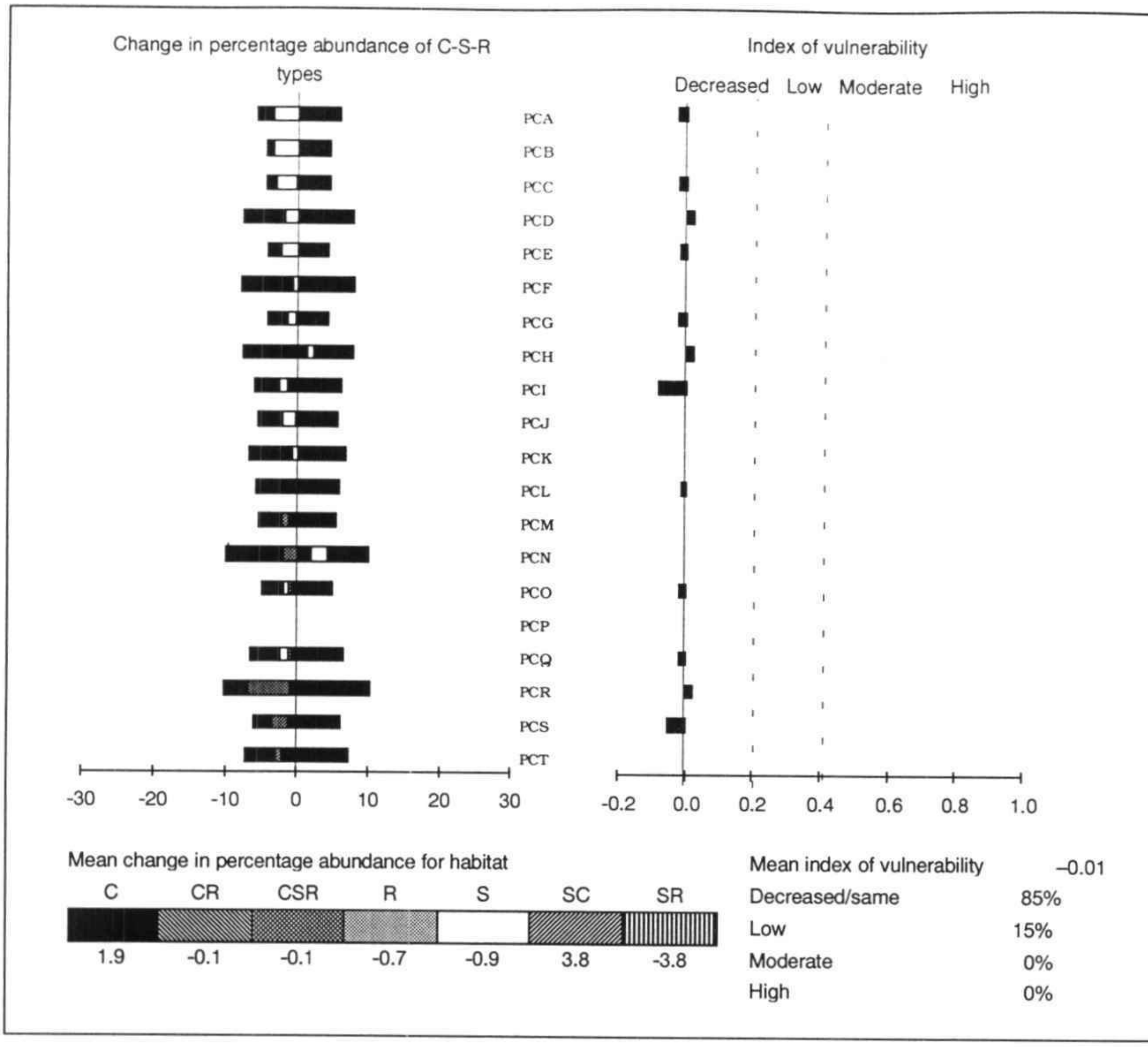
Key species

Heather *(Calluna vulgaris)*, the most characteristic dominant of heathland

Important invaders

- **Derelict conditions**
  Birch *(Betula pendula, B. pubescens)*
  Rhododendron *(Rhododendron ponticum)* and other trees and shrubs
  Bracken *(Pteridium aquilinum)*
- **Derelict eutrophicated conditions**
  Gorse (*Ulex europaeus*) – especially in areas which become burnt
  Bramble *(Rubus fruticosus)*

Scenario 1 – [Disturbance decreased; eutrophication the same]

