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Forest conservation, expansion, restoration and management in a national park : modelling ecology, suitability, biodiversity priorities, temporal and climate change using GIS and spatial data

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By

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A thesis submitted to the University of Wales Bangor for the degree of *Philosophae Doctor* in Forest Ecology & GIS

By

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ABSTRACT

When maintaining the biodiversity and ecological integrity of forests is a goal of management, a primary requirement is to assess the status, condition, conservation value of each forest, and change in forest conditions over time. GIS procedures were used here to compare different map-based surveys and look in detail at changes in woodlands of the Snowdonia National Park, North Wales, from 1970 to 2000. The maps from the 1970s and 1980s generated by Silsoe College did not compare well with the map from the 1990s produced by the Forestry Commission and no meaningful changes could be measured. This was attributed to difficulties with comparison of different interpretations and classification schemes used by the two organisations. A series of landscape surveys using the same minimum mapping unit, classification scheme, and methodology in general is needed.

The potential changes in broadleaved and scrub woodland area were modelled based on the two most extreme climate change scenarios, termed the Low and High scenarios. Temperature and rainfall models formed the basis for logistic regressions of woodland type and distribution. A declining trend in probability of presence for both woodland types from the present sites was shown under the UKCIP98 High climate change scenario. The results emphasized the conceptual difficulties in using fragments of woodland within the realised niche rather than the fundamental niche as the basis for environmental modelling of plant community distributions.

GIS based models were generated to address the key question in the biodiversity action plan process of where should new woodland be created or plantations restored. Ecological criteria were developed to identify the priority areas for native woodland expansion taking into account of the requirements for successful woodland expansion from the nature point of view and specific policy aims. The results were interesting and suggested that there is ample land potentially suitable in Snowdonia for new native woodland. The models could be used to aid decision-making for new native woodland in the National Park.

A further extension of GIS-based modelling was developed for the prediction of individual NVC types and BAP priority woodland types. The environmental spaces occupied by the fragments of NVC woodland types currently present in Snowdonia were defined and used as templates to produce maps of potentially suitable sites for the occurrence of each NVC type. The results were not as clear-cut as had been hoped because of overlaps in the predicted occurrences of various woodland types. Independent verification of the predictions using non-spatial data for 24 sites revealed that the model produced was very poor. This was not, however, a fault of the modelling but a reflection of the fact that some of the environmental data were at too coarse a scale and that NVC types are not solely determined by environmental factors.

In spite of some weaknesses in the data, the use of GIS for modelling these scenarios proved useful. Nowadays, forest policies in Wales, Europe and elsewhere are changing rapidly to meet modified global, national, and local objectives. GIS is, and will increasingly be so, proving to be a useful and flexible tool for translating forest policy into practical application on the ground.

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(a) Refereed Journal Publications

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Gkaraveli, A., Williams, J.H. and Packwood, A.J. (Submitted). Using GIS to model present and future distribution of semi-natural woodland in Snowdonia (UK). In: *Innovations in GIS IX* volume of the GIS Research UK 9th Annual Conference 18-20 April 2001. University of Glamorgan, Glamorgan.

Gkaraveli, A., Good, J.E.G. and Williams, J.H. (2002). Recent changes in woodlands of the Snowdonia National Park, Wales: a spatial analysis. *Quarterly Journal of Forestry*, 96(2), 117-124.

(b) Conference Proceedings

Gkaraveli, A., Good, J.E.G. and Williams, J.H. (2002). Forest restoration in a National Park: modelling biodiversity priorities using GIS. International Conference on Protection and Restoration of the Environment VI, 1-5 July, University of Thessaly, Skiathos, Greece, 1875-1876.

Gkaraveli, A., Williams, J.H. and Good, J.E.G. (2001). Native woodlands in the Snowdonia National Park (UK): spatial analysis and an approach to the restoration of their habitat. International Conference on *Forest Research: a challenge for an integrated European approach*, 27 August-1 September, Forest Research Institute, Thessaloniki, Greece, 371-376.

Gkaraveli, A., Williams, J.H. and Packwood, A.J. (2001). The influence of climate change on the distribution of native woodland in the Snowdonia National Park. In: D.B. Kidner and G. Higgs (ed) *GIS Research in the UK*. GISRUK 2001 Conference Proceedings 18-20 April, University of Glamorgan, Glamorgan, 528-531.

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(c) Conference Posters

Gkaraveli, A., Williams, J.H. and Packwood, A.J. (2001). *Modelling current and future distribution of native woodland in the Snowdonia National Park, north Wales, UK using GIS*. GIS Research UK 9th Annual Conference 18-20 April, University of Glamorgan, Glamorgan.

Gkaraveli, A. and Williams, J.H. (2001). *Woodland changes in the Snowdonia National Park from the 1970s to the 1980s*. Student Conference on Conservation Science 28-30 March, University of Cambridge, Cambridge.

DEDICATION

To my Antoni
and
to all those who helped me to complete this Thesis

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A number of people deserve many thanks for everything that this thesis represents. Without their continuous encouragement and motivation, I would not have attempted the post-graduate studies and I would probably have lived a conventional life far away from the excitement that science and research provide.

In the first instance I would like to thank Prof. John Good for the interest he has taken, advice, guidance and support throughout the duration of this work. All the meetings and discussions we had were a real inspiration. He carefully read this document and provided lots of helpful feedback.

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Anthi Gkaraveli.

'When the cup is full, no more can be poured,
when you are full of your opinions,
no more wisdom can enter'.

Taken from the Internet.

LIST OF ABBREVIATIONS

ASNW	Ancient semi-natural woodland
AWC	Ancient woodland cleared
AWI	Ancient woodland inventory
AWR	Ancient woodland replanted
BAP	Biodiversity Action Plan
BL	Broadleaves
CCW	Countryside Council for Wales
CET	Central England Temperature
ESC	Ecological Site Classification
FC	Forestry Commission
FT	Forest Type
GCMs	general circulation models
GIS	Geographical Information System
GPS	Global Positioning System
HAP	Habitat Action Plan
IFT	Interpreted Forest Type
IPCC	Intergovernmental Panel on Climate Change
JNCC	Joint Nature Conservation Committee
Mix	Mixed forest
MNN	mean nearest-neighbor distance
MPS	mean patch size
MSI	mean shape index
NCC	Nature Conservancy Council
NGOs	Non-Government Organisations
NIWT	National Inventory of Woodland and Trees
NNR	National Nature Reserves
NNSD	nearest-neighbor standard deviation
NP	number of patches
OS	Ordnance Survey
PC	percentage area
PSSD	patch size standard deviation
SNP	Snowdonia National Park
SNPA	Snowdonia National Park Authority
SSSI	Sites of Special scientific interest
UKCIP	UK Climate Impacts Programme
UNEP	United Nations Environment Programme
WGS	Woodland Grant Scheme
WMO	World Meteorological Organisation.

1.0 INTRODUCTION

Forests are species-rich ecosystems and repositories of much of the world's biodiversity, and therefore foresters must assume a degree of responsibility for their management and conservation (Kapos and Iremonger, 1998). The long-term maintenance of such biological diversity has become one of the important goals of managing forests in an ecologically sustainable way (Lindenmayer *et al.*, 1999). This should be done through a global, national and regional conservation priority setting with an understanding of the distribution of species and ecosystems.

In the last twenty years we have become aware of ongoing global changes such as climate change, changes in the chemistry of the atmosphere and land use change, and their present and potential effects on the biotic and abiotic environment. This awareness is the basis for the increasing political and scientific importance of the notion of sustainable development (Schlaepfer and Elliott, 2000).

This was the background for the United Nations Conference on Environment and Development (known as the Earth Summit) held in Rio-de-Janeiro, Brazil in June 1992 and which resulted in several strategically important contributions, including *Agenda 21*, the *United Nations Framework Convention on Climate Change* and the *Convention on Biological Diversity* (Earth Summit, 1992). *Agenda 21* reflects a global consensus and commitment at the highest political level on how to make development socially, economically, and environmentally sustainable. The *Framework Convention on Climate Change* aims to stabilise greenhouse gases in the atmosphere at concentrations that will not upset the global climate system significantly. The *Convention on Biological Diversity* requires governments to develop national strategies, plans or programmes for the conservation and sustainable use of biodiversity.

At the Rio Conference the responsibility was put on all nations to respond to threats to the environment, in their own potential self-interests as well as for moral and cultural reasons (Kirby, 1999). The UK response included the *UK Biodiversity Action Plan* (HMSO, 1994) that lists 59 actions to be taken, among them to continue to protect ancient semi-natural woodlands and to encourage a steady expansion of woodland and forest cover.

Five types of woodland in Wales are recognised as priority habitats in the *UK Biodiversity Action Plan* (Upland Oakwoods, Upland Mixed Ashwoods, Lowland Parkland and Wood Pasture, Wet Woodland and Lowland Beech and Yew Woodland). The local Biodiversity Action Plan for Snowdonia (SNPA, 1999), in particular, emphasized the need to expand the area of Upland Oak and Ash woodlands, and encourages the restoration of their habitats.

In the Welsh Assembly forestry strategy (National Assembly for Wales, 2001) a number of key priorities were set out, including an emphasis on woodland management and a diverse and healthy environment. Some of the key objectives for these priorities were set as to find appropriate sites for new trees and woodland, and conserve and enhance the biodiversity of woodlands through implementing the *Biodiversity Action Plan* targets for their restoration and extension, creating links between fragmented woodlands and increasing the area of native woodlands, targeting extension and connection of existing woods.

If maintaining the biodiversity and ecological integrity of forests is a goal of management, then it is axiomatic that managers be fully informed about the forests being managed (Noss, 1999). A primary requirement is to assess the status, condition, conservation value of each forest, and change in forest conditions over time. There has not been a study of changes in the landscape characteristics of woodlands in the Snowdonia National Park, introduced in Chapter 2, over time, although measures of landscape pattern are increasingly being used in monitoring and assessment programmes, especially for forests (Reed *et al.*, 1996; Kramer, 1997; Kitzberger and Veblen, 1999). In Chapter 3, the first large-area analysis of landscape structure and change in Snowdonia combining data from different sources is presented.

Evaluating how future climate changes may affect habitats has become increasingly important in the study of long-term maintenance of global biodiversity (Peters and Darling, 1985). A number of studies have been published which contribute to the understanding of the potential influences of climate change on vegetation. These include climatic influences on species (Huntley *et al.*, 1995; Sparks *et al.*, 1995a; Proe *et al.*, 1996; Guisan *et al.*, 1998; Iverson and Prasad, 1998; Iverson *et al.*, 1999) or vegetation types (Brzeziecki *et al.*, 1993; Kienast *et al.*, 1998; Eeley *et al.*, 1999). After an exhaustive search in the literature, the author is aware of only one work dealing with modelling of the impacts of climate change on woodland dynamics and distribution in Britain (Berry *et al.*, 2000; Cook and Harrison, 2001). BIOME-UK is a regional version of the global BIOME3 vegetation model and was run for current and predicted climate conditions to identify within England and Wales potential changes in dominant plant functional types, such as temperate deciduous and temperate coniferous woodland (Berry *et al.*, 2000). An attempt to model the present-day distribution of broadleaved and scrub habitats at the finer scale of the National Park, and investigate the potential changes in anticipation of climate change is described in Chapter 4.

A local accord has set the target of increasing the area of native woodland within Snowdonia by 50% within 50 years (SNPA, 1995). However, there has been no comprehensive study of the priority areas for the establishment of woodland habitat networks in the National Park as envisaged in the *Wales Woodland Initiative-Strategy* (Anon., 1998), although Purdy and Ferris (1999) and Good *et al.* (2000) did study objective approaches to the development of forest habitat networks in England and mid-Wales accordingly. In Chapter 5, a methodological approach to woodland creation and restoration modelling responsive to regional conditions and taking account of the needs of non-woodland habitats is established, through the integration of ideas developed in studies by Good *et al.*, (1997), Purdy and Ferris (1999), Gkaraveli (1999), and Good *et al.*, (2000).

In any approach to native woodland creation and restoration of replanted sites it is normally appropriate to have target woodland types in mind, although this may not be required in cases where natural regeneration is an option. Although modelling techniques are becoming available to predict the distribution of National Vegetation Classification (NVC) communities at site (Pyatt and Suárez, 1997; Pyatt *et al.*, 2001) or regional scales (Macmillan *et al.*, 1997; Gray and Stone, in prep.), the distribution and relationship of NVC woodland communities present in Snowdonia with environmental factors has never been studied. Such methods have yet to be widely used in Wales. A suitability model that predicts and maps the occurrence of NVC woodland communities and sub-communities, and Biodiversity Action Plan (BAP) Priority Habitat Types in the Snowdonia National Park has been developed. This work is described in Chapter 6.

The management of all natural resources must now meet global, national, regional and local targets and guidelines. For this to be achieved in a co-ordinated, timely and effective manner, policy makers, managers, ecologists, foresters, economists and field staff must have access to both spatial and attribute data. The techniques for combining, managing and modelling such data are available in Geographical Information Systems (GIS). A GIS can be used to manage the spatial referenced datasets and integrate data in a computer-based platform to inform management decisions through simulation modelling. The main task of this research was to find a means of implementing all the studies that could be made by accessing existing data and utilising the GIS resources of the University of Bangor.

Chapter 7 brings together results from the studies, discusses the outcomes in more detail and makes suggestions for future research; Chapter 8 draws conclusions regarding this work.

The objectives of this work therefore were:

1. To characterise and quantify changes in the woodlands of the Snowdonia National Park, during the period 1970-2000.
2. To model the present-day distribution of broadleaved and scrub woodland in Snowdonia, and extend the model to make predictions of future distribution in anticipation of climate change.
3. To consider GIS modelling as a means of identifying priority areas in the National Park for native woodland creation and restoration.
4. To predict and map the distribution of NVC woodland communities and BAP Priority Habitat Types in Snowdonia for current environmental conditions.
5. To examine differences in the results of multi-temporal woodland surveys, and to test techniques for analysing, interpreting and using such data for management applications such as those in 1 to 4 above.

CHAPTER 2

'Apart from the beauty
and charm of its high mountains,
Snowdonia has inspiring natural
and semi-natural habitats'.

SNPA (1999).

2.0 SNOWDONIA NATIONAL PARK

The Snowdonia National Park, in north Wales, was established in 1951 and is the second largest of the ten National Parks of England and Wales, covering 2142 km^2 mainly of deep valleys, rugged mountains, with a 37km coastline (Figure 2.1). The National Park takes its name from Snowdon which, at 1085m, is the highest peak in Wales and England.

The intention of this Chapter is to describe the study area and provide general information on its location, topography and wildlife.

2.1 Ownership and land use

Snowdonia is essentially owned by its inhabitants, many of whom also make their living off the land. Up to 75% is in private ownership, while the remaining land is divided between Forest Enterprise, Dŵr Cymru, the National Trust and others, with the Snowdonia National Park Authority owning less than 1%.

Ancient stone burial chambers indicate the intimate relationship humans and wildlife have had in Snowdonia since 4000 BC (SNPA, 1999). Since these Neolithic times, humans have settled and farmed in Snowdonia increasingly modifying the land, changing it from area covered by broadleaved woodland to the rugged Snowdonia of today with the introduction of pasturalism and the development of larger settlements.

Today the main land use is sheep farming and, to a lesser extent, cattle farming. More recently coniferous forestry has become important. One of the biggest industries to make its mark is slate quarrying, and tourism and leisure industries are becoming increasingly important.

About 15% of the land is wooded and consists of broadleaves, conifers, mixed forest, and scrub (Figures 2.2, 2.3 and 2.4). Coniferous forest plantations in the study area are wholly comprised of non-native species, chiefly Sitka spruce (*Picea sitchensis* (Bong.) Carr.).There are, however, scattered native yew woods in Wales as understorey in oak and birch woodlands, and juniper woods in small numbers heavily

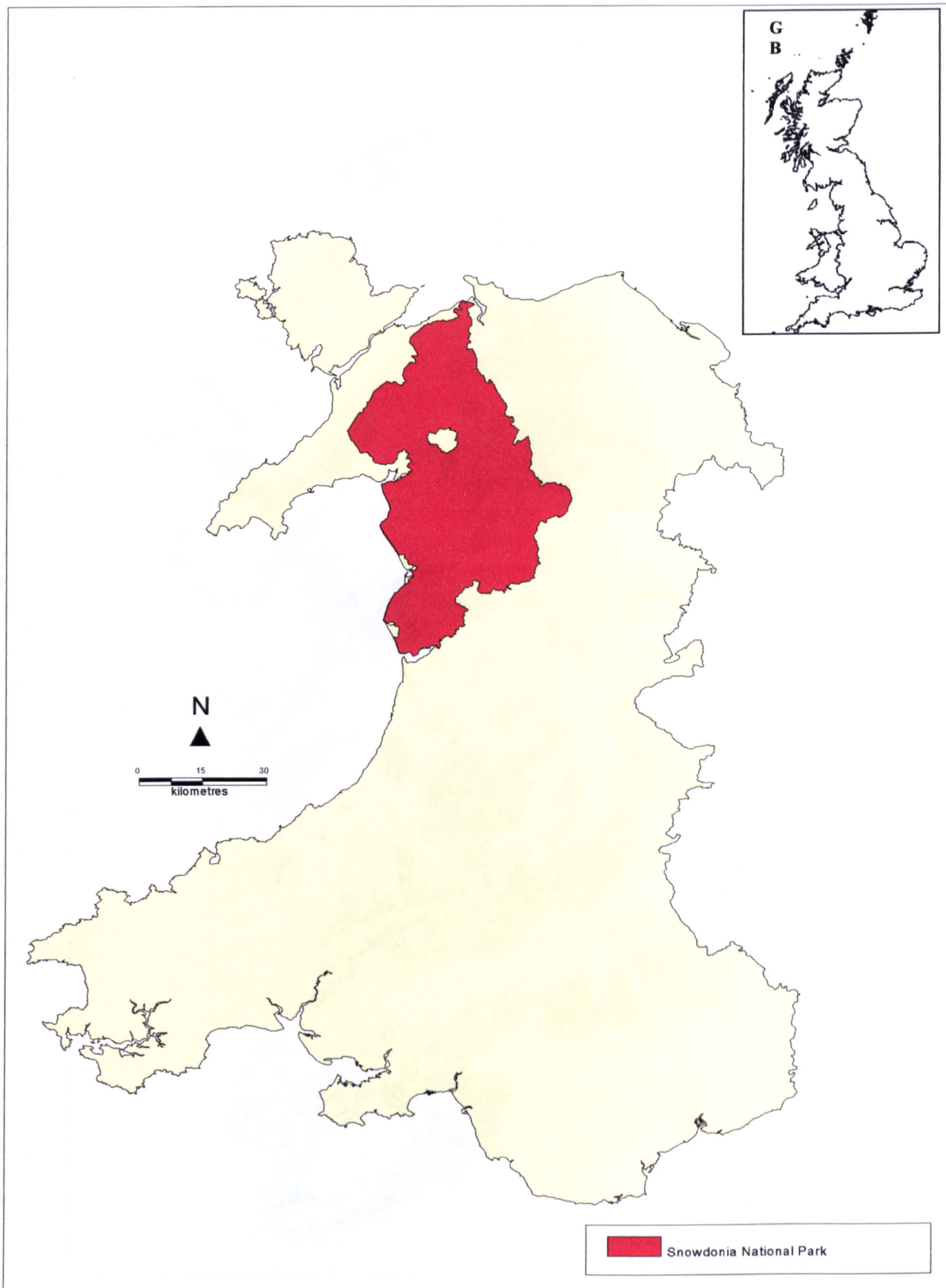


Figure 2.1. Location of the Snowdonia National Park in Wales, UK.

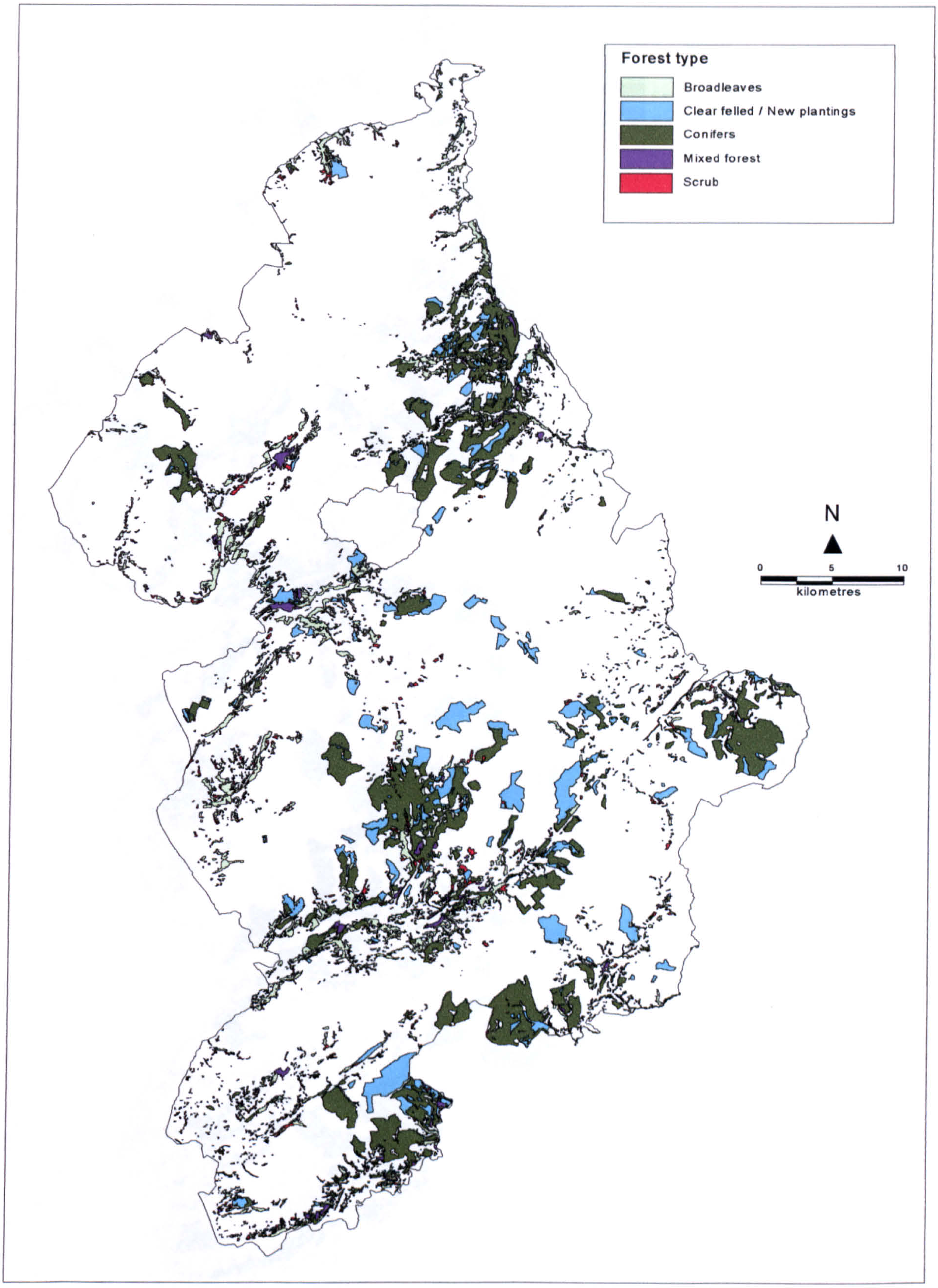


Figure 2.2. Forest types in Snowdonia from the land cover map of the 1970s (Taylor, 1991).

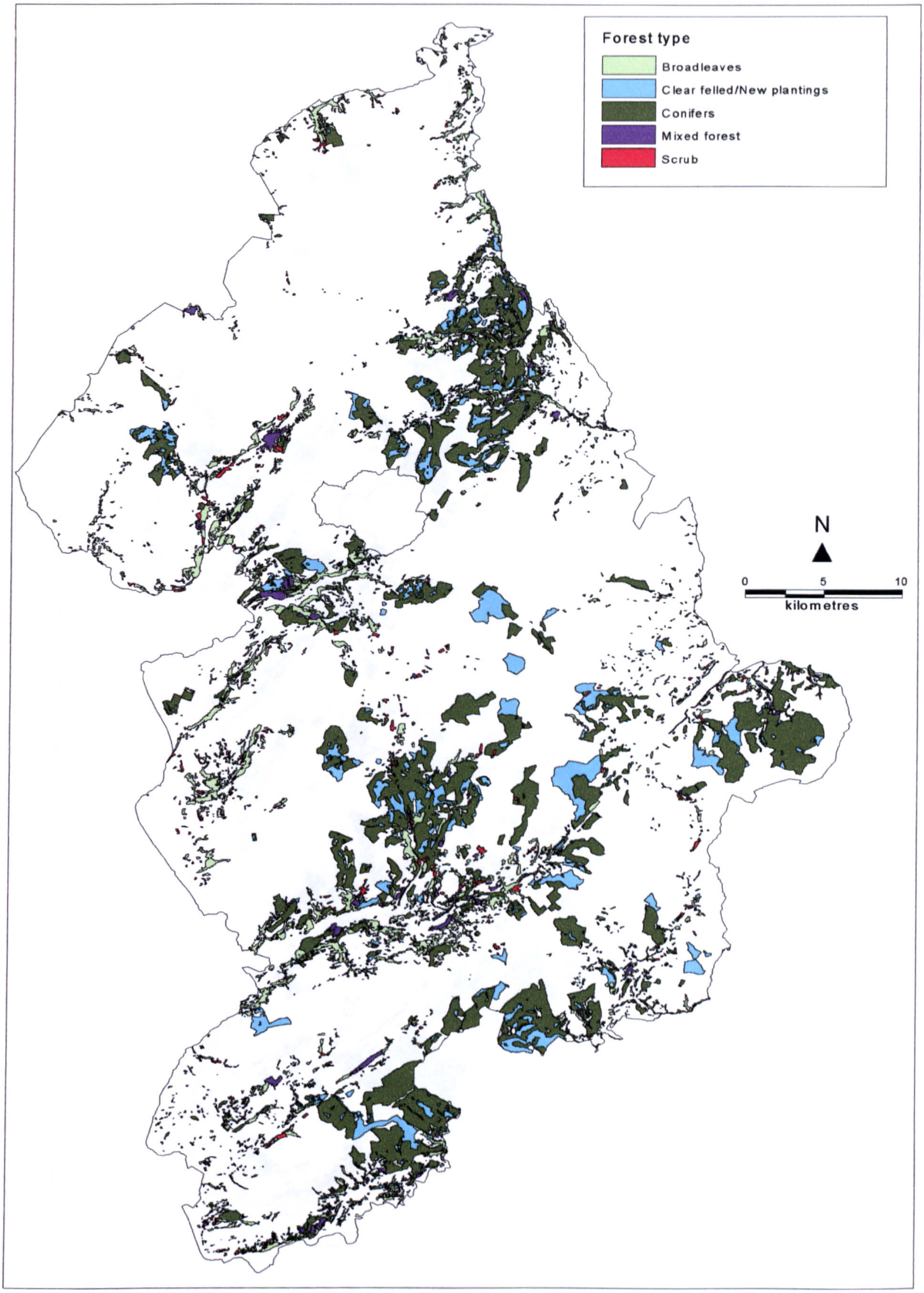


Figure 2.3. Forest types in Snowdonia from the land cover map of the 1980s (Taylor, 1991).

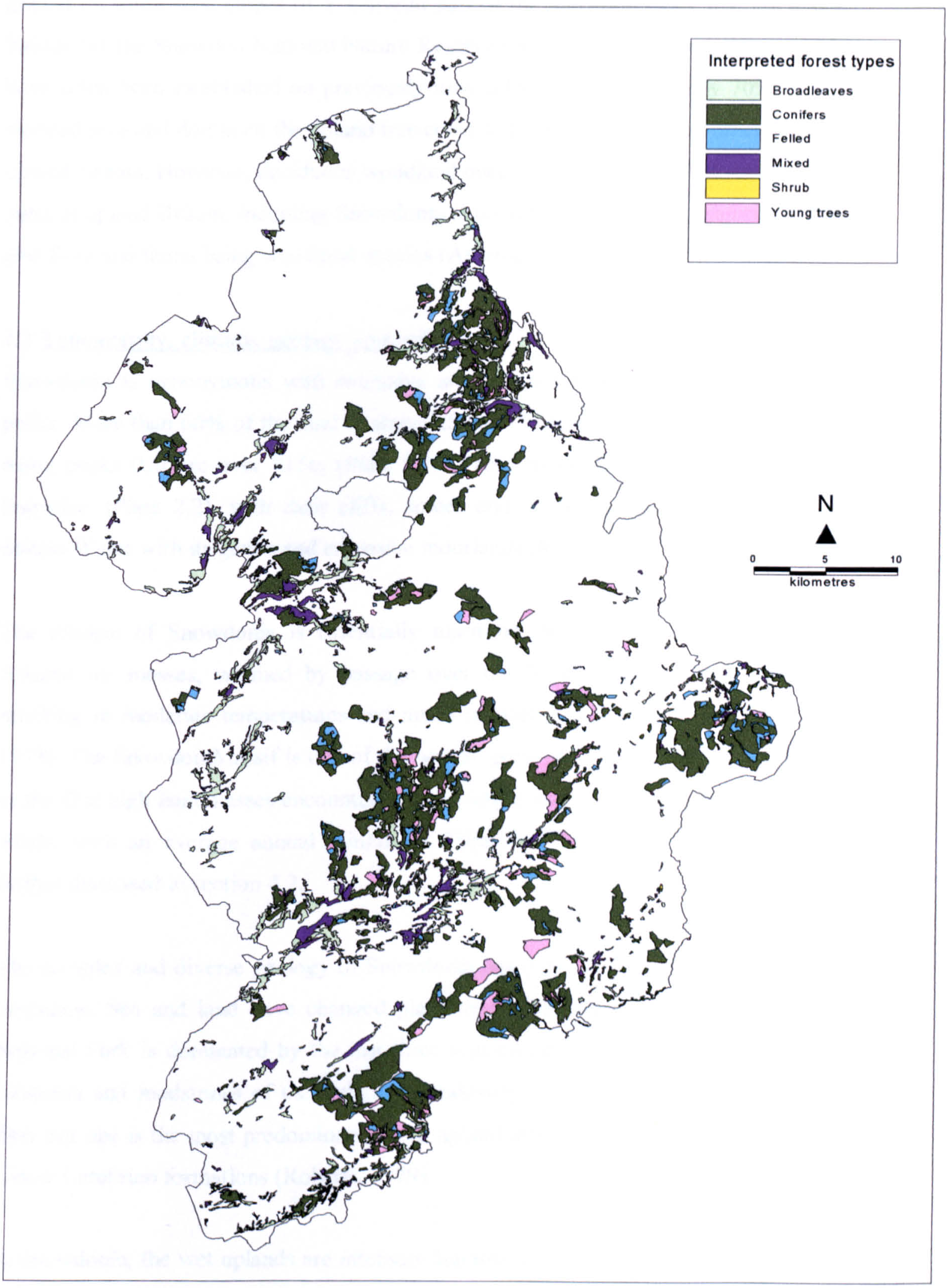


Figure 2.4. Forest types in Snowdonia in the 1990s (Forestry Commission, 2001).

grazed on south-west slopes of Y Lliwedd part of the Snowdon block that are a key habitat for the Snowdon National Nature Reserve (NNR). Conifer plantations, which have often been established on previously unwooded land, cover nearly 70% of the wooded area and dominate the upland tree cover in the Park, as in many other parts of upland Britain. However, deciduous woodland once formed the natural cover for large parts of upland Britain, including Snowdonia (Linnard, 2000) with the majority of the past flora and fauna being woodland species (Atherden, 1992).

2.2 Topography, climate, geology and soils

Snowdonia is synonymous with extensive areas of windswept uplands and jagged peaks. More than 60% of the land is above 250m. The nine mountain ranges include many peaks that are over 915m (Plate 2.1). These mountains, rising to 1085m on Snowdon (Plate 2.2), with their cliffs, screes and lakes, contrast with the rest of upland Wales with its gentle and extensive moorlands (Rudeforth *et al.*, 1984).

The climate of Snowdonia is essentially maritime, being under the influence of Atlantic air masses, warmed by passage over the North Atlantic Drift, and thus resulting in moderate temperatures and much rainfall throughout the year (Perkins, 1978). The Snowdon Massif is one of the wettest parts of the British Isles, being one of the first high land masses encountered by moisture-laden prevailing south westerly winds, with an average annual rainfall of 2508mm (Williams, 2001). Climate is further discussed in section 4.2.

The complex and diverse geology of Snowdonia has done much to shape the present landscape. Sea and land have changed place more than once. The majority of the National Park is dominated by the last three sedimentary formations, mainly slates, siltstones and mudstones of the Ashgill, Llandovery, Llandeilo and Caradoc series. This last one is the most predominant in the upland areas followed by the Upper and Lower Cambrian formations (Roberts, 1979).

In Snowdonia, the wet uplands are intensely leached and strongly acid. Podzolization influences most of the soils and ferric stagnopodzols, humic rankers and brown podzolic soils are most extensive in the upland areas of the National Park.

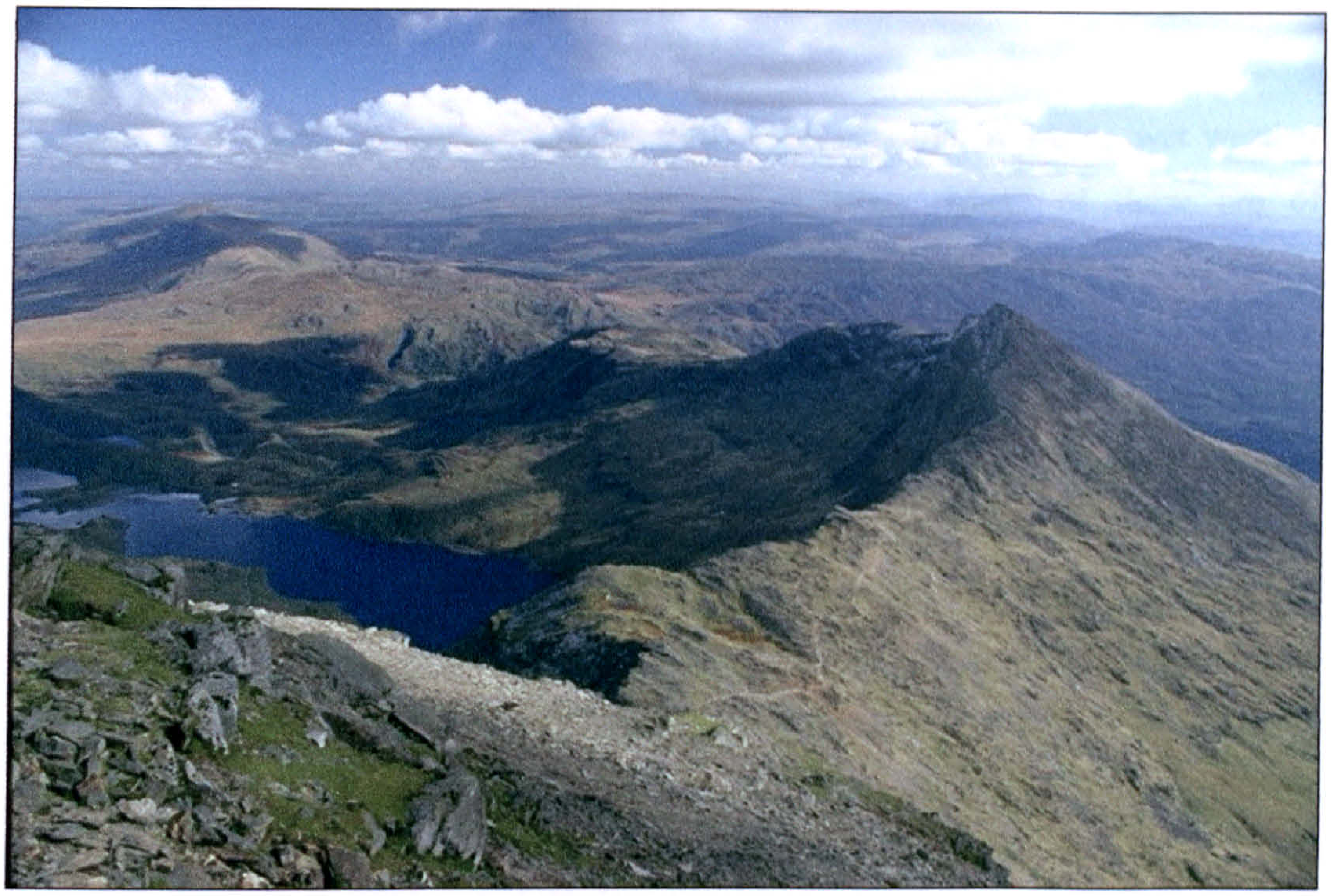


Plate 2.1. From Snowdon summit looking SE (SH 615 545) (taken by J.H. Williams, 1995).