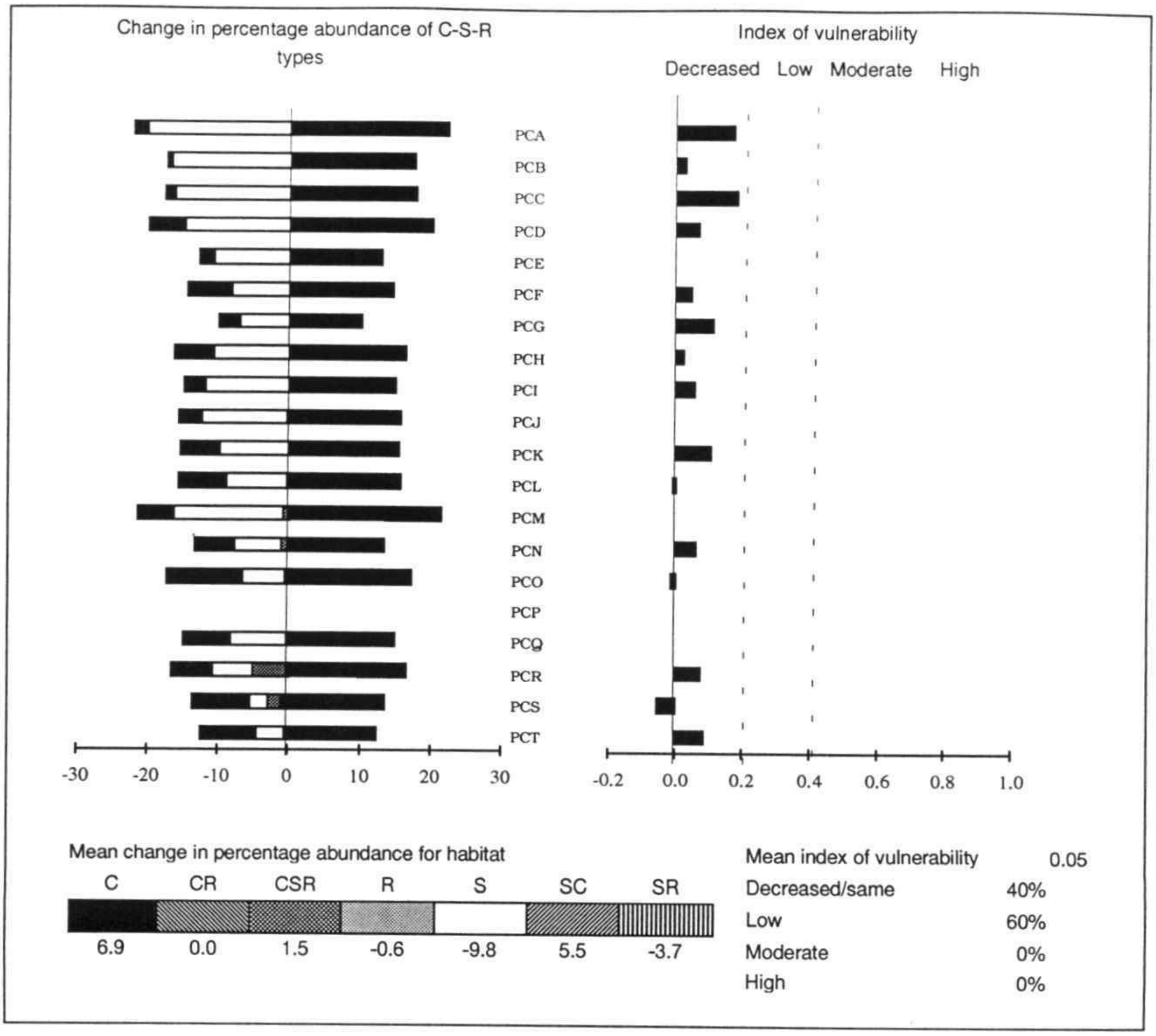


Possible causes of this scenario

- **Heathland** – *decreased disturbance* – reduced incidence of fires, cessation/reduction of grazing, less recreational pressure
- **Woodland** – *decreased disturbance* – reduced incidence of fires (a normal component of forestry practice), no tree thinning
- **Grassland** – *decreased disturbance* – cessation/reduction of grazing or cutting, reduced incidence of fires, less recreational pressure

Decreased disturbance is the scenario associated with abandonment or dereliction. With respect to functional types, in the shorter term this scenario will have moderate but deleterious impacts on the composition of heaths and heath grassland. Losses of heathland bryophtyes of type SR and, to a lesser extent, vascular plants of type S are predicted. At the same time, there will be an increased representation of SC species with the invasion by scrub and/or bracken. In 'woodland' variants, particularly classes PCO and PCS, an expansion of competitive herbs or subshrubs is predicted. This will only occur in less shaded areas. One of the first effects of dereliction is likely to be an increasingly dense tree canopy. The resulting shade will simply reduce biomass within the herb layer and could even encourage species of type S. Paradoxically, reduced disturbance from land use activities could in certain situations eventually result in episodes of increased disturbance. For example, there will be an increase in above-ground biomass and, in the event of fire, a greater quantity of combustible material. The greater heat of any ensuing fire may cause greater mortality, opening up larger areas for recolonisation than would otherwise be the case. Even wetland sites may become more vulnerable to fire. Associated with the increased biomass will be increased water loss through transpiration. The colonisation of wetlands by trees can substantially reduce the water table. Another general longer-term consequence of decreased disturbance may be increased stress. As biomass increases, more soil nutrients will be lost to the plant. The values for index of vulnerability are low. This indicates that short-term impacts on the strategic composition of the vegetation will not be great.

Scenario 2 – [Disturbance decreased; eutrophication increased]