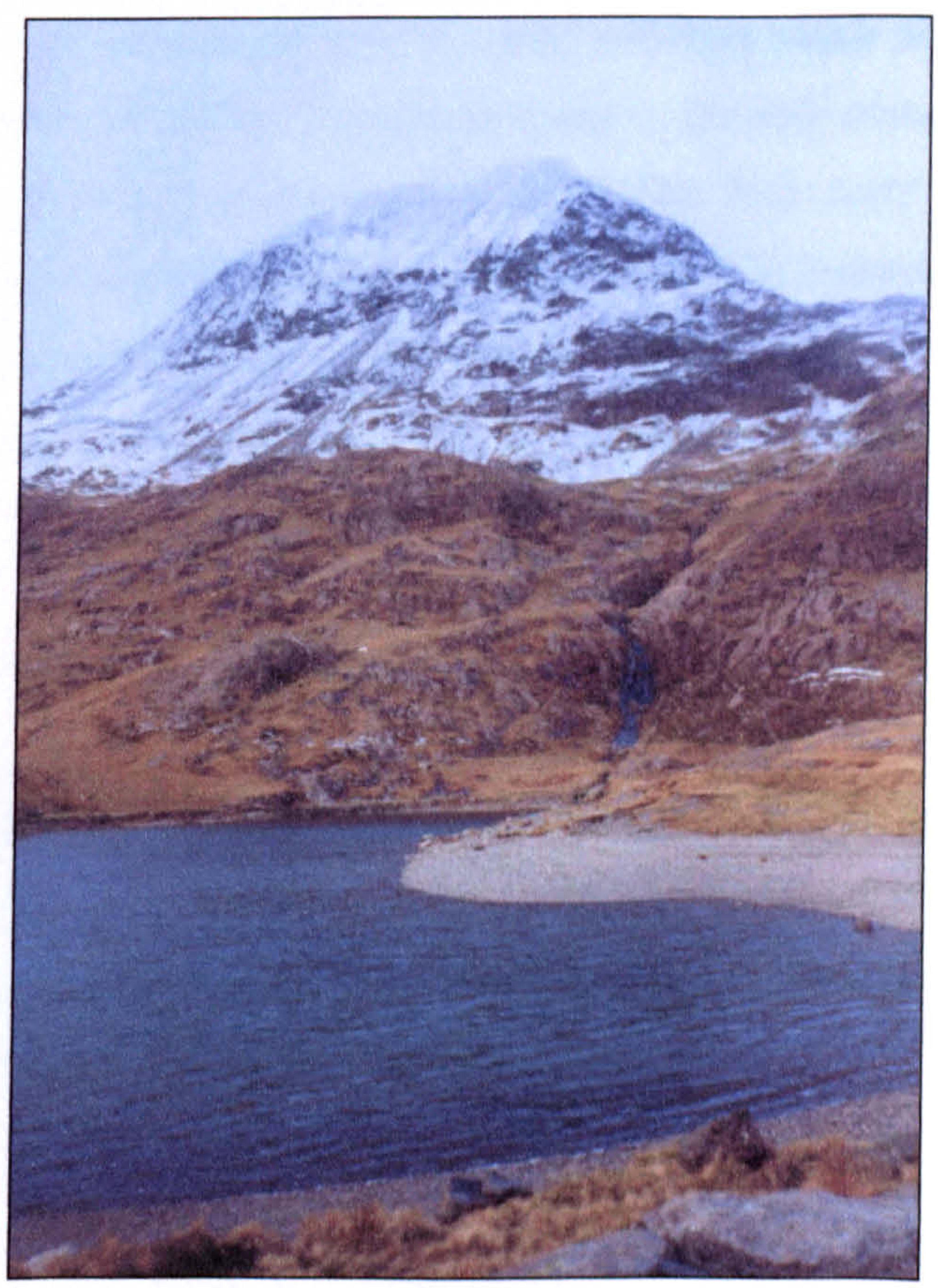


Plate 2.2. Snowdon (1085m)-looking WN, the highest peak of England and Wales (SH 640 540) (taken in February 2001).

2.3 Wildlife

Located on the western edge of Europe, Snowdonia is swept by warm, wet weather that supports thousands of species and their habitats. Many of these are of international importance and some are found nowhere else in the world.

The range of habitats found in Snowdonia is recognised nationally and internationally by the numerous designations ranging from Local Conservation Areas and Sites of Special Scientific Interest to Special Areas of Conservation, and the Dyfi Estuary which is a Word Biosphere Site (Figure 2.5). With such complicated geology and habitat variety, it is not surprising that more National Nature Reserves have been designated in Snowdonia than in any other comparable area in Britain. Approximately 20% of the National Park is specially designated or declared under UK and European law, to protect characteristic features of its wildlife (SNPA, 1999).

Plants of notable interest include the arctic-alpines that are found in the high mountains, such as the Snowdon Lily (*Lloydia serotina*) which is endemic and only found in Snowdonia in the UK. Snowdonia is one of the only places in Britain where the chough (*Pyrrhocorax pyrrhocorax*) a crow-like bird nests inland, using the artificial crags of abandoned quarries. Several mammals in Snowdonia are nationally rare including the dormouse (*Muscardinus avellanarius*), watervole (*Arvicola terrestris*), red squirrels (*Sciurus vulgaris*) and pine marten (*Martes martes*) (SNPA, 1999).

Upland oak woods and especially ravines within them, are especially important habitats because of their unusual communities of mosses, liverworts and lichens which makes them internationally important (Plates 2.3 and 2.4). Furthermore, Mixed ashwoods are a relatively rare habitat that occurs within Snowdonia and amongst the richest habitats for wildlife in the uplands, notable for flowers, lichen flora, rare beetles, flies and other invertebrates (SNPA, 1999).

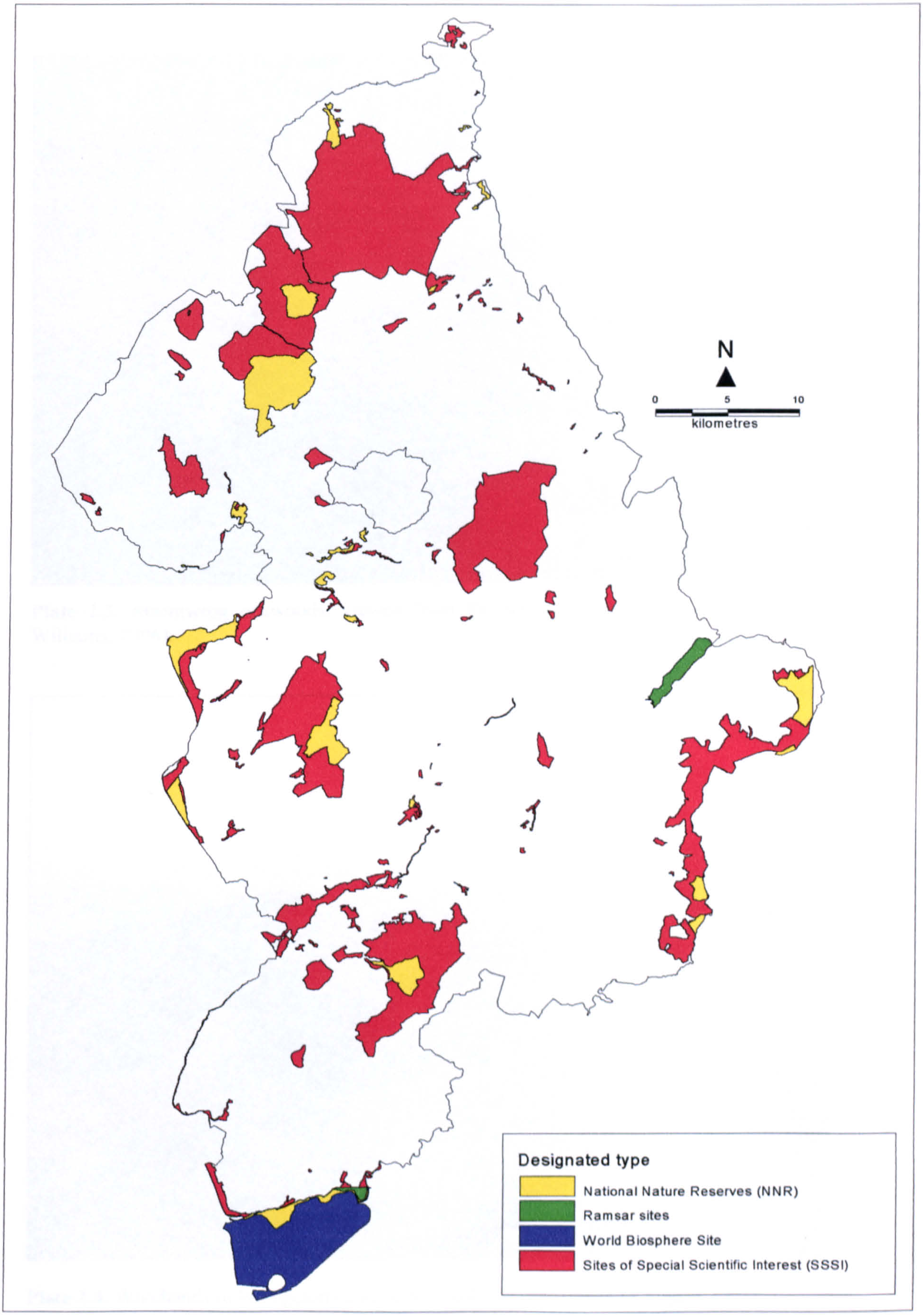


Figure 2.5. Designated areas in Snowdonia.

Plate 2.3. Maentwrog oakwoods, viewed from the south (SH 660 430) (taken by J.H. Williams, 1996).

Plate 2.4. Woodlands in Beddgelert-looking NE (SH 630 465) (taken in August 2001).

CHAPTER 3

'Long term research on land use and land cover changes can provide a temporal context in which global environmental change becomes visible'.

Magnuson (1995).

3.0 RECENT CHANGES IN WOODLANDS: DRIVING FORCES AND SPATIAL ANALYSIS

Landscape change is a naturally occurring phenomenon that has been compounded by human activities. Driving forces of landscape change can be either physical, as for example natural disturbance and forest development (Foster *et al.*, 1992), or they can be anthropogenic, such as property ownership (Turner *et al.*, 1996) and land-management schemes. Influences causing change within landscapes occur at many temporal and spatial scales, making the study of landscape change a complex, multi-dimensional problem.

Remote sensing and geographical information systems (GIS) have provided the basis for recent exploration of spatial processes within the landscape and have proven to be valuable tools in the field of landscape ecology (Forman and Godron, 1986). Repeated aerial photographs and/or satellite images play a major role in setting up inventories of natural resources as they give a visual assessment of land cover change over a period of time and provide quantitative information on the dynamics between different land cover categories. There have been many studies using remote sensing and GIS that have described landscape change through time (*e.g.* Turner, 1990; Reed *et al.*, 1996; Pan *et al.*, 1999; Tekle and Hedlund, 2000). In Britain, a project carried out by Silsoe College (Taylor, 1991) on behalf of the Countryside Commission and National Park Authorities provided statistical and mapped information for the National Parks. This included the extent, distribution and change over time of the wide range of landscape features (linear, small or isolated points, land cover changes) which exist in the National Parks of England and Wales, including the Snowdonia National Park in north Wales. Changes in the landscape characteristics of the main vegetation categories in the Snowdonia National Park over time were not however analysed in that 1991 project.

Four scenarios have been set out (National Assembly for Wales, 1999) offering a range of options for the future of Welsh woodlands and the timber industry in Wales. All are based on assumptions about future policies and budgets, and take account of the need to protect and enhance biodiversity and landscape values. In devising these options the Habitat and Species Directive (Council of the European Communities,

1992) was consulted. This refers to the need to promote the conservation of hedges, walls and other features (such as small woods) that might act as 'stepping stones' or 'corridors' to promote species movement through the countryside. This approach has been taken forward in Wales through the development of plans for a forest habitat network including core woodland areas (Anon, 1998a). In addition, Tir Gofal, a new all-Wales agri-environment scheme, recognises the need to create and enhance natural habitats on farms wherever possible. A number of prescriptions are proposed including the planting of new woodland and the creation of wildlife corridors along streams and rivers (CCW/FC Wales, 1999).

When applying any of these scenarios or guidelines to woodland conservation planning in the National Park it is helpful to assess changes in the landscape characteristics of the main Snowdonian woodland vegetation types over the past and relate them to changes in national policy. This aids understanding of the relationships between their present conservation status and past landscape change associated with forest planting and loss. With policies such as the new agri-environment schemes underway, a more detailed understanding of past patterns of change in the landscape of the National Park will aid predictions of where most future changes can be expected to take place. This study represents the first large-area analysis of landscape structure and change combining data from different sources in the Snowdonia National Park.

The objectives of the research described here were to:

1. use the functionality of GIS technology to characterise and measure changes in the woodlands of Snowdonia, north Wales, UK, during the period 1970-2000;
2. relate these woodland dynamics to changes in national policies and determine the likely processes that shaped the landscape of the Park during the study period;
3. use landscape indices to analyse the changes in forest patches in terms of their area, density, degree of isolation and shape in order to understand their spatial distribution and connectivity; and
4. consider the implications of the pattern of woodland change for future ecological conditions.

3.1 Forest history in Wales

Pollen evidence in mid-Wales suggests that many upland areas formerly supported an extensive mixed woodland but successive clearance episodes, attributed mainly to human activity, reduced the previously wooded landscape to open grassland and upland heath (Walker, 1994). This continuing story of how humans have used, destroyed and modified the woodlands of Wales over the centuries and their changing attitudes to woods, is important for understanding much of the Park's landscape today.

Woodland history in Britain began after the end of the last glaciation, about 11,000 BC, when tree species which had retreated to warmer latitudes during the Ice Age started the recolonisation of land that became suitable for their establishment (Rackham, 1986). The first tree species to colonise large areas of Wales was birch (*Betula spp.*). The next invading species of tree was pine (*Pinus spp.*) followed by species such as oak (*Quercus spp.*), elm (*Ulmus spp.*) and hazel (*Corylus spp.*) (Linnard, 2000).

By about 7,000 years ago, there was a period of climatic stability during which tree species formed a series of 'climax' woodland types that covered all the British Isles. In upland England, Wales and southern Scotland there was a mixed deciduous woodland with oak and hazel as the most important species, whilst pine and birch remained dominant in the Scottish highlands (Atherden, 1992). During this period almost the entire land surface of Wales carried forest except the highest mountains and areas of sand, lakes, bare rock, salt marsh or very exposed sites (Linnard, 2000). These forests constituted the natural woodlands which existed prior to large scale human activity and the destruction of forests for farmland and moorland (Rackham, 1986).

In the space of a few millennia the natural vegetation of the whole of Wales had been radically altered, mainly as a result of deliberate human activity in the form of cultivation and stock-grazing. The most obvious and fundamental consequence has been the reduction of the forest area from a maximum of some 90% of the land area to between 4 and 5% by the beginning of the 20th century. This long process of decline in forest area had also occurred in all other countries of Europe, but nowhere was it more pronounced than in the British Isles, and especially in Ireland and Wales (Linnard, 2000).

The long period of devastation presumably began with the earliest settlers, during Neolithic times, who cleared the easier slopes for shifting cultivation and grazed livestock in the more open woodlands. As technology advanced, forest clearance spread into denser forest; the process accelerated through Roman and medieval times, with extensive clearance of areas needed to house and feed the growing population and vast felling programmes to ensure security along military routes (Lacey and Morgan, 1989, cited in Linnard, 2000). From the sixteenth century onwards, woods have never covered more than 10% over much of Wales and only in a few areas such as remote valleys has there been as much as 20% forest cover (Linnard, 2000).

The story has been one of destruction following degradation after exploitation, until by the early 20th century the forest resource had dwindled away to mere fragments of its former glory. However, the 20th century brought a considerable change in the tree cover of North Wales, with forest now occupying about 12% of the ground area (Linnard, 2000). This is the result of commercial plantations made in Wales mainly from the end of the 19th century onwards, marking the beginning of upland afforestation (Atherden, 1992). For economic reasons and also because of the nature of the sites available, most recent plantations have been of exotic conifers such as Sitka spruce, larches (*Larix spp.*), Douglas fir and lodgepole pine.

The area of woodland in Wales had been in decline for a long time prior to the formation of the Forestry Commission in 1919. After its establishment the Forestry Commission set about reversing the long decline in forest area, its remit being to produce a strategic timber reserve for use in case of future conflict. The total area of Forestry Commission plantations in Wales peaked in the year 1982/83, with 136 849 ha (Linnard, 2000) (Table 3.1) and then declined as disposals took place during the era of privatisation in the eighties and nineties, up until the recent moratorium on large sales. It also shows how new planting (*i.e.* afforestation of bare land) has virtually stopped, while restocking of felled areas and volume production have increased steadily and inexorably as the forests approach maturity. The total area of woodlands in Wales from 1871 to 1992 is shown in Table 3.2.

Table 3.1. Forestry Commission plantation area, annual planting and production (thinnings plus fellings) at 5-year intervals from 1975 to 1995 in Wales (adapted from Linnard, 2000).

Year	Total area of plantations (ha)	New planting (ha)	Restocking (ha)	Volume production ('000 m^3 o.b.)
1975	132 300	1 412	649	289
1980	135 902	797	1 241	480
1985	134 407	161	1 300	621
1990	127 029	96	1 364	689
1995	118 863	0	1 972	912

Table 3.2. Total area of woodlands over 0.25ha in area in Wales, 1871-1992 (adapted from Linnard, 2000).

Year	Area (ha)	Area as % of land area of Wales	Year	Area (ha)	Area as % of land area of Wales
1871	62 797	3.02	1938/39	127 530	6.2
1887	77 182	3.72	1947	141 000	6.8
1891	84 365	4.06	1965	202 000	9.7
1895	86 778	4.17	1980	241 000	11.6
1905	87 655	4.20	1992	248 000	11.9
1913/14	87 649	4.20			
1924	102 615	4.90			

Wales now has 12% of its land area under woodlands, and is certainly more wooded than at any time since the Middle Ages. For comparison, the figure for England is only about 7.5% and for Scotland 14.5%, while for Denmark it is 12%, France 27%, Ireland 5%, Netherlands 9% and Sweden 70%.

On 1st July 1999 the Welsh Assembly assumed full power for funding and directing the Forestry Commission in its activities in Wales. The UK government, jointly with the Assembly as regards Wales, will continue to ensure an overall strategic approach for forestry in the UK, and Welsh policies must fulfil and be consistent with the UK's international and European Union obligations (Linnard, 2000).

3.2 GIS and landscape change over time

A Geographic Information System (GIS) is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough and McDonnell, 1998). Basically a GIS consists of a digital cartography information display, powerful processing modules and linked database containing the attributes of point, line or area features (Burrough, 1994; Lillesand and Kiefer, 1987).

GIS methodologies have been used in a wide variety of settings such as civil engineering, military planning, landscape architecture, land-use planning, vegetation modelling, agriculture and forestry. In landscape ecology, GIS technology can be used for interpreting land-use policy and modelling the effects of land-use change, for assessing and monitoring the impact of human activity on spatial patterns and ecosystem dynamics, and for manipulating and displaying the information for those involved in studying or planning the landscape and its use.

In Britain, a project carried out by Silsoe College (Taylor, 1991) on behalf of the Countryside Commission and National Parks Authorities provided statistical and mapped information on the extent, distribution and change over time of the wide range of landscape features (linear features, point features and land cover types) which exist in National Parks of England and Wales, including the Snowdonia National Park. The study involved interpretation of aerial photographs at two dates, ground survey, transformation of the information obtained from the aerial photographs into a digital format, analysis and output of statistics using a GIS and accuracy assessment to quantify the magnitudes of errors from the different sources.

Reed *et al.* (1996) reconstructed and quantified the change in landscape structure in a part of the Medicine Bow National Forest, Wyoming, USA, during the period 1950-1993. Forest fragmentation as a result of clearcut logging from 1950 to 1993 was quantified using a GIS in combination with the r.le. (rule) patch program (Baker and Cai, 1992) to calculate twelve indices of landscape structure. The observed trends in landscape pattern indicated increasing forest fragmentation since 1950 and suggested that previous management practices had lacked monitoring and analysis of landscape-scale impacts, indicating that increased attention to the landscape-scale was needed in future management actions.

Changes in vegetation patterns associated with fire exclusion in northern Patagonia, Argentina were examined across a range of spatial scales from local changes in patch boundaries to regional changes in broad cover types by Kitzberger and Veblen (1999). A GIS was used to quantify changes in land cover at a regional scale based on comparison of vegetation maps from 1913 and 1985. Changes in landscape structure based on comparison of vegetation patterns on aerial photographs taken in 1940 and 1970 were evaluated by comparing a series of metrics that quantify landscape composition and pattern using FRAGSTATS software (McGarigal and Marks, 1994).

Remote sensing, GIS, and global positioning system (GPS) techniques were utilised by Duncan *et al.* (1999) to map historic land cover and compare landscape dynamics with both past and present management practices in two sites of Florida, USA. The primary aim was to understand the relationship between management treatment and land cover response. The analysis showed that humans had played an important and active role in determining current landscape composition at both study sites.

A rural landscape of Canada was studied by Pan *et al.* (1999) to detect spatial and temporal (1958 to 1993) patterns of land cover changes at field, patch and landscape level. Spatial analyses were carried out by a GIS in order to describe structural landscape patterns and overall land use changes over time and measure the rate of change. The overall land use dynamics were then related to physical features of the landscape using the GIS and canonical correspondence analyses. Different geomorphological deposit types were used as stable discriminant factors which may constrain land use. The study showed that although land use changes were triggered by socio-economic forces in the area, these changes were nevertheless constrained by the underlying physical landscape structure.

Kramer (1997) used remotely sensed images and GIS to characterize and measure changes in the vegetation of a Costa Rican Park from 1979 to 1985. Spatial pattern analysis was performed using FRAGSTATS software (McGarigal and Marks, 1994). As the author pointed out, GIS are powerful tools that allow the user to expand his view beyond the isolated forest patch or nature reserve. Their use is becoming increasingly important because forest remnants do not exist in isolation. Physical and biological factors affecting a patch are controlled by the type of vegetation adjoining the forest edge as well as the shape, size, and position of the patch within the surrounding landscape. In combination with remote sensing GIS can be used to quantify landscape patterning, guide our research questions and develop frameworks for modelling.

3.3 Data sources and methodology

This section describes the data obtained from different sources and outlines the way the landscape analysis was done.

3.3.1 Data sets

The data sets used in the study were derived from two different sources and are subject to their accuracy and limitations. The 1970s and 1980s land cover maps of the entire Snowdonia National Park were obtained from an aerial photography/ground survey undertaken for a research project carried out by Silsoe College (Taylor, 1991). The 1970s coverage of Snowdonia consisted of five sets of aerial photography from 1971, 1973 and 1976 whereas the 1980s coverage consisted of two sets both taken in 1990. The resulting maps were manipulated using the IDRISI for Windows v.2.0. geographical information system (GIS) (Eastman, 1997). Both were with a 20m pixel resolution and were converted to IDRISI format from SPANS GIS system used by Silsoe. The conversion produced an IDRISI map of 3384 columns x 4480 rows with a 19.89m pixel resolution. This was the result of conversion of maps from one GIS to another. The minimum size of woods mapped was 0.25ha. Both land cover maps had 38 cover types and included five categories of woodland cover type within the area. These included broadleaved, coniferous and mixed high forest, scrub and clear felled/new plantings. According to each category definition, broadleaved and coniferous high forest are areas greater than 0.25ha which are wider than 20m and have a tree canopy of at least 20% by area, and 80% at least of the canopy is of broadleaved or coniferous species respectively. Mixed high forest areas are greater than 0.25ha, wider than 20m and have a tree canopy of at least 20% by area, and 80% at least of the canopy is composed of an intimate mixture of broadleaved and coniferous species. Scrub areas have diffused boundaries with less than 20% cover by area of mature timber species and with a rough understory of shrubs and grasses. Clear felled/new plantings are areas that have recently been felled or planted. A full description of each category is given in Appendix 1.

The 1990s woodland map of the National Park was provided by the Forestry Commission as part of their national inventory of woodland and trees (Forestry Commission, 2001). This was based on 1997 aerial photography interpretation and ground survey work carried out during 1999. The Forestry Commission woodland data were supplied for woodland of 2ha and over. The original ArcShape vector file received was converted to an IDRISI vector file and then to a raster image (POLYRAS module in IDRISI) having a 19.89m pixel resolution in order to compare woodland changes with the 1970s and 1980s land cover maps. The National Inventory of Woodland and Trees (NIWT) digital map identifies six categories of interpreted forest types (IFT) for Snowdonia defined as following: (1) broadleaved forest, with greater than 80% of the area consisting of broadleaved trees; (2) coniferous forest, with greater than 80% of the area consisting of conifers; (3) mixed forest, with greater than 20% proportion of both conifer and broadleaves; (4) shrub, which includes areas that may possibly be woodland and the cover is at least 20%; (5) young trees and (6) felled woodland, containing areas of woodland that the trees have been harvested or felled with a canopy cover less than 20%. Appendix 1 provides full descriptions for each woodland cover type.

The Forestry Commission also conducted a survey of small woods and trees (woodland less than 2ha) that was completed in 2001. For this survey, the land area of Wales was stratified into coastal and inland 1km x 1km squares and a random sample of 1km^2 plots were then selected, representing around 1% of the land area. 1:25 000 scale aerial photos were then used to identify features in each sample square. Each 1km^2 was then divided into 16 parts, and two of these were selected at random for field data collection. Data was collected on small woodlands (0.1-<2.0ha), linear features, groups and individual trees (Brown, 2001). There were 23 x 1km^2 sample plots within Snowdonia. The analysis of this data gave 453ha of woodland (all broadleaved) in 566 small woods (average size of 0.8ha). These ground samples refined the estimate of woodland area, and gave a more precise breakdown by Forest Type (FT); it is these results that appear in Forestry Commission's reports. The FTs in this NIWT ground survey were: conifer, broadleaved, mixed, coppice, felled and open space. It is noteworthy that some IFTs do not appear as FTs. Young trees, for instance, can be identified as conifer, broadleaved or mixed forest, and shrub is either woodland or it is shrub species, not regarded as woodland (Smith, 2001). The small woods survey was sample-based only, so there was no map that could contribute to the spatial analysis. However, the results of this survey were used in this study because they can be useful for detailed analysis or comparison of woodland changes over the past decades.

3.3.2 Landscape analyses

The detection of landscape change involved overlaying the 1970s, 1980s and 1990s land cover and woodland maps respectively. To examine pixel-to-pixel changes in cover class, the 1970s and 1980s images were cross-tabulated (CROSSTAB routine in IDRISI). This yielded a 5x5 cross-classification table that indicated class-to-class transition areas. The procedure was repeated for the 1980s and 1990s maps.

To analyse woodland change within the National Park from the 1970s to 1990s in relation to changes in national policy, information was gathered on policies relating to forestry from the 1960s to the present. The findings were used to evaluate the likely key factors for landscape change during the study period.

Overlay techniques are useful for determining trends in landscape change, but additional information on patch spatial distribution and shape is necessary to examine why and how the landscape is changing. Spatial pattern analysis was performed using the FRAGSTATS v.2.0 software (McGarigal and Marks, 1994). This software is perhaps the most comprehensive set of landscape indices to be found in a single program (Haines-Young and Chopping, 1996). The structural changes in the forested area of the Park were evaluated by comparing a series of metrics that quantify landscape composition and pattern. Changes in cover types were analysed by comparing the percentage area (PC) and number of patches (NP) in each decade. Changes in patch size distribution were assessed by computing the mean patch size (MPS) and patch size standard deviation (PSSD) in the 1970s, 1980s and 1990s. The mean shape index (MSI) (average perimeter-to-area ratio measured against a square standard) was used to assess changes in the complexity of patch shapes. MSI equals 1 when all patches are square and increases when patches become more irregular. Patch isolation was quantified with the mean nearest-neighbor distance (MNN) (average distance from a patch to the nearest neighboring patch of the same type, based on edge-to-edge distance) and patch dispersion with the nearest-neighbor standard deviation (NNSD). A small NNSD relative to the mean implies a fairly regular distribution of patches across the landscape (McGarigal and Marks, 1994).

The program calculates a set of pattern metrics for each patch within a landscape, each cover class within a landscape, and the entire landscape. Because the primary interest was in the amount and distribution of the woodland patch types (classes), the pattern metrics were analysed only for the broadleaved, coniferous, mixed high forest and scrub cover classes within the landscape of the National Park. The 1970s, 1980s and 1990s maps were resampled (RESAMPLE routine in IDRISI) from 19.89m to 20m pixel resolution in order to use the FRAGSTATS software. An experiment in FRAGSTATS, using the maps with their original resolution, gave an error message that '*pixels in the image must be square*'. All the maps of the entire Park were then reclassified to form new images with a unique identifier for each woodland patch type. All other categories of the existing maps were coded as non-forested land which was considered as the matrix with woodland patches embedded within. The area outside the Park was coded as background cover, so that it was not treated as patch itself, but formed a distinct edge. To achieve this the land cover maps were reclassified again to create mask images containing only land outside the Park and all land uses being given the value of zero. Because the background has to be typically set to a negative integer non-patch code, the mask images were multiplied by a negative integer non-patch code number (SCALAR process in IDRISI). The latter images were then overlaid on to the reclassified cover maps to create the analysis maps, used to run FRAGSTATS. Eight-neighbor tracing, which considers any two adjacent pixels to be a part of the same patch if they only share a common side and common corners, was used for patch definition, and zero proportion of the landscape boundary and background class edges was selected to be considered as edge. A complete definition of all metrics included in the analysis and all algorithms used in their calculations are given in FRAGSTATS manual (McGarigal and Marks, 1994).

The size distribution of woods over the past three decades was compared across the whole Park. The size of each woodland patch in the 1970s and 1980s was computed in IDRISI using the GROUP, OVERLAY and AREA procedures. The 1990s woodland dataset provided by the Forestry Commission included a file having the size of each woodland patch in the landscape of the Park. An experiment in Cartalinx v.1.2 software (Hagan and Eastman, 1999), using the converted IDRISI vector file from the original ArcShape vector, provided exactly the same number and size of woods in the landscape and showed that there were no distortions in the dataset following conversion from one GIS to another. In addition, the class area, number of patches and mean patch size statistics for each woodland patch type given by FRAGSTATS were compared with IDRISI computations for the 1970s and 1980s raster maps (19.89m pixel resolution), and an ArcShape file with the 1990s woodland dataset.

The results from the Silsoe College project (1970s and 1980s land cover maps) and the NIWT (1990s woodland cover map) were difficult to compare without the results from the NIWT's survey of small woods and trees because of the different minimum mapping unit chosen in each survey. A summary of the NIWT's small woods results produced by the Forestry Commission was used in this work for a detailed analysis of changes in woodland area and woodland character over the past decade.

3.4 Results of analyses

3.4.1 Woodland cover changes

The proportion of land in the Snowdonia National Park carrying woodland and forest increased from the 1970s to the 1980s by 13% (from 34 378ha to 38 832ha) (Table 3.3). These forests developed from areas that were formerly moor and heath land as well as agricultural land. Moor and heath land declined by 4% (from 100 727ha in the 1970s to 96 284ha in the 1980s). Most moorland and heathland was converted to forest or pasture. Agricultural land showed a slight decrease in area (0.04%) mainly due to the conversion of pasture to forest.

An analysis of the NIWT digital map and its IFT polygons (Table 3.4) showed a decrease in woodland and forest land by 5% (from 38 832ha in the 1980s to 36 763ha in the 1990s), with broadleaved forest apparently declining by 27% (from 8 273ha in

Table 3.3. A transition matrix showing changes (1970s-1980s) in land cover classes for the Snowdonia National Park.

1980s		1970s A	B	C	D	E	Total
Wood and Forest	A	34 156	3 746	921	5	4	38 832
Moor and Heath	B	75	95 871	297	6	35	96 284
Agro-pastoral	C	138	1059	65 274	14	92	66 577
Developed land	D	7	9	105	2 142	219	2 482
Other/not classified land	E	2	42	7	1	9 935	9 987
Total		34 378	100 727	66 604	2 168	10 285	**214 162**

Note: Values shown are in hectares. The row heads at the left represent the classes for the 1980s land cover, while the column heads across the top represent those for the 1970s land cover. The diagonals represent retention values, whereas the off-diagonals show the areas lost (column elements) or gained (row elements) between the two dates.

Table 3.4. A transition matrix showing changes (1980s-1990s) in land cover classes for the Snowdonia National Park.

1990s	1980s BF	CF	MF	Scrub	CF/NP	MH	AP	Other	NCL	Total
BF	4 376	235	150	204	57	359	1 018	31	15	6 489
CF	468	16 696	199	34	4 152	654	398	40	18	22 665
MF	791	774	647	44	95	50	183	17	8	2 616
Shrub	0	0	0	2	3	1	1	0	0	7
YT/F W	48	2 749	20	8	1 597	440	107	12	3	4 986
NCL	2 590	1 155	205	1 081	452	94 780	64 870	9 887	224	177 399
Total	8 273	21 609	1 221	1 373	6 356	96 284	66 577	9 987	268	**214 162**

Note: Values shown are in hectares. The row heads at the left represent the classes for the 1990s land cover, while the column heads across the top represent those for the 1980s land cover. The diagonals represent retention values, whereas the off-diagonals show the areas lost (column elements) or gained (row elements) between the two dates. BF=Broadleaved Forest; CF=Coniferous Forest; MF=Mixed Forest; YT/FW=Young trees/Felled woodland; NCL=Not classified land; CF/NP=Clear felled/New plantings; MH=Moor and Heath; AP=Agro-pastoral.

the 1980s to 6 489ha in the 1990s). However, while some of this loss may be genuine and largely attributable to conversion of broadleaved forest to mixed forest, it is partly spurious resulting from the fact that a substantial part of the broadleaved land in 1980s was not classified in the 1990s. This is because in the Forestry Commission's recent inventory only woodland blocks of 2ha and over were mapped while areas

>0.25ha were mapped in the earlier decades. Studies have stated that broadleaved woods are often small (CCW/FC Wales, 1999) with a small mean patch size (Gkaraveli *et al.*, 2001). Coniferous and mixed forest areas seem to have increased by 5% and 114% respectively between the 1980s and 1990s. These forests mainly developed from areas that were newly planted in the 1980s for the former, and from areas that were broadleaves or conifers for the latter (Table 3.4). In addition, the analysis of the Forestry Commission's woodland map showed that some scrub areas in the 1980s developed into broadleaves while the majority (79%) was not classified in the 1990s inventory as a result of the minimum mapping unit chosen and differences in woodland cover classification. Furthermore, it is worth noting that 3% of the pasture land in the 1980s was converted to woodlands, mainly broadleaves, over the past decade. This was chiefly as a result of the decline in financial returns from agriculture and the offering of incentives for tree planting on farms (Good, 2000).

As it has been mentioned, the results from the Silsoe College project and the Forestry Commission's NIWT survey were difficult to compare without the results from the NIWT's survey of small woods and trees. The overall mapped area in Snowdonia was 36,760ha (the 3ha difference with Table 3.4 is a result of rounding and conversion of the original vector file received from the Forestry Commission to a raster image with approximately 20m pixel resolution), but ground sampling showed 27ha non-woodland, so the reported woodland area was 36 733ha (Table 3.5). The ground sample Forest Type breakdown of the 36 733ha of woodland in Table 3.6 could indicate that a) the coarser resolution of the aerial photo interpretation (minimum mapping unit 1ha) was hiding some broadleaved area within the conifer IFT; b) a majority of the young trees IFT must have been broadleaved species and c) there is not a significant difference between mixed IFT and mixed FT, but there could be differences in interpretation between Silsoe maps and NIWT digital map. In addition, there was not a scrub woodland category in the NIWT survey as in Silsoe's project. This category was not defined as woodland by the NIWT for canopy cover and/or species reasons. The IFT shrub class was used where the interpreter had some doubt, and the area could have been woodland (Smith, 2001). If the scrub area in the 1980s figure for woodland area (Table 3.4) is not included, the difference in woodland change over the two decades is down to 1.8%. If then the <2ha woods in the NIWT survey (Tables 3.5 and 3.6) are added to the 1990s figure for woodland area, then the difference in woodland area has almost been wiped out (it is down to 0.7%). Therefore, there may not be any real evidence of a 5% reduction in overall woodland area.

Table 3.5. Woodland area results for Snowdonia in the 1990s from the Forestry Commission's NIWT survey (ref. date 31 March 1998).

Woodland size (ha)	Woodland area (ha)	% of Woodland area
2.00 and over	36 733	98.8
0.25 - <2.00	453	1.2
Total Woodland Area	37 186	100
% Woodland Cover	17.4%	

N.B. Overall land area: 214 162ha.

Table 3.6. Woodland area by Forest Type in Snowdonia in the 1990s from the Forestry Commission's NIWT survey (ref. date 31 March 1998).

Forest Type	Woodland size (ha)		Total area (ha)	% of Total area
	2.0 and over	0.25 - <2.0		
Conifer	20 345	0	20 345	54.7
Broadleaved	10 663	453	11 116	29.9
Mixed	2 385	0	2 385	6.4
Coppice	0	0	0	0.0
Felled	1 141	0	1 141	3.1
Open Space	2 200	0	2 200	5.9
Total	36 733	453	37 186	100.0

In view of the above, the comparison of broadleaved forest (Silsoe forest type category) in the 1980s with broadleaved forest (NIWT IFT category) in the 1990s to get a 27% decline in broadleaves is probably too simplistic. Broadleaves seem to occur in broadleaved, young trees, new plantings and mixed forest (and shrub and scrub come to that) categories, and the NIWT alone shows that even looking at the same woodland at the same point in time you can get a different breakdown in woodland area using different classes and resolutions. Furthermore, given there may not be a significant difference in overall woodland area between the 1980s and 1990s, there are three views of the breakdown of that woodland (Silsoe aerial photo interpretation, NIWT aerial photo interpretation and NIWT ground survey), all using different resolutions, and slightly different classifications. The trend seems to be that finer resolutions uncover more broadleaves. The extra information from the NIWT ground survey does not indicate that there was a real loss in broadleaves overall. Conifers cannot be said to be significantly different either. Perhaps the mixed woodland has increased, but that needs to be investigated more closely before making any firmer conclusions.

While the bulk of both broadleaved and coniferous forest were identified consistently between Silsoe and NIWT, this is not the case for mixed forest. With regard to whether there was a real increase in mixed forest between the 1980s and the 1990s, there does not seem to be a problem with the definition of mixed forest between the Silsoe College project and the Forestry Commission's survey or to be any evidence of a problem related to resolution of the different methods, and the NIWT figure for mixed forest is consistent between aerial photo interpretation and ground survey (Tables 3.4 and 3.6). Given that the overall woodland area has not changed significantly, and assuming that there have not been large woodland losses and gains cancelling each other out, then most of Table 3.4 is not showing a transition matrix, rather it is showing a difference in interpretation matrix, as the two surveys were carried out by different organisations, personnel and technology. This is a well-known problem in monitoring change over time. The aerial photographs used for each survey were not studied anew to examine if the apparent anomaly could be overcome. Large proportions of NIWT's mixed forest were identified as broadleaved or coniferous forest by Silsoe, and *vice versa*. It may be that interpretation of mixed forest is quite difficult particularly in areas of rough terrain. Boundaries between broadleaves and conifers can also be difficult to discern and map. These problems are widely acknowledged in the research and survey communities. It is an area that merits research and development. If the difference was real, then over 1,000ha of new mixed forest must have arisen from somewhere. However, the evidence does not seem to support a real doubling of mixed forest area, or even a real increase come to that.