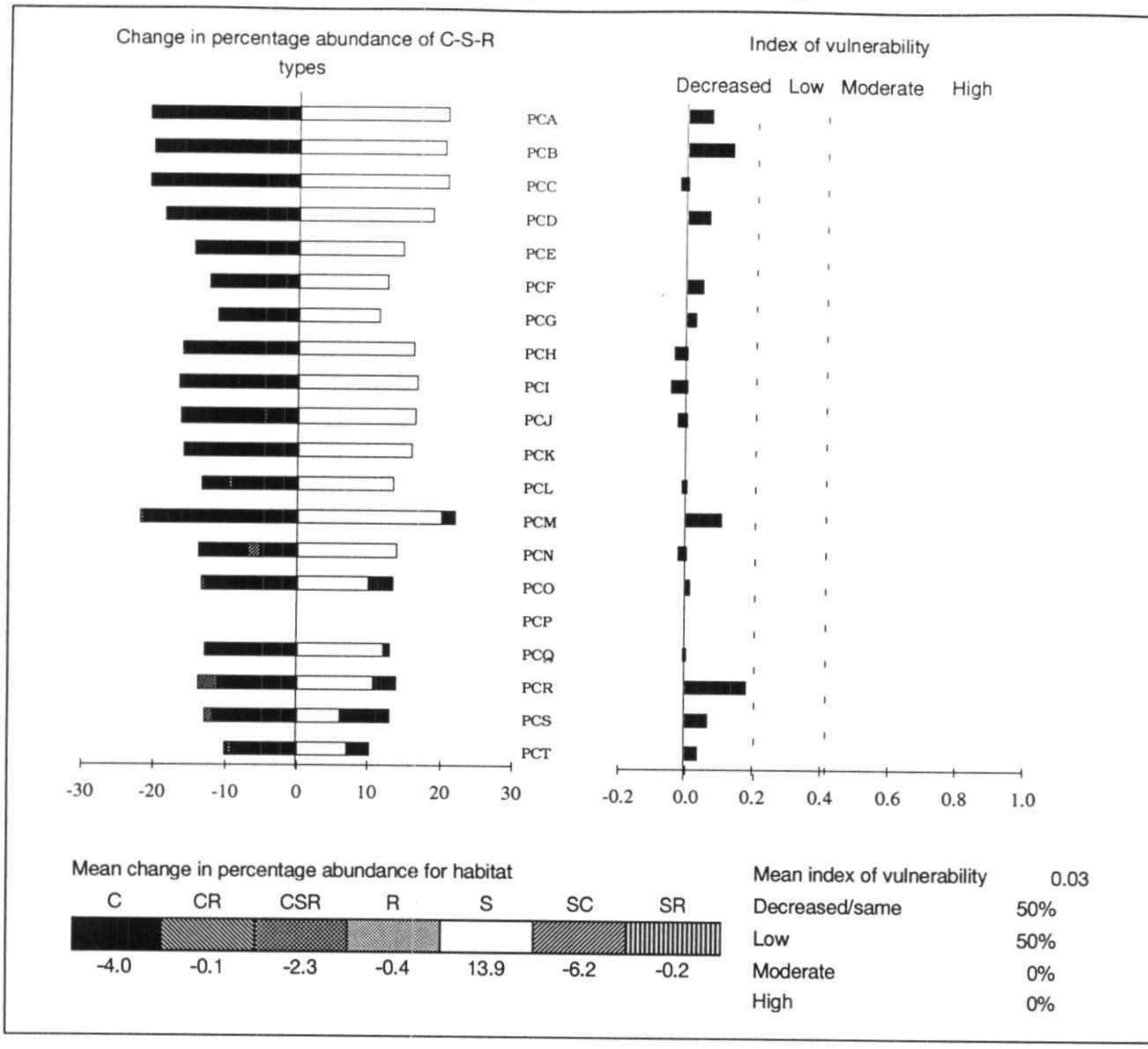


Possible causes of this scenario

- **Heathland** – *decreased disturbance* – reduced incidence of fires, cessation/reduction of grazing, less recreational pressure; *increased eutrophication* – fertilizer runoff or atmospheric deposition
- **Woodland** – *decreased disturbance* – reduced incidence of fires (a normal component of forestry practice), no tree thinning; *increased eutrophication* – fertilizer runoff or atmospheric deposition mainly from agricultural sources, fertilizer applications as a part of silvicultural practice
- **Grassland** – *decreased disturbance* – cessation/reduction of grazing or cutting, reduced incidence of fires, less recreational pressure; *increased eutrophication* – fertilizer runoff or atmospheric deposition

Increased eutrophication acting in combination with decreased disturbance will have a greater and more rapid impact on the distribution of functional types in 'grassland' and 'heath' groupings than in the previous scenario (disturbance decreased; eutrophication the same). There will be losses of types S and SR, two of the most typical of the habitat, and an increased representation by types C and SC. Initially, species like bracken may be the first species to increase. However, eventually, heathland and grassland may become over-run with tall herbs and shrubs. Because the litter of species of functional type C is decomposed rapidly, there is less risk of fire than in the previous scenario. In the case of woodland variants, eg classes PCO, PCQ, PCS and PCT, conditions favouring the invasion by competitive herbs will be restricted to open areas such as woodland rides. Elsewhere, for reasons discussed under the previous scenario, a dense canopy will restrict growth of the herb layer. The relatively low values for index of vulnerability indicate that immediate impacts on the strategic composition of the vegetation will be small.

Scenario 3 – [Disturbance same; eutrophication decreased]