3.4.2 Likely driving forces

The area of woodland in Wales had been in decline for a long time prior to the formation of the Forestry Commission in 1919. Linnard (2000) suggested that by 1000 AD woodland cover was probably only 25%, falling to 10% by the 16th century as a result of continuing clearance, primarily for agriculture. After its establishment, the Forestry Commission set about reversing the long decline in forest area, its remit

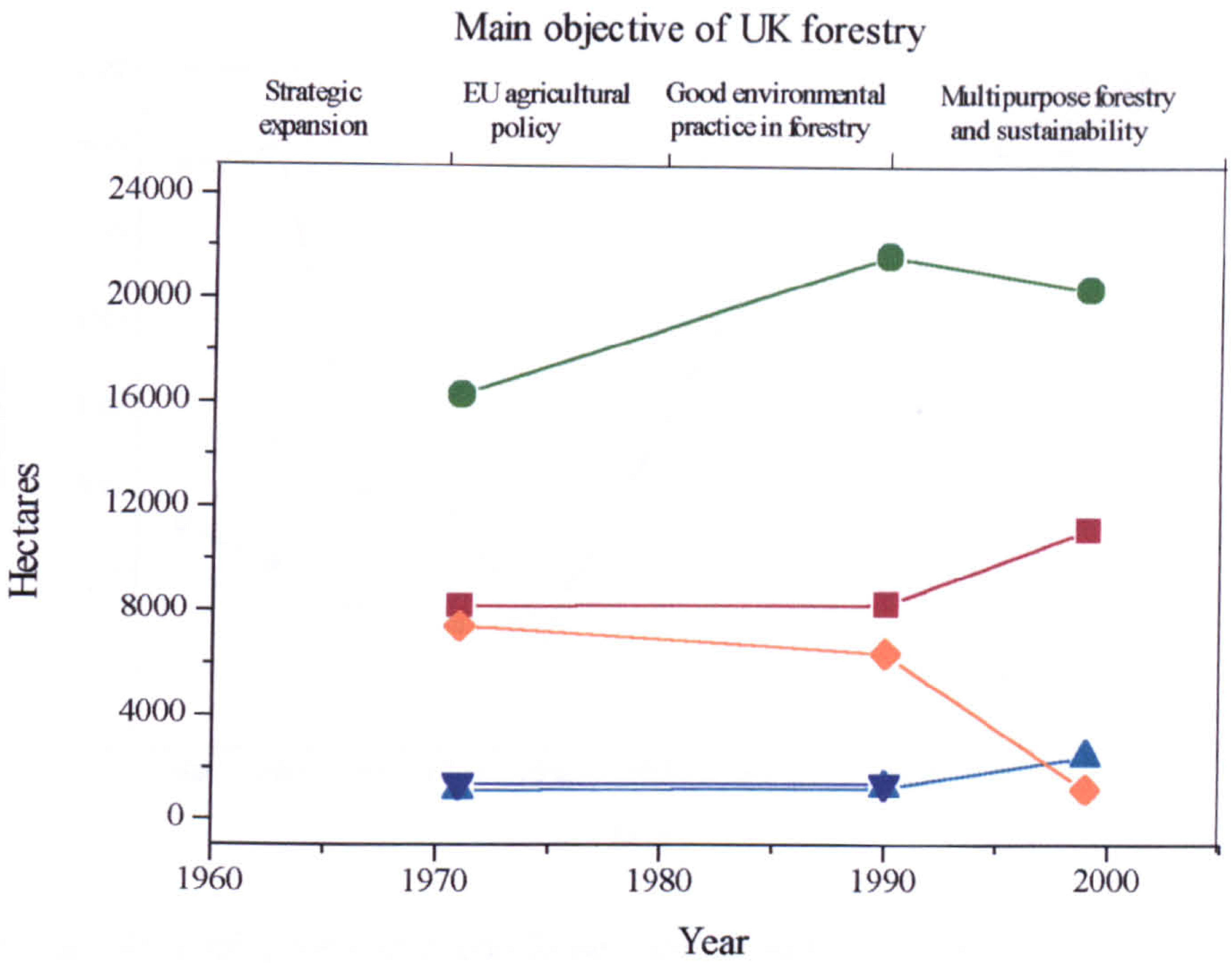


Figure 3.1. Woodland changes in Snowdonia in relation to changes in national policy. Important events are indicated along the top axis. Broadleaves = ■, Conifers = ●, Mixed forest = ▲, Scrub = ▼, Clear felled/new plantings = ◆ (from the 1990 to 1999 it only indicates felled woodland).

being to produce a strategic timber reserve for use in case of future conflict. Until the 1960s, the main objective of UK forestry was strategic afforestation leading to an unprecedented expansion in forest area, mainly after the Second World War (Price and Samuel, 1999). This resulted in commercial coniferous plantations covering nearly 47% of the wooded area of Snowdonia in the 1970s and in 7,396ha of new plantings (Figure 3.1).

In 1973, the UK joined the European Economic Community and land use was thereafter dominated by an EEC agricultural policy which involved huge farm subsidies. However, by the early 1980s protest against production-driven agricultural policy was building up and conservation of the environment became a major European issue. European legislation and policy affected UK forestry. Changes in the Common Agricultural Policy as a consequence of over-production of food strongly directed the UK's forest expansion towards farmland. Grants from the Forestry Authority were favourable to the planting of arable land, while the Farm Woodland Scheme (Ministry of Agriculture, Fisheries and Food, 1987), in line with European

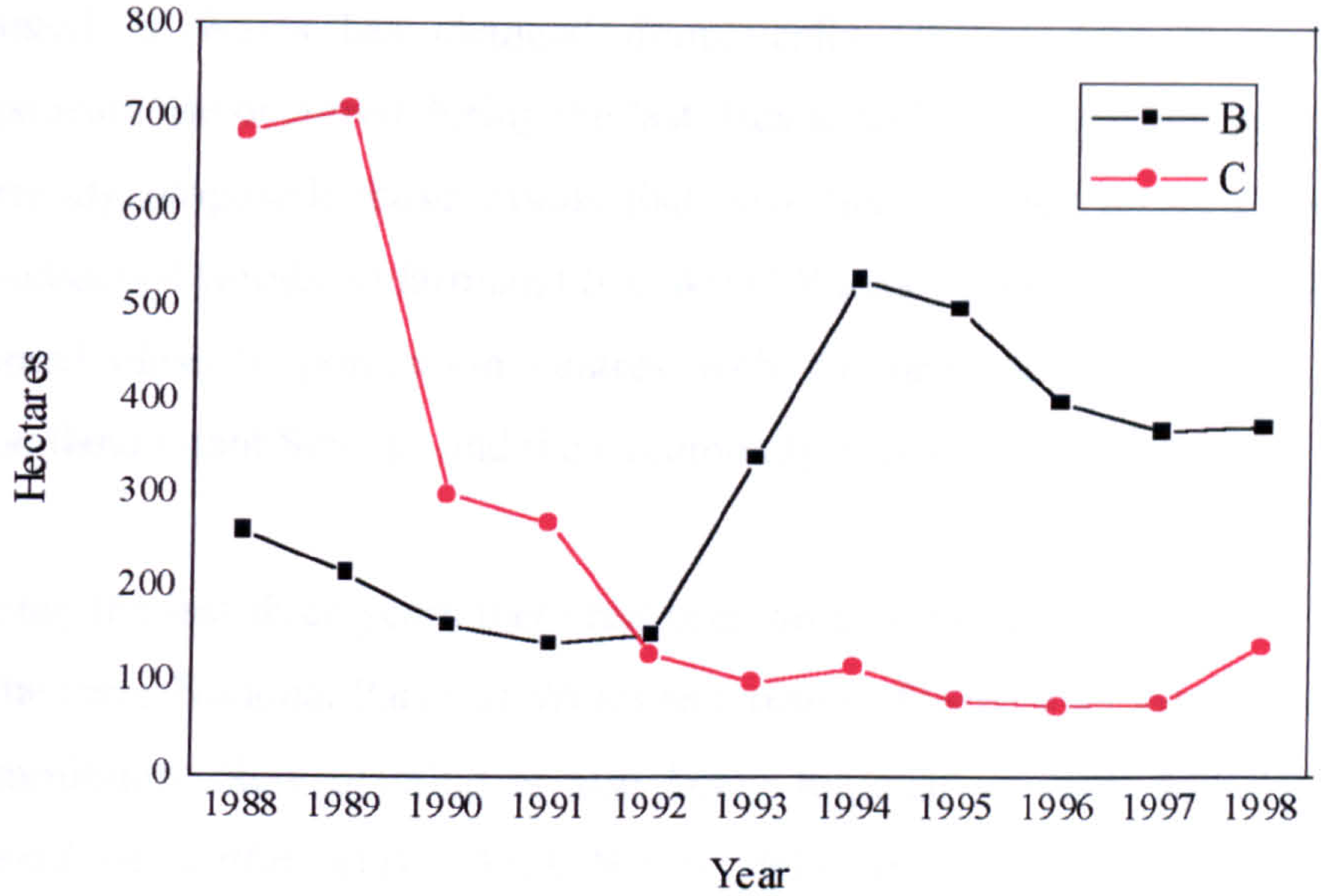


Figure 3.2. Area of grant-aided coniferous and broadleaved woodland planted by private owners in Wales between 1988 and 1998 (adapted from CCW/FC Wales, 1999). Broadleaves = B, Conifers = C.

policy, gave an annual payment for land diverted into forestry, according to the amount of agricultural productivity decommissioned (Price, 1999). In the first two years of the Farm Woodland Scheme, 87% of planting in Wales was with broadleaves while the mean size of scheme approved was 5.2ha (Price and Willis, 1994). All these changes resulted in an increase of broadleaved, coniferous and mixed forest habitats in Snowdonia by as much as 1%, 33% and 11% respectively from the 1970s to the 1980s (Figure 3.1).

The Finance Act 1988 (Forestry Commission, 1989) made significant changes in the tax treatment of commercial woodlands in the UK. It removed tax relief for any interest paid in connection with forestry activity. This resulted in a sustained reduction in new planting. During the 1990s the Government formally adopted a forestry policy to promote sustainability; examples are *The UK Forestry Accord* and *The UK Forestry Standard* (Forestry Authority, 1998). In 1993 a National Accord between the Forestry Authority and the National Parks of England and Wales was signed to encourage the management and extension of native woodlands in National Parks. In response to this, a local accord has set the target of increasing the area of native woodland within the Snowdonia National Park by 50% within 50 years (SNPA, 1995). Over the last decade the proportion of conifer and broadleaved woodland planted in Wales has changed dramatically (Figure 3.2). Very little woodland expansion has occurred during the last decade and few new substantial plantations are currently proposed; those woods that have been planted recently are mostly small broadleaved woods on farmland (CCW/FC Wales, 1999). Some woodlands have been planted close to population centres with the help of the Forestry Commission's Woodland Grant Scheme and the Community Woodland Supplement.

During the last three years there has been an increase in planting of native woodland in the three National Parks of Wales as a result of targets set jointly with the Forestry Commission. New planting is also being targeted on land dominated by bracken (*Pteridium aquilinum*) (CCW/FC Wales, 1999). In its six years, Tir Cymen, one of the forerunners of the Tir Gofal all Wales agri-environment scheme, which has operated in the Meirionnydd area of the Park has provided protection and more appropriate management for many habitats, including native woodlands (CCW/FC Wales, 1999). Tir Gofal, the new all-Wales agri-environment scheme, was launched in March 1999 and will last for ten years. It aims to protect the heritage of rural Wales including the restoration or creation of certain habitats, such as the planting of new woodland. Furthermore, a new initiative supported jointly by the Countryside Council for Wales and the Forestry Commission, Tir Coed, was launched in the summer of 1999 aiming to restore the tree cover in Wales through a strategy to develop sustainable woodland in the Welsh landscape. The effects of these new initiatives on landscape change in the Park remain to be seen. Despite these initiatives, however, over the last decade in Snowdonia, it seems that there is no evidence for a significant change in woodland area, and that there is no clear evidence for a change in woodland character, at least in terms of the general conifer/broadleaves split (Table 3.6 and Figure 3.1).

3.4.3 Woodland landscape characteristics

Changes in areas of woodland classes, patch size and spatial arrangement have resulted in different landscapes over the past years spanned by the 1970s, 1980s and 1990s aerial photographs (Table 3.7). Given that the majority of the young trees IFT must have been broadleaved species and that this was included in the broadleaved forest figure in Table 3.6, it could be concluded that there may not have been a significant change in broadleaves over the past decade. The increase in mixed forest was not caused by an increase in the number of patches, but rather by expansion and fusion of existing patches. Scrub habitat showed no significant change from the 1970s to the 1980s. Patch size SD for scrub is several times smaller than in other classes in both time periods, due to the many small and similar-sized patches. These reflect the origins of scrub, most of which probably developed by natural regeneration during the periods of agricultural depression when grazing intensity by domestic livestock (chiefly sheep) was considerably less than at present (Good *et al.*, 1990). It is now maintained as a plagio-climax through intensive grazing. In contrast, conifer forest is more clumped, in all time periods, containing larger patches with higher variability in size, as would be expected given its origins as uniform plantations.

Table 3.7. Patch area, number of patches, size and other spatial indices for each forest patch type of the Snowdonia National Park from the 1970s to the 1990s. Abbreviated indices are class area (CA), percent of landscape (PC), number of patches (NP), mean patch size (MPS), patch size standard deviation (PSSD), mean shape index (MSI), mean nearest-neighbor distance (MNN) and nearest-neighbor standard deviation (NNSD).

	CA (ha)	PC (%)	NP	MPS (ha)	PSSD (ha)	MSI	MNN (m)	NNSD (m)
1970s								
Broadleaves	8191.28	3.82	2205	3.72	12.86	1.73	113.72	219.69
Conifers	16293.76	7.61	654	24.91	127.73	1.63	314.89	539.96
Mixed Forest	1102.53	0.51	251	4.39	9.89	1.66	734.71	995.10
Scrub	1394.21	0.65	991	1.41	2.24	1.52	278.54	391.41
1980s								
Broadleaves	8272.84	3.86	2170	3.81	13.02	1.74	112.16	217.45
Conifers	21608.72	10.09	769	28.10	125.48	1.66	260.42	434.96
Mixed Forest	1221.40	0.57	246	4.97	10.93	1.67	757.47	1060.78
Scrub	1372.53	0.64	926	1.48	2.41	1.53	296.27	428.62
1990s								
Broadleaves	6489.19	3.03	632	10.27	20.96	2.20	262.63	474.57
Conifers	22665.05	10.58	315	71.95	199.99	1.95	403.76	613.08
Mixed Forest	2615.92	1.22	177	14.78	25.20	1.92	867.59	1315.88
Shrub	7.28	0.003	2	3.64	1.46	1.25	22840.54	0

N.B. Shrub category in the 1990s, although it has been included in the spatial analysis, has no meaning as this IFT category was used where the interpreter had some doubt, and the area could be woodland.

The differences in class area, number of patches and mean patch size statistics of woodlands over the past three decades after using two ways to compute them are shown in Table 3.8. The small differences in statistics between the IDRISI and FRAGSTATS computations are a result of the scale. The IDRISI image had to be resampled to 20m pixel resolution in order to be used in FRAGSTATS. The ArcShape vector file was converted to a raster image and used in FRAGSTATS. Conversion to a finer scale would have resulted in smaller differences.

Table 3.8. Differences between two ways of computing the class area, number of patches and the mean patch size of woodlands in the landscape of the Park over the past three decades. The IDRISI image was with a 19.89279m pixel resolution, the image used in FRAGSTATS had a 20m pixel resolution and the ArcShape file was a vector file. BF = broadleaved forest; CF = coniferous forest; MF = mixed forest.

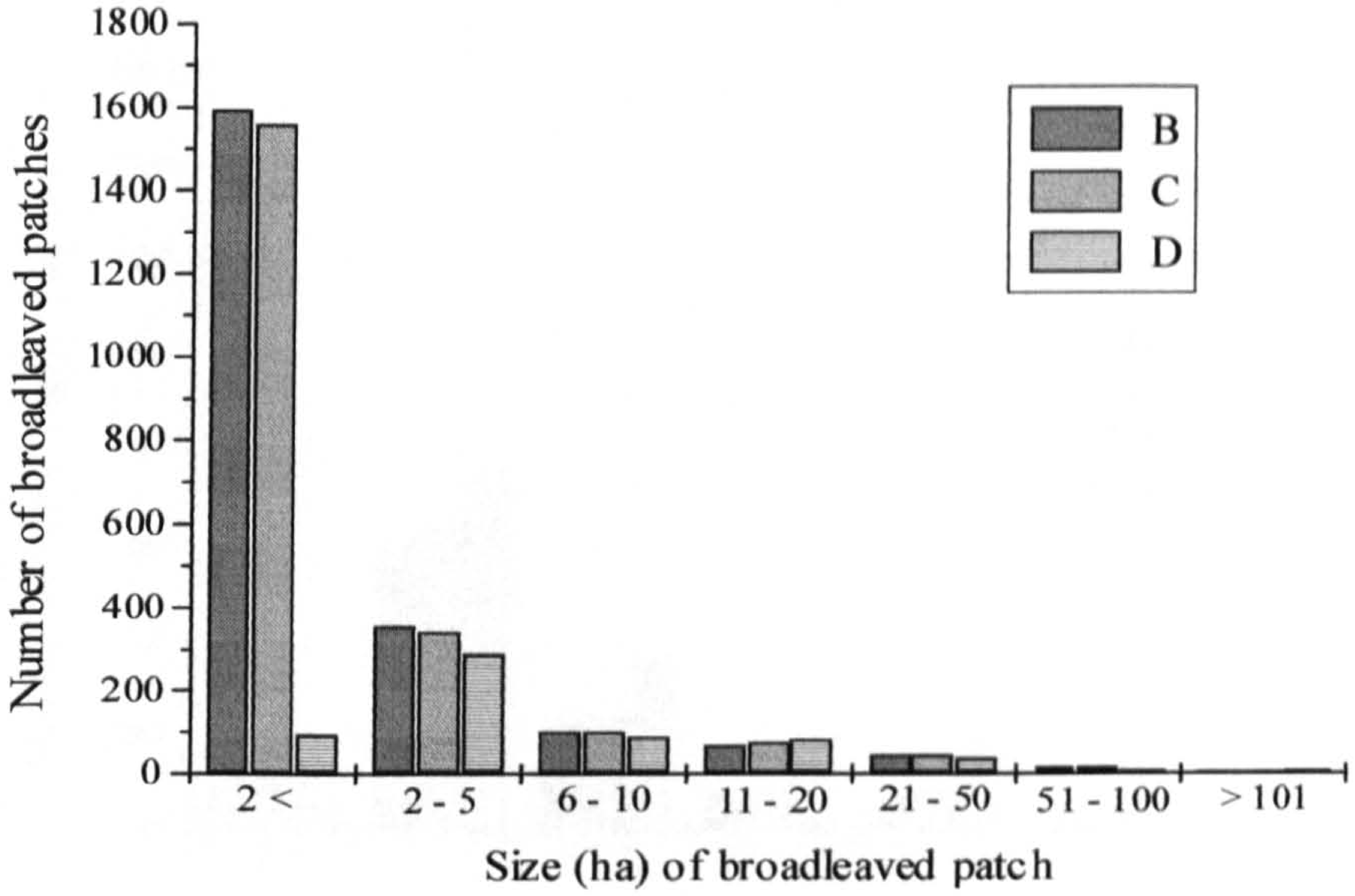
	Class area (ha)		No. of patches		Mean patch size (ha)	
1970s	IDRISI	FRAGSTATS	IDRISI	FRAGSTATS	IDRISI	FRAGSTATS
BF	8191.28	8183.40	2205	2211	3.72 (12.86)	3.70 (13.03)
CF	16293.76	16297.60	654	655	24.91 (127.73)	24.88 (121.69)
MF	1102.53	1104.24	251	252	4.39 (9.89)	4.38 (9.95)
Scrub	1394.21	1393.92	991	997	1.41 (2.24)	1.40 (2.29)
Total	26981.78	26979.16	4101	4115		
1980s	IDRISI	FRAGSTATS	IDRISI	FRAGSTATS	IDRISI	FRAGSTATS
BF	8272.84	8264.96	2170	2176	3.81 (13.02)	3.80 (13.17)
CF	21608.72	21607.68	769	770	28.10 (125.48)	28.06 (121.49)
MF	1221.40	1222.32	246	246	4.97 (10.93)	4.97 (10.98)
Scrub	1372.53	1371.80	926	929	1.48 (2.41)	1.48 (2.43)
Total	32475.49	32466.76	4111	4121		
1990s	ArcShape	FRAGSTATS	ArcShape	FRAGSTATS	ArcShape	FRAGSTATS
BF	6489.19	6487.64	632	653	10.27 (20.96)	9.94 (21.10)
CF	22665.05	22651.12	315	308	71.95 (199.99)	73.54 (197.53)
MF	2615.92	2611.28	177	178	14.78 (25.21)	14.67 (26.85)
Shrub	7.28	7.08	2	2	3.64 (1.46)	3.54 (1.02)
Total	31777.44	31757.12	1126	1141		

N.B. Values in parentheses indicate standard deviation in hectares for the mean patch size of each woodland category.

A number of trends are evident through time in the analysis of size distribution of woods (Figures 3.3 and 3.4). The broadleaved habitat is dissected into a great number of patches with the majority having a size of less than 5ha (89% of the total number of patches in the 1970s, 88% in the 1980s and 63% in the 1990s although this figure must be affected by the exclusion of woods with less than 2ha size in the Forestry Commission's survey). Coniferous forest contains quite few large patches. The analysis of size distribution of mixed woods, showed that larger patches were created through time which may be resulting from the fact that the NIWT digital map shows a doubling of the mixed forest area whereas, as discussed in section 3.4.1, there is no evidence to support this. Scrub habitat consists of many very small patches; 81% and 80% of the total number of patches in the 1970s and 1980s respectively having a size of less than 2ha. The 1990s woodland dataset (Figures 3.3 and 3.4) contains some woods that are less than 2ha for two reasons. Firstly, the Forestry Commission mapped initially all woodland blocks of 2ha and over in Wales and then 'cut' the dataset to provide woodland areas for specific regions (*e.g.* Snowdonia). So although these woodland areas measure less than 2ha within Snowdonia, they may form part of a 2ha and over wood outside the Park boundary. Secondly, these woodland blocks were further subdivided internally into different forest types (Brown, 2001). Unfortunately, the NIWT survey of small woods was sample-based only, so it could not contribute to the spatial analysis.

Values for the mean shape index are all greater than 1 reflecting the fact that overall vegetation within the classes diverges from a regular shape (Table 3.7). All the classes, from the 1970s to the 1980s, maintained the same shape complexity despite the expansion and fusion of formerly disjunct patches, whereas over the last decade they all became more irregular in shape. This may be a result of the exclusion of the small woods survey results.

Mean distance decreased among coniferous patches from the 1970s to the 1980s as they increased in area (Table 3.7). Conversely, mean distance increased among mixed forest and scrub patches as they declined in number. The mean distances appear to have increased in all woodland types over the last decade, but this must be a spurious



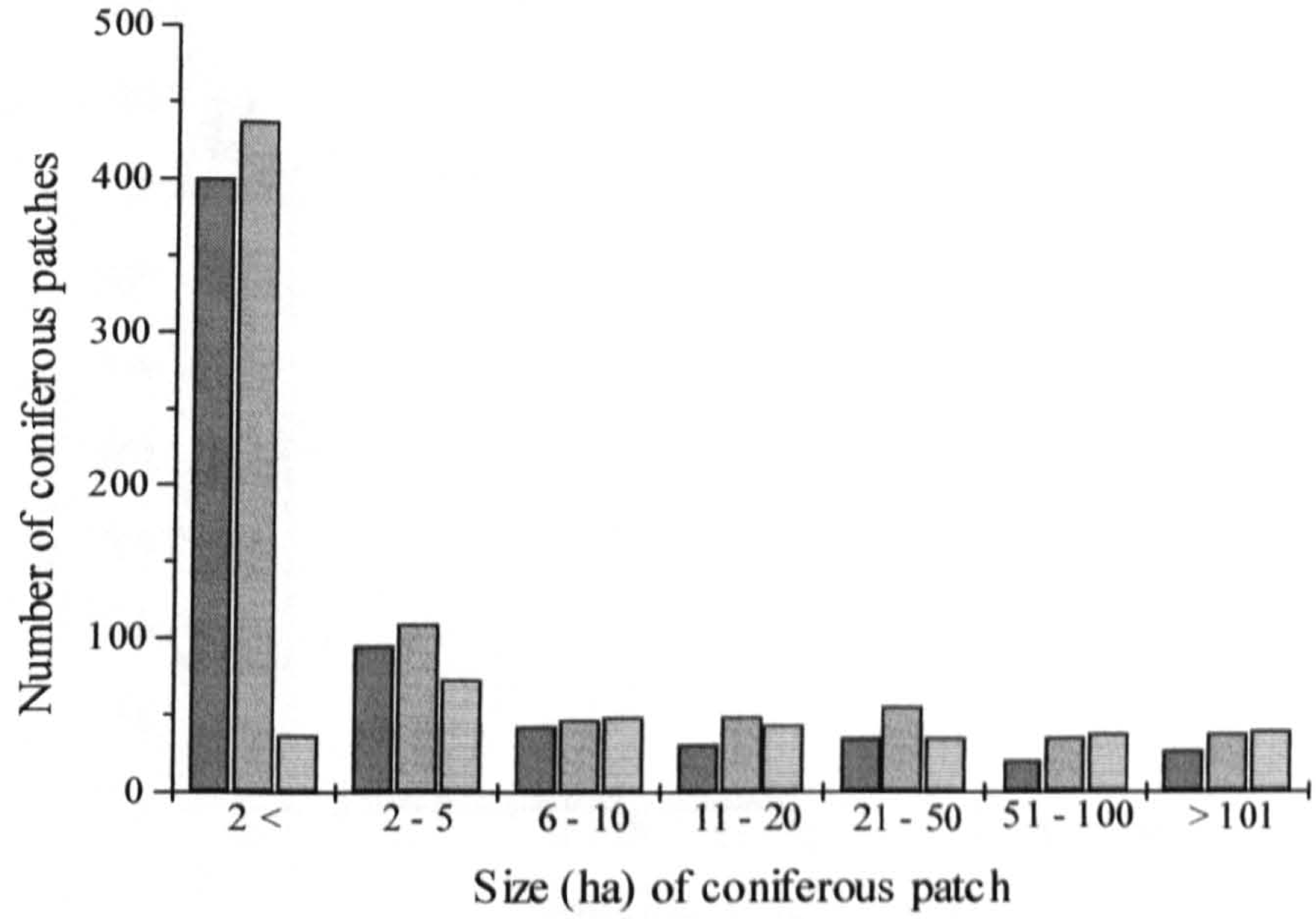


Figure 3.3. The size distribution of broadleaved and coniferous woodland types in the Snowdonia National Park over the past three decades. B = 1970s; C = 1980s; D = 1990s. The legend applies to both histograms.

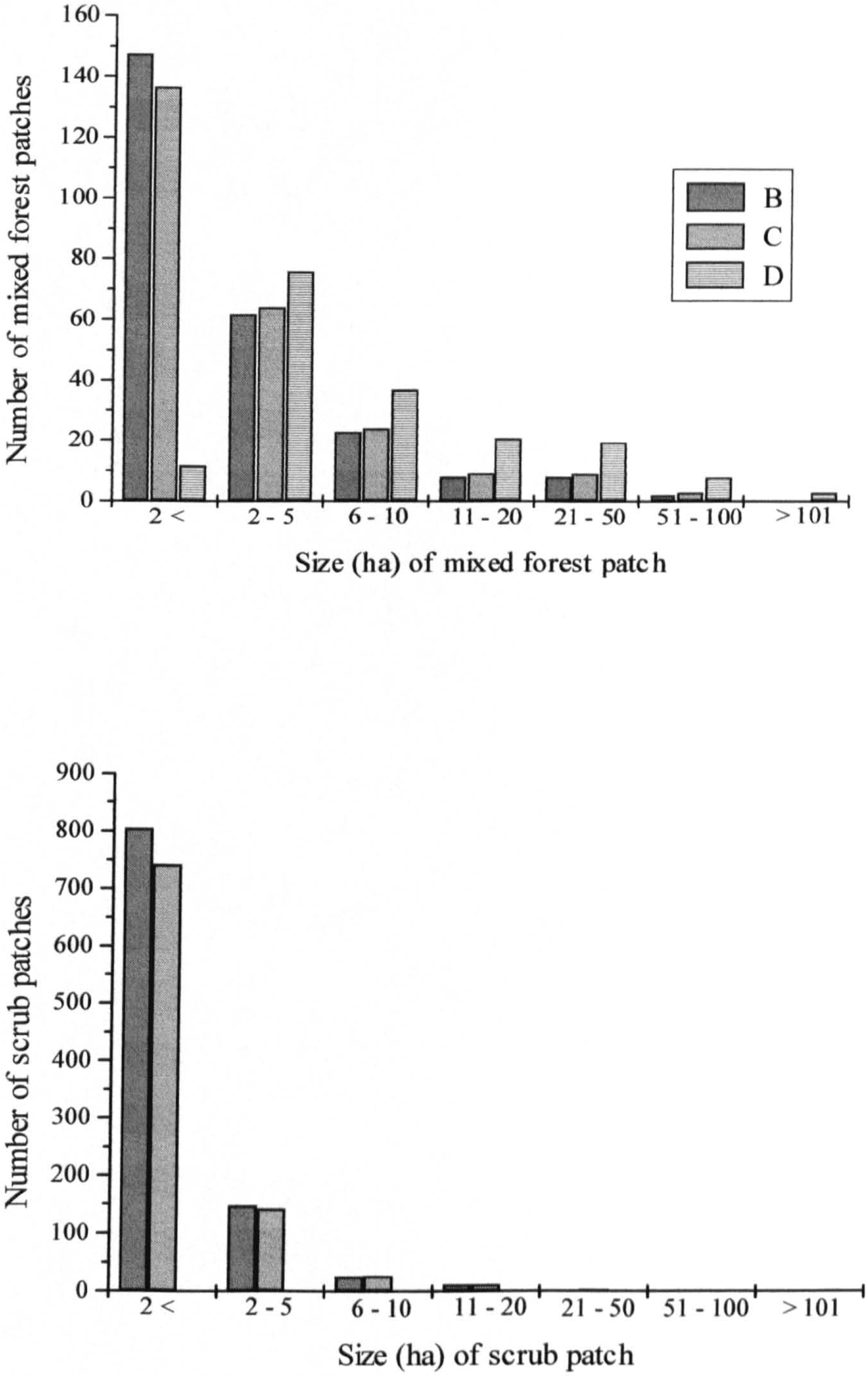


Figure 3.4. The size distribution of mixed and scrub woodland types in the Snowdonia National Park over the past three decades. B = 1970s; C = 1980s; D = 1990s. The legend applies to both histograms.

result due to the exclusion of small woods (less than 2ha). In all time periods, the distance between mixed forest patches was greater than for other classes suggesting that patches were more isolated in this habitat. The broadleaved forest patches seem to be the least isolated. This trend was consistent with the higher and lower values of nearest-neighbor SD in mixed and broadleaved forest respectively, implying a more irregular distribution of patches of the former and a more uniform distribution of patches of the latter across the landscape.

3.5 Discussion of results

3.5.1 Woodland changes

The Welsh landscape is the result of million of years of natural change and thousands of years of its adaptation by people. The largest land use change taking place in Britain's uplands in the 20th century was the use of agricultural land of low productivity and semi-natural habitats for afforestation. In 1986/87, 43000ha of agricultural land were released for afforestation in Scotland alone (Mowle and Bell, 1988). Almost 1 million ha of upland in Britain have been planted since 1924 (NCC, 1986). From the 1970s to the 1980s, forestry was encouraged to expand in Snowdonia onto land that was formerly moor and heathland as well as agricultural land in response to national policies and other socio-economic forces. Coniferous forest became more prevalent up to the end of the 1980s, and mixed forest also increased. Over the last decade, there is no evidence for a significant change in woodland area, and there is no clear evidence for a change in woodland character, at least in terms of the general conifer/broadleaved split.

The consequences of afforestation for landscape value, soils, water quality, vegetation and animals have been widely reviewed (NCC, 1986; Thompson *et al.*, 1988; Wong, 1992; Wallace and Good, 1995). Large scale forest developments, using close-planted exotic conifers have been considered damaging to the environment (NCC, 1986). Such plantations affect river systems and peatlands, eliminate characteristic open ground moorland and upland bird communities, and affect the landscape.

Despite losses of habitats, there are sound reasons for optimism. *The UK Forestry Standard* (Forestry Authority, 1998) for sustainable forest management illustrates how Government commitments made at the Rio and Helsinki Summits can be put into practice. Combined with a series of practice guidelines, the *Standard* provides a measure against which to assess the performance of forestry practice within Welsh woodlands, ensuring that international commitments for sustainability are met. Furthermore, the Forestry Commission, working with landowners and other partners, is helping to reverse the fragmentation of woodland in Wales and to ensure that it is appropriately managed. In 1998/99, grant aid from the Woodland Grant Scheme brought into management nearly 8500ha of native woodlands in Wales while a new initiative, Tir Coed, has been set up to expand areas of woodland, primarily broadleaved, by tree planting (CCW/FC Wales, 1999).

3.5.2 Geographical characteristics of the woods

In the study area, the analysis of size distribution of woods has shown that broadleaved, mixed and scrub fragments are often small (<5ha). The minimum dynamic area for most species in the UK is unknown but some area requirements in relation to woodland species have been estimated. Dormouse (*Muscardinus avellanarius*) needs woods exceeding 50ha in size to sustain healthy populations (Bright, 1996). In a lowland arable landscape in eastern England it has been found that for all but the commonest woodland birds, the probabilities of breeding do not approach 100 per cent until woodland size reaches about 10ha or more. Woodlands of about 25ha are required for marsh tits (*Parus palustris*), and nuthatches (*Sitta europea*) are rarely encountered even in woods of 100ha or more (Hinsley *et al.*, 1994). As most of the native woodland fragments in Snowdonia were small they consist mainly of edge rather than core habitat. Artificial and natural edge effects, *e.g.* effects of fertilization on neighbouring arable land, light and wind penetration, may influence habitats deep into forests. This may affect plant species which only occur in forest core areas with suitable habitat. For example, ferns and many members of the Atlantic bryophyte communities for which native Welsh oakwoods provide prime habitat (Ratcliffe, 1968, 1977) are very sensitive to low air humidity. They are unlikely to be able to colonise small forest patches where high air humidity is not sustained. Creating new edges is, however, not always undesirable for nature conservation (Kirby, 1995). There are species that depend on mosaics of habitats with abundant edges. Most edges show increased species richness compared to the interior habitat.

In 62 Danish beech forests examined by Lawesson *et al.* (1998) the forest species value tended to decrease with increasing forest size. This was related to forest management; the larger forests are heavily managed and while they tend to contain most species in total, the high levels of disturbance can be tolerated by relatively fewer forest species. In contrast, the smaller forests have been disturbed to a much lesser extent, and have a relatively high proportion of forest specialists, including ancient forest indicator species. This is similar to findings in English woodlands in Shropshire by Helliwell (1976), and in Flemish forests in Belgium by Honnay *et al.* (1999a). These studies indicated that other features aside from forest area, such as the forest habitat characteristics, may play the most important role in predicting a relationship between species and habitat diversity. Furthermore, Honnay *et al.* (1999a) found that inter-patch and intra-patch habitat diversity was more important for species richness than the limitations imposed by individual patch area.

Over the past three decades, woodlands in Snowdonia became more irregular in shape. The study of Honnay *et al.* (1999a) in Belgium demonstrated that habitat diversity at the patch level can be increased when patches have irregular shape. A high shape index seemed to have a positive effect on species quantity without yielding a negative effect on species quality. This contrasts with Dzwonko and Loster (1989) in Poland who found, after controlling for the effects of forest patch area, no correlation between forest shape and species richness.

The effect of inter-fragment distance on the value of fragments as habitat for particular organisms was difficult to estimate in our study as the dispersal ability of different groups of organisms varies greatly and is not well understood. Plants using wind dispersal such as birch or rhododendron may spread their seed over tens of kilometres, but for some invertebrates and small mammals, a road of a few metres may be an insuperable barrier (Forman, 1995). Studies in Britain demonstrate, for several butterfly species, that long-distance dispersal is extremely rare (Thomas and Harrison, 1992). As woodland isolation increased, the incidence of both dormice (*Muscardinus avellanarius*) and red squirrels (*Sciurus vulgaris*) decreased (Bright, 1993). In recent woods (Peterken and Game, 1981), dog's mercury (*Mercurialis perennis*) has a higher incidence in less isolated woods as colonization across hostile territory is less likely with increasing isolation from ancient woods. In the Netherlands, Grashof-Bokdam and Geertsema (1998) examined the colonization success of woodland originating after 1850 for late successional forest species having different dispersal strategies. For most of the species, the occurrence in forest habitat patches decreased significantly with increasing distance to the nearest source. In an analysis of forest plant species distribution over isolated forest patches in Belgium (Honnay *et al.*, 1999a) patch isolation was found, however, to be of minor importance in species richness. In addition, Peterken and Game (1984) in a study of woodlands in Lincolnshire, UK, concluded that variation in the number of plant species in ancient woods was not significantly affected by isolation. Rather, such variation was determined by the range of soils and variety of vegetation structure.