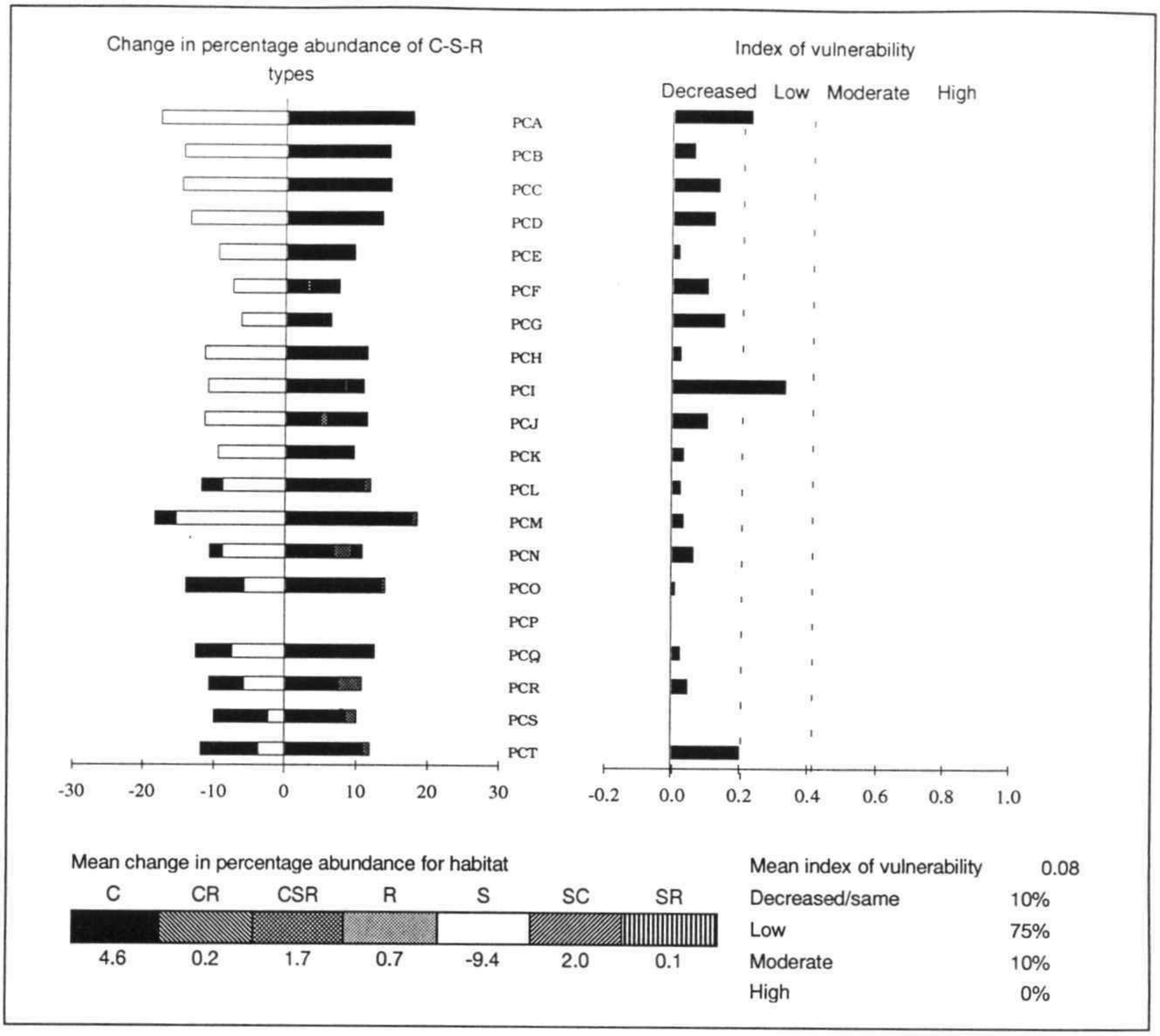


Possible causes of this scenario

- **Heathland** – *decreased eutrophication* – decreased usage of or pollution from fertilizers
- **Woodland** – *decreased eutrophication* – potentially a natural consequence of woodland aging; the soil becomes progressively depleted of nutrients as the tree biomass increases
- **Grassland** – *decreased eutrophication* – decreased usage of or pollution from fertilizers

As with the previous scenario (disturbance decreased; eutrophication increased), large changes are forecast for heath and grassland groupings. However, an increase in the main beneficiary, type S, which grows very slowly, will take considerably longer to achieve. Decreased eutrophication could have a beneficial impact on the composition with respect to functional types with losses of types C and CSR, both atypical of 'core' heathland. Also, the decreased representation by SC species is likely initially to involve a reduction in tall woody species rather than in heather. Impacts on the woodland grouping, eg classes PCO, PCQ, PCS and PCT, are difficult to predict. If growth of the tree canopy is reduced, an increase in the biomass of the ground flora is possible. Because the nutrient demands of small fast-growing herbs may well be less than those of large slow-growing trees, increasing types could even include C. The low values for the index of vulnerability indicate that short-term impacts on the strategic composition of the vegetation will be small. In some instances they may even, in the longer term, be less marked than those predicted here. Many species of type S do not form a persistent bank of seeds in the soil or exhibit long-distance dispersal. Thus, some sites in plot classes where type S is poorly represented (eg PCS and PCT) may fail to be colonised by type S.

Scenario 4 – [Disturbance the same; eutrophication increased]

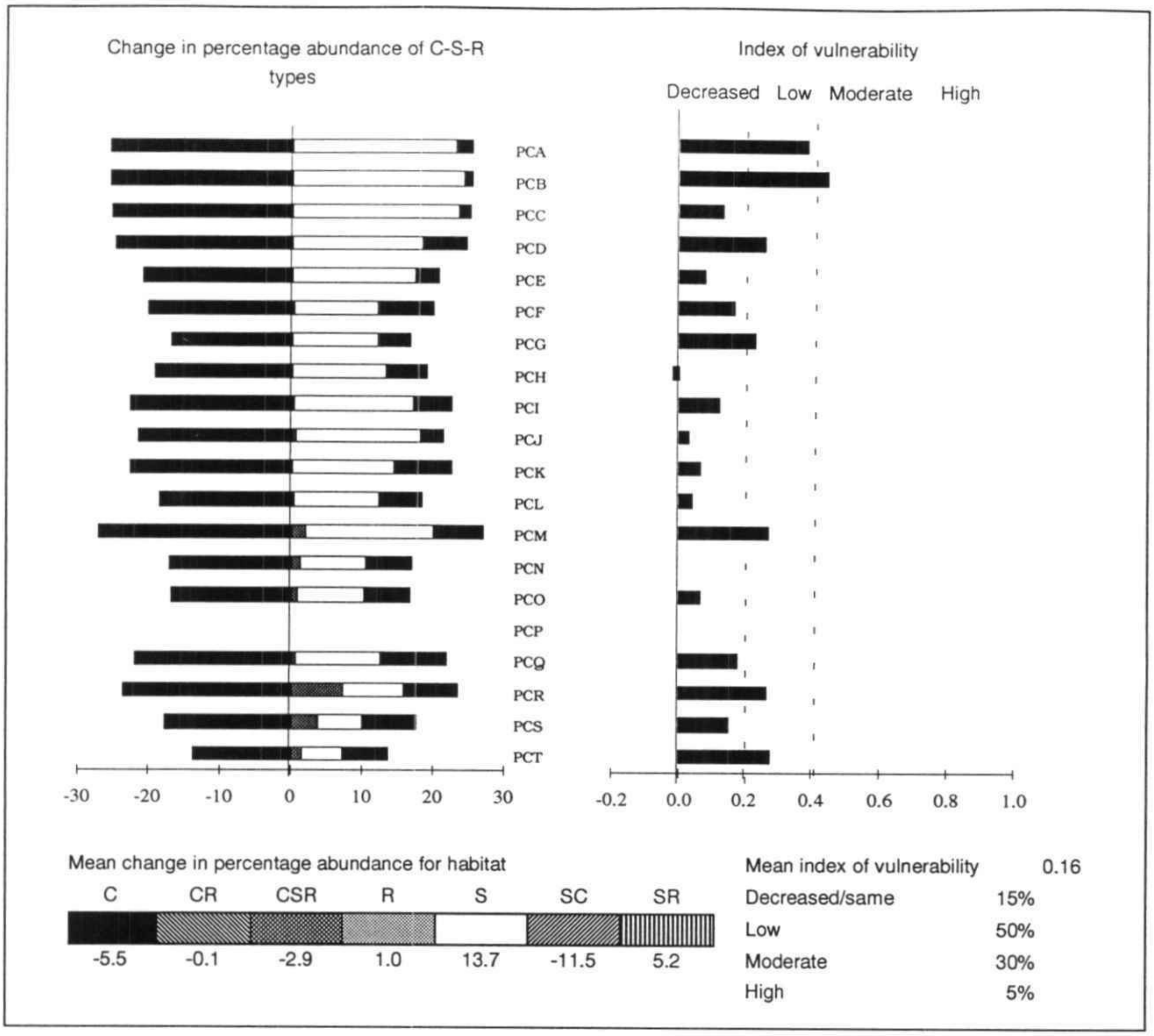


Possible causes of this scenario

- **Heathland** – *increased eutrophication* – fertilizer runoff or atmospheric deposition
- **Woodland** – *increased eutrophication* – fertilizer runoff or atmospheric deposition mainly from agricultural sources, fertilizer applications as a part of silvicultural practice
- **Grassland** – *increased eutrophication* – fertilizer runoff or atmospheric deposition

Increased eutrophication will have a moderate and potentially deleterious impact on the composition with respect to functional types. In 'heath' and 'grass' this will involve losses of types S and SR, two of the most typical of the habitat. In addition, an increased representation by SC species may permit the first stages of scrub invasion. This could lead, over a prolonged period, to the formation of a rather different vegetation, or may indicate invasion by bracken. In the woodland classes PCO, PCQ, PCS and PCT, the initial predicted invasion by competitive herbs will perhaps only occur at the woodland margin. Increased eutrophication may increase tree growth and shade. This would reduce the cover of ground flora species of all functional types, except perhaps type S. The low values for index of vulnerability indicate that short-term impacts on the strategic composition of the vegetation will be small in most plot classes.

Scenario 5 – [Disturbance increased; eutrophication decreased]