Snowdonia contains a large number of deciduous woods, some of which may be relics of ancient woodland (Edwards, 1986). In the 1980s, there were 6,608ha of ancient woodland in Gwynedd county (Spencer and Kirby, 1992), and at that time all of the Park was within Gwynedd. Ancient woodland in Wales is highly fragmented; 89% of sites were less than 20ha in size (Spencer and Kirby, 1992). The mean patch size of broadleaved, mixed and scrub fragments in this study is in agreement with the 51% of ancient woodland sites in Wales being less than 5ha reported by Spencer and Kirby (1992). Ancient woods are indeed richer in species than recent woods (Peterken and Game, 1984). One of the reasons the authors reported that recent woods have remained poorer is because they are isolated in time from original natural woods and some species often cannot bridge the isolation in space from refuges mostly found in ancient woods. Bryophytes are generally effective dispersers because of their small wind- or water-borne spores. However, some of the rarer Atlantic bryophytes for which north Wales oakwoods are famed appear to be much less mobile, probably because they produce no spores, being clones, and therefore rely on dispersal by fragmentation. The need for new forest habitats to be located very close to old forest if late successional woodland plant species are to colonise has been emphasised by Grashof-Bokdam and Geertsema (1998).

3.5.3 Methodology and limitations

In the analysis, the results of the overlay technique were useful as qualitative data, but provided no quantitative information. The FRAGSTATS program computed several statistics and provided a description of the pattern in each forest class in the landscape of the Park. It is important, however, to consider that the nature of the pattern detected in a landscape is dependent on scale (Forman and Godron, 1986; McGarigal and Marks, 1994); parameters and processes important at one scale are frequently not important or not predictive at another scale, and information is often lost as spatial data are considered at coarser scales of resolution (Turner, 1990). The results given by the program are constrained by the extent (214162ha) and grain (about 0.04ha) of the landscape. Any inferences produced cannot be generalised beyond the extent of the landscape and cannot be used to detect pattern below the resolution of the grain (Wiens, 1989).

This study presents the first large-area analysis of landscape structure and change combining data from different sources in the Snowdonia National Park. The results from the Silsoe College project and the Forestry Commission's woodland inventory proved difficult to compare because of the minimum size of woodland selected to be mapped in each survey. The results from the NIWT's survey of small woods and trees provided extra information and were useful for comparisons of woodland changes in Snowdonia over the past three decades. Without this extra information, however, the results from the NIWT digital map alone would be misleading. Unfortunately, the small woods survey was sample-based only, so it could not contribute to the spatial analysis. Although the indices of each forest category in the 1990s follow similar trends to those of the 1970s and the 1980s decades the results of the last decade in Table 3.7 are not directly comparable to those of the previous decades because of the minimum mapping unit in this survey being 2ha and over. This work emphasizes the need for a series of landscape surveys using the same minimum mapping unit and classification scheme, which is further discussed in the following paragraph, and methodology in general.

A major factor to be considered is the process of surveying and recording land cover and vegetation type. Surveys such as those providing data for this study often make use of field observation and aerial survey or a combination of the two. It has long been known that achieving comparable results using different people, albeit adhering to an agreed methodology, is difficult. Quantifying these differences or consistencies is often addressed by re-surveying a sub-sample of sites using different personnel (*e.g.* Fuller *et al.*, 1998). There are also problems in reconciling ground and aerial survey. Ground survey involves trained botanists who are able to identify a plant whether it is displaying the full glory of unrestricted growth or is a mere stump due to heavy grazing. Botanists are also able to take account of the phenological changes in plant appearance (Williams, 1992); was the bracken green or brown, erect or prostrate? Other factors affecting aerial imagery, such as substrate background, surface moisture slope, aspect and sun angle are altogether less interesting factors in the botanist's perception of the terrain. Aerial imagery produces a much more objective assessment of plant/community appearance, but often cannot compete with the field botanist. The different methodologies of the Silsoe and Forestry Commission surveys must, therefore, be borne in mind when considering the comparability of their data.

3.6 Conclusions and implications for landscape management

The analysis of woodland change in Snowdonia over the past showed that there was an overall increase in the forested land from the 1970s to the 1980s. Woodland and forest land increased by 13%. These forests developed from areas that were formerly moor and heath land as well as agricultural land. Broadleaved and scrub habitats showed no significant change, and coniferous and mixed forests increased in the landscape by as much as 33% and 11% respectively over this period. There is no evidence for a significant change in woodland area between the 1980s and 1990s, and there is no clear evidence for a change in woodland character over the past decade, at least in terms of the general conifer/broadleaves split. The evidence does not also seem to support a real doubling of the mixed forest area, or even a real increase come to that.

In this study, woodland cover data from two different sources, the Silsoe College and Forestry Commission surveys, were combined in order to compare woodland changes in the past. The results from both surveys were difficult to compare due to problems of different minimum mapping unit selected in each survey and trying to reconcile different classifications and definitions. The NIWT digital map and its IFT polygons gave an initial estimate of woodland, location of the woodland, and a broad characterisation of forest type distribution but was not useful for detailed analysis or comparisons. This study emphasized the need for landscape surveys using the same methods.

The primary utility of landscape assessment is in understanding the characteristics of ecosystems that we manage (Morgan *et al.*, 1994). Knowledge of landscape pattern change at regional and subregional scales provides critical context for forest-level planning, and valuable insight for ecosystem restoration, conservation, and monitoring decisions. Landscape change analysis provides an empirical basis for evaluating future management decision. The study confirms the important role that afforestation and deforestation have played in recent decades in determining current landscape composition in the Snowdonia National Park. This will continue in the future but perhaps in different ways. A threefold vision for the future of forestry in Wales is proposed (National Assembly for Wales, 1999); woodlands for rural development and the wider economy, for the environment, and for people. Due to the retirement of a large proportion of Welsh farmers over the next 15 years, and the absence of successors to many of these farmers, it is likely that increasing amounts of land will come up for sale (Stevens, 2000). Some of this may become available for large scale plantings of one form or another. If so there may be new opportunities to join up and expand existing farm woodlands, which are mostly very small (<1ha) and isolated (Stevens, 2000; Gkaraveli *et al.*, 2001). Attention should also be focused on extending woodland area on farms by all possible means, since larger woodlands provide better habitat for specialist flora and fauna including birds (Hinsley *et al.*, 1994; Opdam *et al.*, 1985) and woodland macrolepidoptera (Usher and Keiller, 1998).

Studies from countries in northern Europe where woodlands have been fragmented for centuries, as in Britain, have suggested the importance of habitat diversity and forest continuity for species richness. Lawesson *et al.* (1998) demonstrated that plant richness, and probably biodiversity in general, depends more on the range of habitats, and thus, of environmental variation in a forest, than on its actual area, shape or isolation. As a result, the conservation of plant biodiversity in forests on the basis of forest area alone would not be prudent. Smaller forests may also merit management measures for biodiversity conservation. An example would be long-established woodlands in areas of predominantly intensive agriculture which have developed rich and varied edge communities. Some of the plant and animal species found there may have been eliminated from the surrounding countryside and be unable to colonise the centre of larger woodlands and forests (Peterken, 1993). British experience suggests that many of the core woodland species, particularly perennial plants, can also be maintained for long periods in areas of just a few hectares provided the management is right, and the appropriate range of structural conditions is maintained. In practical conservation terms it may be more effective sometimes to use resources to improve the management of an area rather than to increase its extent or to reduce isolation (Kirby, 1995). Tir Gofal, the agri-environment scheme that will last for ten years, has potentially an important role to play. Two of its objectives are the management of all existing habitats according to guidelines and the practical training of farmers in habitat management.

Changes to the pattern of habitat in the landscape result in changes to ecological processes that in turn affect the status of flora and fauna. Relationships between landscape pattern and species abundance and distribution have not been studied in Snowdonia so far. Hence it was not possible to assess the consequences for given species or communities in this study. Studies of 'edge effect' and 'inter-patch distance' in the National Park will therefore be very important in future work. Furthermore, the local Biodiversity Action Plan for Snowdonia (SNPA, 1999) considered as fundamental the need to link species with habitats and set the target to evaluate species and habitat priorities, and produce action plans to safeguard them. The landscape indices calculated in this analysis could be used to monitor the changes in habitats, provided categories are the same in the consecutive surveys, as they provide a straightforward and effective means of landscape monitoring and could be combined with studies in the field of particular species identified as being vulnerable to habitat changes.

3.7 Summary

The purpose of this chapter was to study changes in the forests and woodlands of the Snowdonia National Park. Using a GIS, several landscape indices were calculated for the broadleaves, conifers, mixed forest and scrub areas over the past three decades. The analyses showed that from the 1970s to the 1980s coniferous forest became more prevalent, mixed forest areas also increased. Broadleaved and scrub habitats remained approximately the same. Over the past decade, there was not any real evidence of a significant change in overall woodland. The study resulted in a more detailed understanding of the pattern of change in the landscape and could provide the basis for informing policy and management aimed at enhancing native woodland extent and quality in the National Park and elsewhere.

The next chapter examines the physical characteristics of broadleaved and scrub habitats in order to model their present distribution in Snowdonia and discusses an attempt made to extend these models to make predictions in anticipation of climate change.

CHAPTER 4

'The climatic control of plant distribution
has not been regarded as a central research
field in ecology or biogeography
for fifty years or more...
...the need to anticipate the effects of potential
global warming began to focus the
attention of ecologists on this'.

Prentice *et al.* (1992).

4.0 MODELLING CURRENT AND FUTURE DISTRIBUTION OF NATIVE WOODLAND AS A RESULT OF CLIMATE CHANGE

Evaluating how future climate changes may affect habitats has become increasingly important in the study of long-term maintenance of global biodiversity (Peters and Darling, 1985). Ecologists are now being forced to predict how individual plants, populations and ecosystems will respond to expected future changes in climate and CO_2 (Houghton *et al.*, 1990). These predictions will have important consequences for a range of concerns such as conservation, hydrology, erosion and agricultural productivity. For instance, although it may prove impossible to prevent changes in vegetation it is possible that greater weight could be given to the conservation of certain species (Elmes and Free, 1994). The predictions are therefore crucial for future management (Woodward, 1993).

At the regional (to global) level it is climate that sets the broad limits to the distribution of plant taxa (Woodward, 1987). The distribution of many plant species in Britain is largely determined by climatic variables which limit their ability to survive. Species with a pronounced northern distribution are largely remnants from early past-glacial time. These are among the most endangered members of the British flora. Many plant species are restricted to the south of England by a requirement for higher summer temperature that limits plant development and seed production further north. If the climate changes radically, profound effects can be expected on the native flora (Fowler and Brown, 1993). A number of studies have been published which contribute to the understanding of the potential influences of climate change on vegetation. These include climatic influences on species (Huntley *et al.*, 1995; Sparks *et al.*, 1995a; Proe *et al.*, 1996; Guisan *et al.*, 1998; Iverson and Prasad, 1998; Iverson *et al.*, 1999) or vegetation types (Brzeziecki *et al.*, 1993; Kienast *et al.*, 1998; Eeley *et al.*, 1999). After an exhaustive search in the literature, the author is aware of only one publication dealing with modelling of the impacts of climate change on woodland dynamics and distribution in Britain (Berry *et al.*, 2000; Cook and Harrison, 2001). BIOME-UK is a regional version of the global BIOME3 vegetation model and was run for current and predicted climate conditions to identify within England and Wales potential changes in dominant plant functional types, such as temperate deciduous and temperate coniferous woodland.

The objectives of this study were to:

1. create an environmental database for the Snowdonia National Park, using the functionality of GIS technology;
2. define the physical characteristics of semi-natural woodland and model the present-day distribution of broadleaved and scrub habitats at the finer scale of the National Park;
3. investigate the potential for extending the model to make predictions in anticipation of climate change.

4.1 Climate change and related issues

4.1.1 Global change

Global change has gained prominence as an environmental issue nowadays encompassing three well known components i) land use/cover change; ii) changes in atmospheric composition; and iii) climate change. To these a fourth factor is added, changes in biological diversity which, from the perspective of terrestrial ecosystems, should be considered as a component as well as a consequence of global change (Walker and Steffen, 1999).

Human-driven changes in land use and cover are by far the most dominant component of global change in terms of impacts on terrestrial ecosystems (Houghton, 1994). The second major component is the alteration of the chemical composition of the atmosphere by human activities. The best-known change is the build-up of carbon dioxide, primarily due to fossil fuel burning. Climate change is the most well publicised component of global change. Changes in the atmospheric components of global biogeochemical cycles are predicted to affect the earth's climate because many of the C- and N-based gases that are increasing in atmospheric concentration (*e.g.* CO_2, CH_4, N_2O) absorb long-wave radiation emitted from the earth's surface and thus change the heat balance at the surface. This enhanced 'greenhouse effect' is the basis for predictions of increases in global mean temperatures (Walker and Steffen, 1999). The alteration to the composition and spatial arrangement of the Earth's biota is an additional and very significant global process. The human and climate forces leading to loss of biodiversity are illustrated in Figure 4.1.

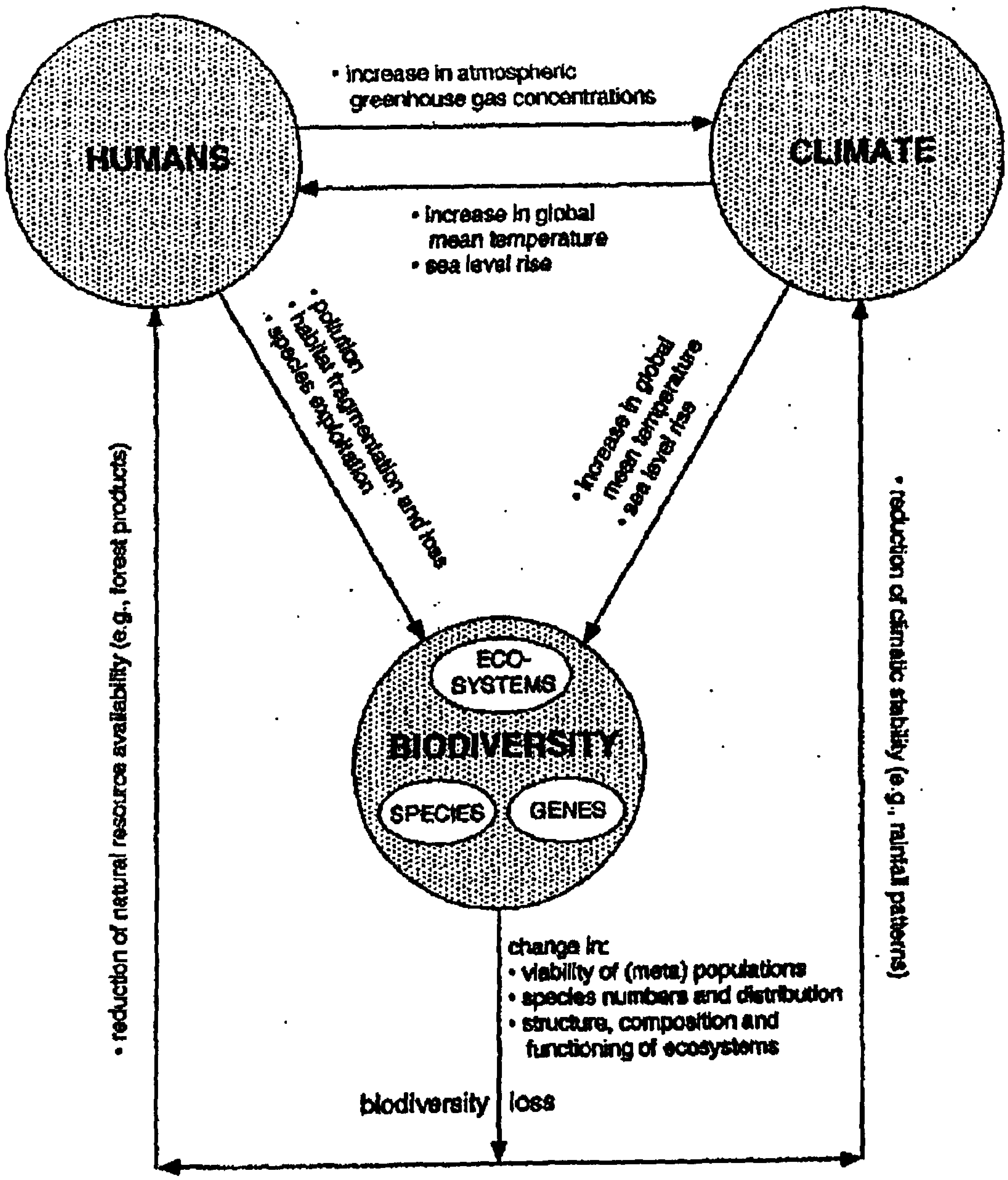


Figure 4.1. Schematic diagram illustrating the alleged human and climatic forces leading to loss of biodiversity (source: Kappelle *et al.*, 1999).

The drivers of global change are not separate effects but interact together. The interactions among them will strongly determine how terrestrial ecosystems respond to an environment of accelerating change. Land-use types, for instance, are broadly constrained by climate. Changes in land use lead to emissions of trace gases that affect climate; changing climate then influences the distribution of future land uses; which again affect climate, and so on (Walker and Steffen, 1999).

The following sections of this review will mainly concentrate on the climate change component of global change and will describe how studies of past changes in climate can help in understanding potential future changes in climate; the state of the present climate; the role of GCMs in forecasting climate change scenarios; the likely impacts of climate change on vegetation and methods employed to model such effects.

4.1.2 Projected climate change

Climate has varied over a large range in the history of the earth. It has been suggested that major shifts in climate are controlled by variations in CO_2 with related functions in modes of ocean circulation (McElroy, 1994). The climate system, however, is very complex involving processes both internal and external to the atmosphere, interactions that couple the atmosphere to the biosphere, cryosphere and ocean, and on a long time-scale the lithosphere (Graham, 1995).

Global climate change is one of the most contentious topics in environmentalism, ecology and politics (Houghton *et al.*, 1990, 1992, 1996). It can be simply defined as a change in the average climate from one averaging period to the next (Parry and Carter, 1998). However, the United Nations Framework Convention on Climate Change (FCCC) uses the term 'climate change' to refer exclusively to 'change that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.

Human-induced increases of atmospheric concentrations of gases such as carbon dioxide, methane, nitrous oxide and chlorofluorocarbons (CFCs) may result in unparalleled increases in global temperature (Houghton, 1995). This would happen through an intensification of the so-called 'greenhouse effect' *i.e.* the absorption of infrared radiation by gases and its re-radiation back toward the surface of the earth. Measurements over the past 130 years show that atmospheric temperatures have already risen considerably and have been the highest in the last few years (Kappelle *et al.*, 1999).

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment

Programme (UNEP) to assess the available scientific information on climate change, its environmental and socio-economic impacts and to formulate response strategies. The IPCC's First Scientific Assessment in 1990 concluded that '*...the increase in atmospheric concentrations of greenhouse gases since the pre-industrial period had altered the balance of the earth/atmosphere and that global warming would result*' (Houghton *et al.*, 1990). This assessment provided the basis for negotiating the United Nations Framework Convention on Climate Change in 1992 which along with the Kyoto Protocol in 1997 represented the first steps taken by the international community to protect the climate system from anthropogenic interference. In 1996, the IPCC issued its Second Assessment Report (Houghton *et al.*, 1996) which represents the degree of consensus on various climate change issues and concluded that '*... the balance of evidence suggests that there is a discernible human influence on global climate*'. Under the IPCC business-as-usual scenario (*i.e.* no reduction in carbon dioxide emissions) global environmental change in the next century may include an increase of atmospheric carbon dioxide concentrations from 350 ppmv in 1993 to 525 ppmv in 2050. This may imply a 0.3^0C rise in global mean temperature per decade (Houghton *et al.*, 1992). A third report from the IPCC is due in 2000 but a review of the draft report (Pearce, 1999) indicates that the IPCC has broadened its estimates of their forecasts of greenhouse emissions (twice current estimates or they could be reduced by 30%). The estimates take into account the unknown factor of how technology will develop. The draft indicates that technology is at least as important a driving force of future greenhouse emissions as population and economic development.