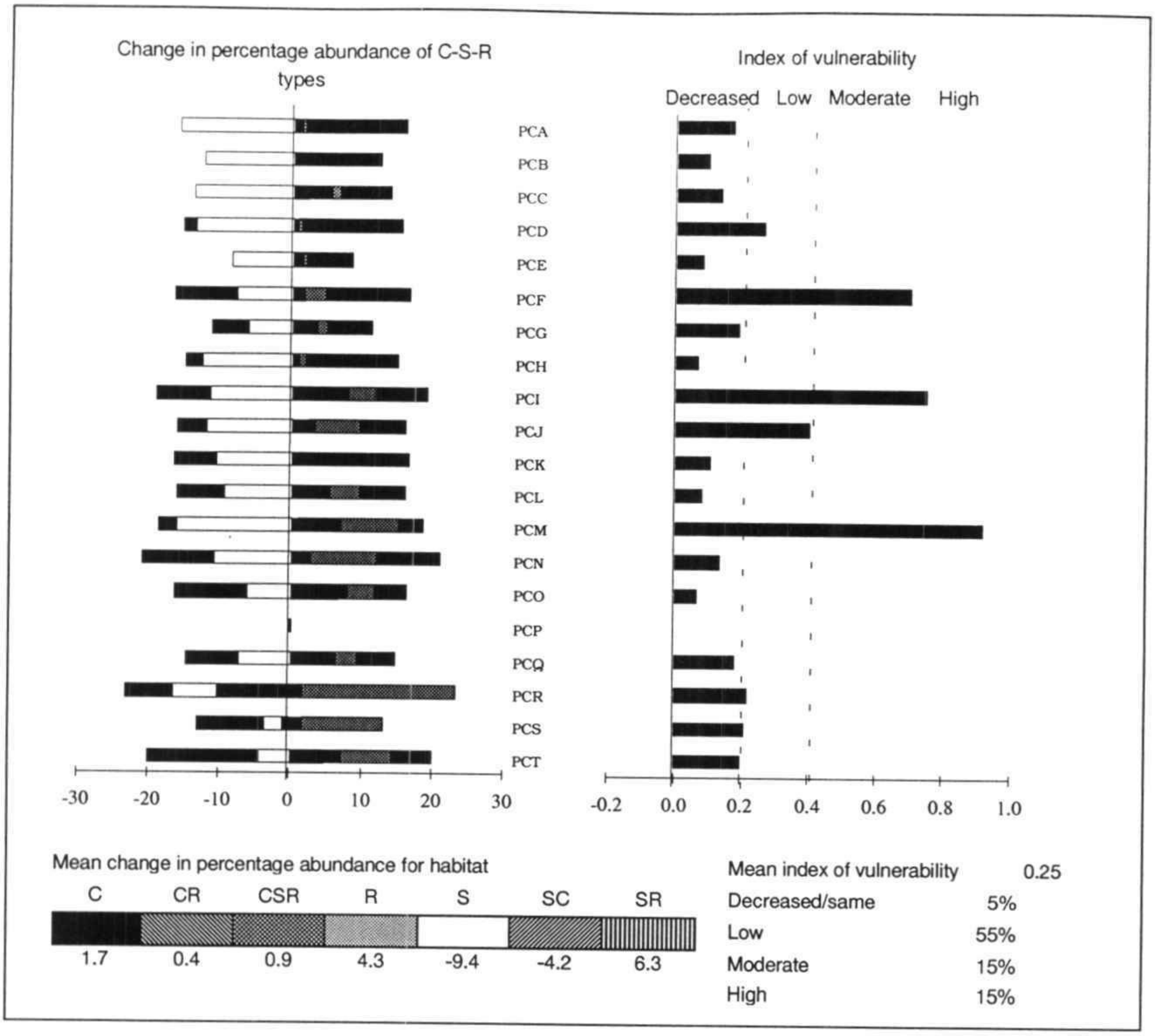
Possible causes of this scenario

- **Heathland** – *increased disturbance* – higher incidence of fire, increased grazing, more recreational pressure; *decreased eutrophication* – less fertilizer runoff or atmospheric deposition
- **Woodland** – *increased disturbance* – tree thinning, incidence of fire (discouraged during forestry practice); *decreased eutrophication* – less fertilizer runoff or atmospheric deposition mainly from agricultural sources, less fertilizer added as a part of silvicultural practice or more leaching
- **Grassland** – *increased disturbance* – increased grazing or cutting, reduced incidence of fires, less recreational pressure; *decreased eutrophication* – less fertilizer runoff or atmospheric deposition

Increased disturbance coupled with decreased eutrophication will have a major impact on the composition with respect to functional types. Impacts of increased disturbance will be rapid, with heath and grassland increases in types SR and R, and a concomitant decrease in C and SC. Any increase in type S, the main beneficiary of decreased eutrophication but one which grows very slowly, will take considerably longer. Initially, this scenario could have a beneficial impact on the composition with respect to functional types, with losses of types C and CSR, both atypical of 'core' heathland. This is particularly true for 'grassland' plot classes PCM and PCR. Also, the decreased representation by SC species in these more productive plot classes is likely to involve initially a reduction in tall woody species rather than in heather. Any increase in type R is likely to be temporary. However, changes in the less productive plot classes may be less beneficial. The abundance of heather will be reduced in plot classes where it is the predominant SC type. The initially more productive 'grassland' grouping (plot classes such as PCM and PCR) may become more vulnerable to fires because more persistent litter will be formed. Other less productive classes (eg PCA and PCB) will become less fire-prone because of reduced above-ground biomass. This trend may be accentuated in these two classes by a reduction in transpirational water loss leading to a slightly increased water table. The changes affecting woodland, eg classes PCO, PCQ, PCS and PCT, are difficult to predict. Increased disturbance coupled with decreased eutrophication will reduce the density of the tree canopy. The extent to which the lower strata can respond to the decreased shading will depend on the severity of the nutrient stress imposed and on whether disturbance directly affects all strata. If it does, the predicted increase in type SR will probably be realised through an expansion in bryophytes. Less severe scenarios may encourage the expansion of all functional types in the ground layer. The low values for index of vulnerability indicate that short-term impacts on the strategic composition of the vegetation will be small in a majority of cases. Greatest vulnerability is associated both with the very unproductive classes (PCB and PCA) and with the very productive ones (PCT, PCM and PCR).

NB This scenario assumes only modest changes in disturbance and eutrophication. Under conditions both of high stress (which permits only slow growth) and of high disturbance (where recovery necessitates rapid growth), no plant species can survive. This combination of high stress and high disturbance is characteristic of many areas of 'open country' suffering problems of recreational damage (eg the Pennine Way).

Scenario 6 – [Disturbance increased; eutrophication increased]



Possible causes of this scenario

- **Heathland** – *increased disturbance* – increased incidence of fires, more grazing, more recreational pressure; *increased eutrophication* – fertilizer runoff or atmospheric deposition
- **Woodland** – *increased disturbance* – tree thinning, reduced incidence of fires (a normal component of forestry practice); *increased eutrophication* – fertilizer runoff or atmospheric deposition mainly from agricultural sources, fertilizer applications as a part of silvicultural practice
- **Grassland** – *increased disturbance* – increased incidence of fires, more grazing, more recreational pressure; *increased eutrophication* – fertilizer runoff or atmospheric deposition

The combination of increased eutrophication and increased disturbance will have major impacts on the composition with respect to functional types. For the heath and grassland groupings these impacts will be deleterious, involving losses of S-type species and any low-growing variants of type SC (particularly heather). These are the most typical plants of the habitat. Types SR, R and, to a lesser extent, C will increase. There will be fewer fires because of the reduced biomass and less persistent litter associated with this scenario. In the woodland grouping, eg classes PCO, PCQ, PCS and PCT, this combination of events may result in periods with a relatively open canopy immediately following disturbance but with rapid recovery because of eutrophication. Under these circumstances, fast-growing species of type C, CR and R might be encouraged, particularly if these species had good dispersal in space (numerous, wind-dispersed seeds or spores) and/or in time (a persistent seed bank in the soil). Highest values for index of vulnerability are associated with plot classes PCM, PCI and PCF, but long-term impacts on the composition of the vegetation with respect to both functional types and individual species will be large and difficult to reverse.

Index of vulnerability

'Lowland heath' is a heterogeneous grouping of heath, grassland and woodland. However, the individual classes all have one thing in common: they are relatively unproductive. Using ecological theory we would predict that all the classes would be relatively unresponsive, at least in the shorter term, to changing land use. This prediction is borne out by the above: only one class reaches 'moderate' vulnerability. However, the index of vulnerability differs markedly between treatments. The most extreme scenario appears to be 'increased disturbance and eutrophication' with three plot classes showing high vulnerability. The impact to the various scenarios can be summarised as follows.

Low – moderate impacts
('Disturbance – decreased; Eutrophication – same< 'Disturbance – same; Eutrophication – decreased'< 'Disturbance – decreased; Eutrophication – increased'<'Disturbance – same; Eutrophication – increased')

High impacts
('Disturbance – increased; Eutrophication – decreased'< 'Disturbance – increased; Eutrophication – increased')

Although the differences between habitat groupings are relatively slight, grasssland classes appear to be among the most vulnerable and woodland among the least vulnerable, with heath (both wet and dry) occupying an intermediate position. This sequence accords with expectation. Plot classes M (damp acid grassland) and I (grassy heath) have greatest average vulnerability and H (dry heath often planted), L (plantation over bracken/ heath) and O (plantation often open) the least. However, vulnerability differs markedly according to scenario. For example, for 'disturbance – same; eutrophication – increased', plot class M, the highest overall, is low but plot class I is high. It is therefore important in all predictions to match exactly the plot class with the scenario.