4.1.3 Past changes in climate

Knowledge of past climates helps in judging the severity and uniqueness of potential future changes in climate. Further, by studying past climates we have a way to test the accuracy of the climate models used to predict the regional climate patterns of the future (Webb III, 1992). Evidence of past climate comes from three main sources paleoclimatic, historical and instrumental evidence.

A combination of these main sources shows that over the past million years, the most noticeable pattern of global climate variation has been the oscillation between glacial and interglacial climates, with glacial periods occurring roughly every 100 000 years (Figure 4.2.e). A detailed view of the last 150 000 years (Figure 4.2.d) shows three things: first, the last interglacial period, which may have been slightly warmer than today (by $2^0 \pm 1^0$C at most), lasted from 130 000 to 120 000 years ago. Second, the present interglacial began about 10 000 years ago. Third, the last full-glacial period was from 23 000 to 13 000 years ago (Figure 4.2.c). Over the past million years, the earth's climate has varied continuously and has been in interglacial and full-glacial modes for only 20% of the time. The rest of the time, it was somewhere in between (Webb III, 1992).

Over these long time spans, the recent variability of global temperature has been more than matched by geographic variations in temperature, moisture and atmospheric circulation (COHMAP, 1988). For example, during the last full-glacial period, sea surface temperatures varied geographically from being more than 10^0C lower than those today in the North Atlantic Ocean to being 2^0C higher than those today in the tropical Pacific Ocean. These geographic variations and the changes in the ice sheets, and sea ice are what plant, animal distributions respond to. According to Webb III (1992) the past 18 000 years are particularly interesting because the rise in global mean temperature of $5^0 \pm 1^0$C during this period closely approximates the $4.2^0 \pm 1.2^0$C rise that is predicted for the near future as the result of a doubling in the effective concentration of greenhouse gases (Schlesinger, 1989).

Over short time spans of 100 to 1 000 years (Figure 4.2.a,b), climate has also varied continuously but the magnitude of change has been less than that between glacial and interglacial periods (Webb III, 1992). Within the North Atlantic region, historical, archaeological and fossil records show there was a warmer period from AD 800 to 1200 when Scandinavians were able to in settle Iceland and Greenland (Lamb 1979, cited in Webb III, 1992) but the global extent of those warmer temperatures is as yet unknown. A long time-scale cooling period, generally known as the Little Ice Age, followed this period (Hulme and Barrow, 1997). Instrumental records indicate that the earth has warmed by $0.5^0 \pm 0.1^0$C since the end of the Little Ice Age in AD 1850 ± 30 years (Jones *et al.*, 1986). The maximum rate of this warming was about 0.5^0C per century. Although it is unclear what triggered the Little Ice Age it has been speculated that the recovery might have been promoted in part by the post-industrial increase in the concentration of greenhouse gases (McElroy, 1994).

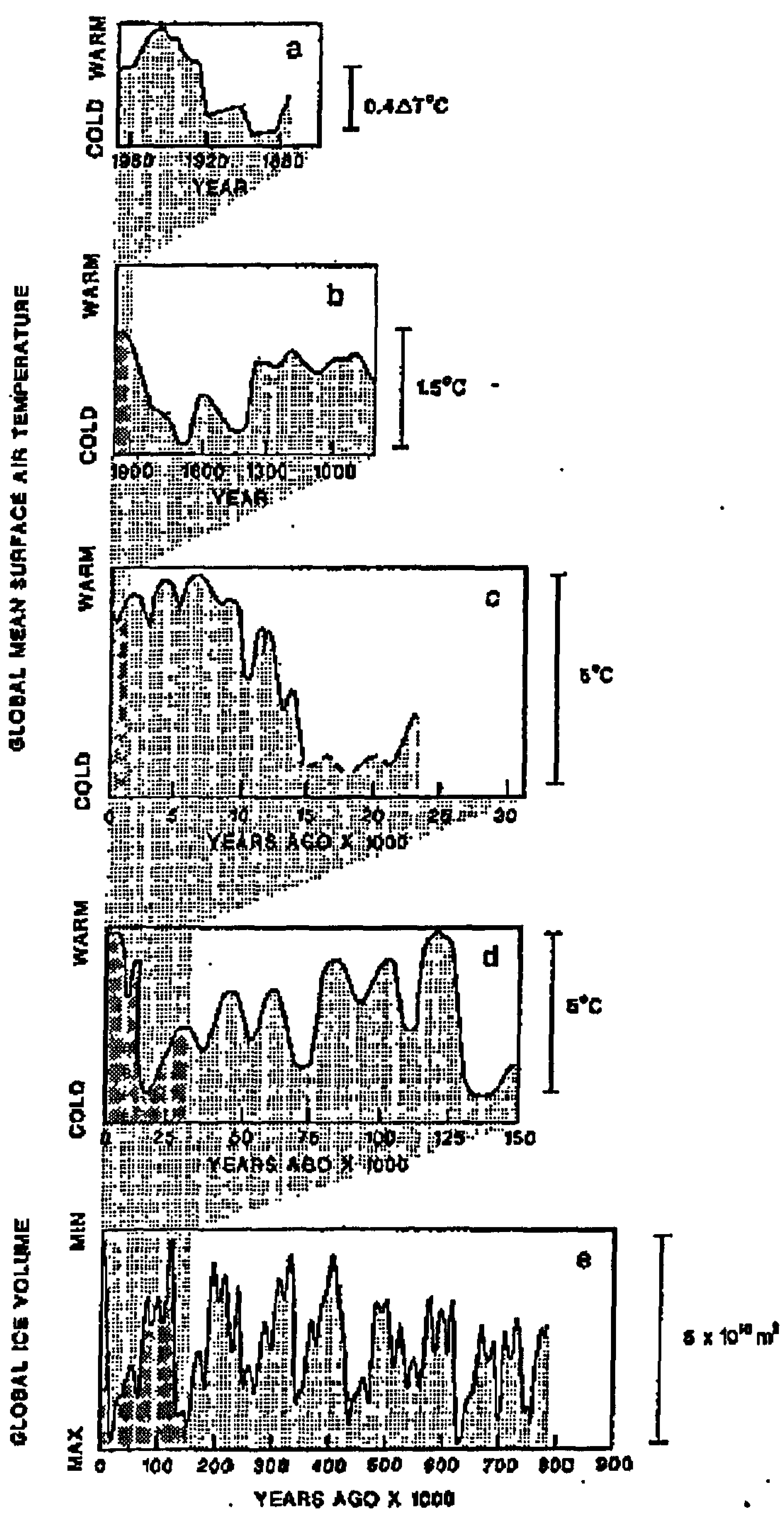


Figure 4.2. General trends in global climate for various time scales ranging from decades to hundreds of millennia. Each shading represents a detailed view for each subsection of the figure (for example Figure 4.2.d is a detailed view of Figure 4.2.e for the last 150 000 years). Note that local and regional climate changes may not resemble these global trends. The time series of climatic information are (a) from instrumental data for 1880-1970, (b) from historical information primarily from the North Atlantic region and Europe for the last thousand years, (c) from pollen data and alpine glaciers for 30 000 years, (d) from marine plankton data covering 150 000 year), and (e) from oxygen-isotope fluctuations in foraminifera shells in deep-sea sediments covering roughly one million years (source: Webb III, 1992).

4.1.4 Recent trends in climate

The UK possesses some of the longest instrumental climate time series in the world with the Central England Temperature (CET) series extending back to 1659. There has been a warming of UK climate since the seventeenth century. Mean annual temperatures have risen by about 0.7^{0}C over three hundred years and by about 0.5^{0}C during the 20th century (Figure 4.3-However this is from a different data source and does not show the change). The last decade (1988 to 1997) has been the warmest in the entire series, with four of the five warmest years since 1659 occurring in this short period. In increasing order the three warmest years have been 1990, 1997 and 1995. The UK has also some of the longest records of precipitation (Figure 4.4). Although some variability is shown from decade to decade no longer-term trends are discernible (Hulme and Jenkins, 1998).

The increase in global annual mean temperature (Figure 4.5) has been attributed to the rise in concentration of CO_2 which has risen from its pre-industrial level of 280 ppmv to a level of more than 350 ppmv today (Figure 4.6) (McElroy, 1994). This rise has largely been attributed to emissions associated with the burning of fossil fuels and is predicted to rise over the next few decades to levels more than twice those of the pre-industrial era (Houghton *et al.*, 1996). There is uncertainty about attributing the recent observed increase in global mean temperature to human factors (Walker and Steffen, 1999). In addition, the changes in global temperatures over the last 40 years do not closely mirror the changes in CO_2 according to Beerling and Woodward (1994). Thus any predictions made solely on the basis of CO_2 must be taken with caution.

4.1.5 Future changes in climate

The desire to predict climatic changes arises from concern over the rapidity and magnitude of those changes and from the need in some cases to plan how to respond to the changes far in advance (Schneider *et al.*, 1992). The current challenge is to predict the response of the climate system to increasing levels of greenhouse gases. One response to the need for information on future climatic changes has been the analysis of large climatic changes in the geologic past (Budyko *et al.*, 1987). Looking at more recent climatic records, the so-called historical analogue method, can also provide insights into climatic behaviour and societal vulnerabilities (Pittock and

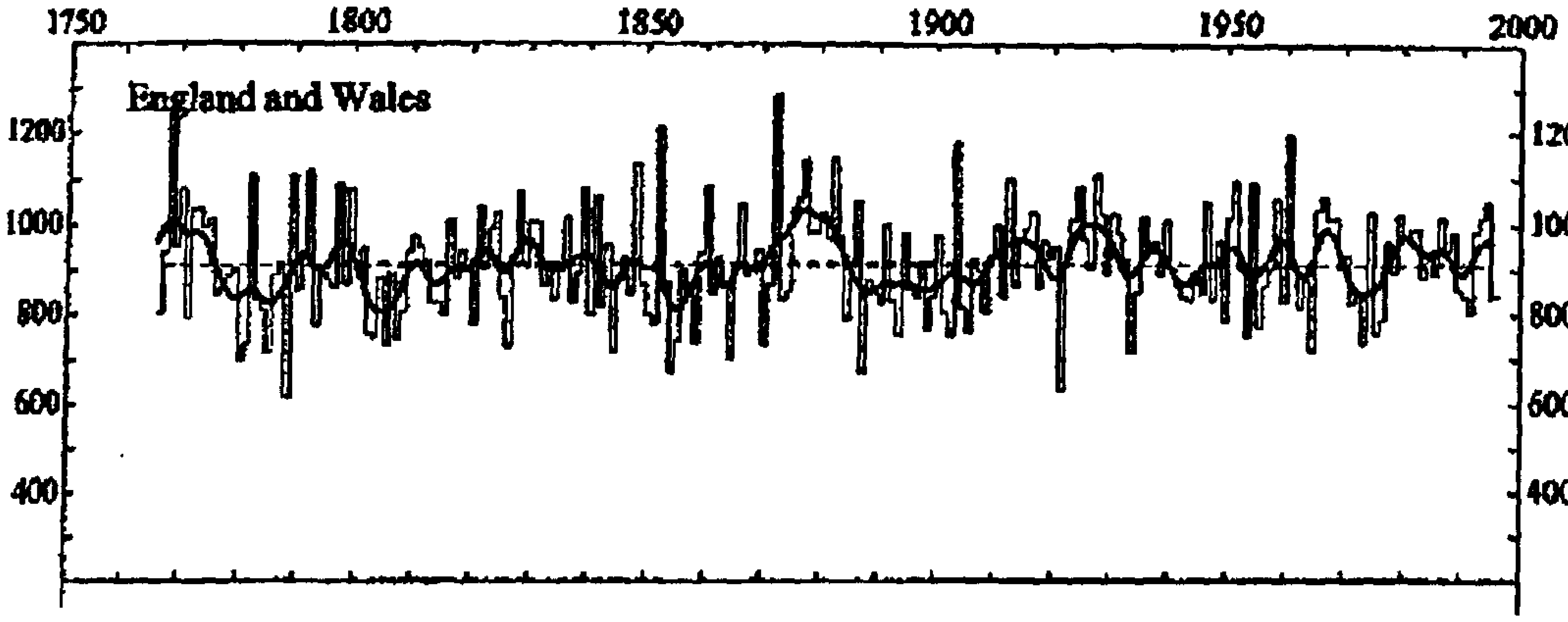


Figure 4.3. Annual temperature for 'Central England' from 1659 to 1995. Mean decade temperature is shown by the bold line (source: Jones and Hulme, 1997).

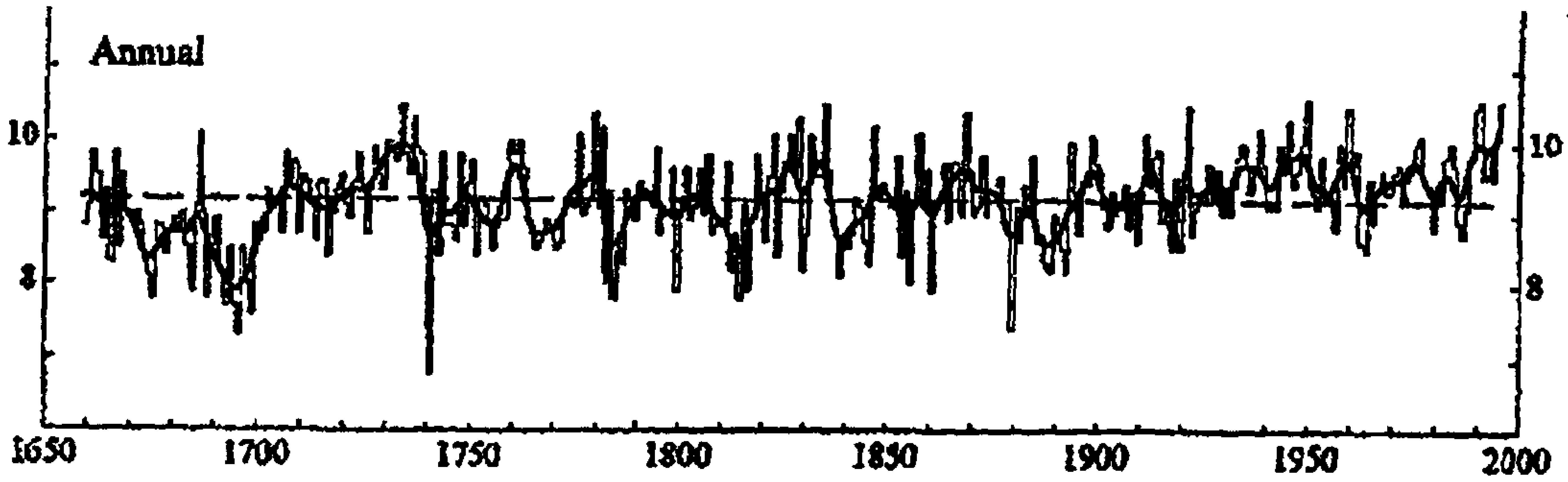


Figure 4.4. Annual precipitation for England and Wales (source: Jones *et al.*, 1997).

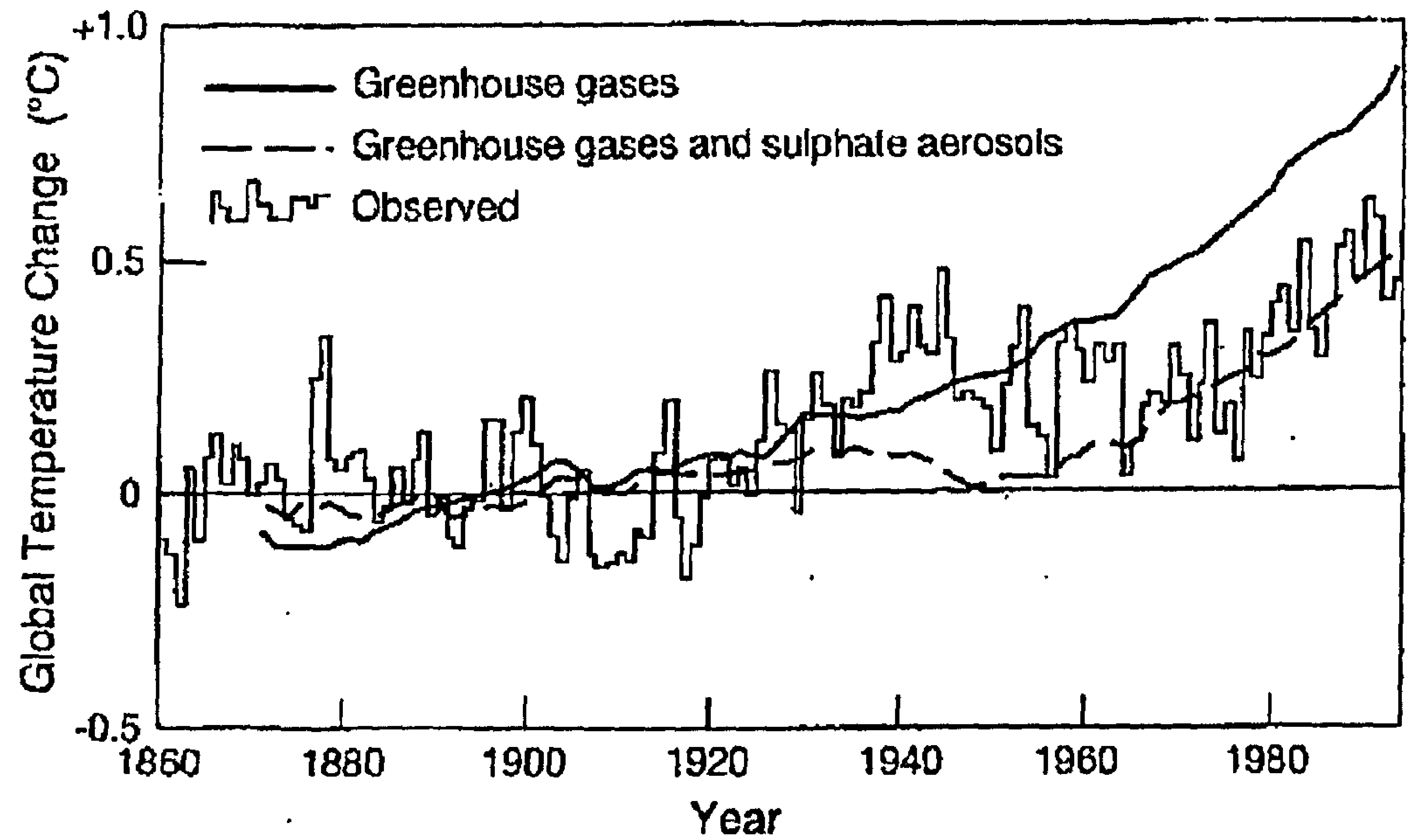


Figure 4.5. Simulated global annual mean warming from 1860 to 1990 allowing for increases in greenhouse gases only (solid curve) and greenhouse gases and sulphate aerosols (dashed curve), compared with observed changes over the same period (source: Houghton *et al.*, 1996).

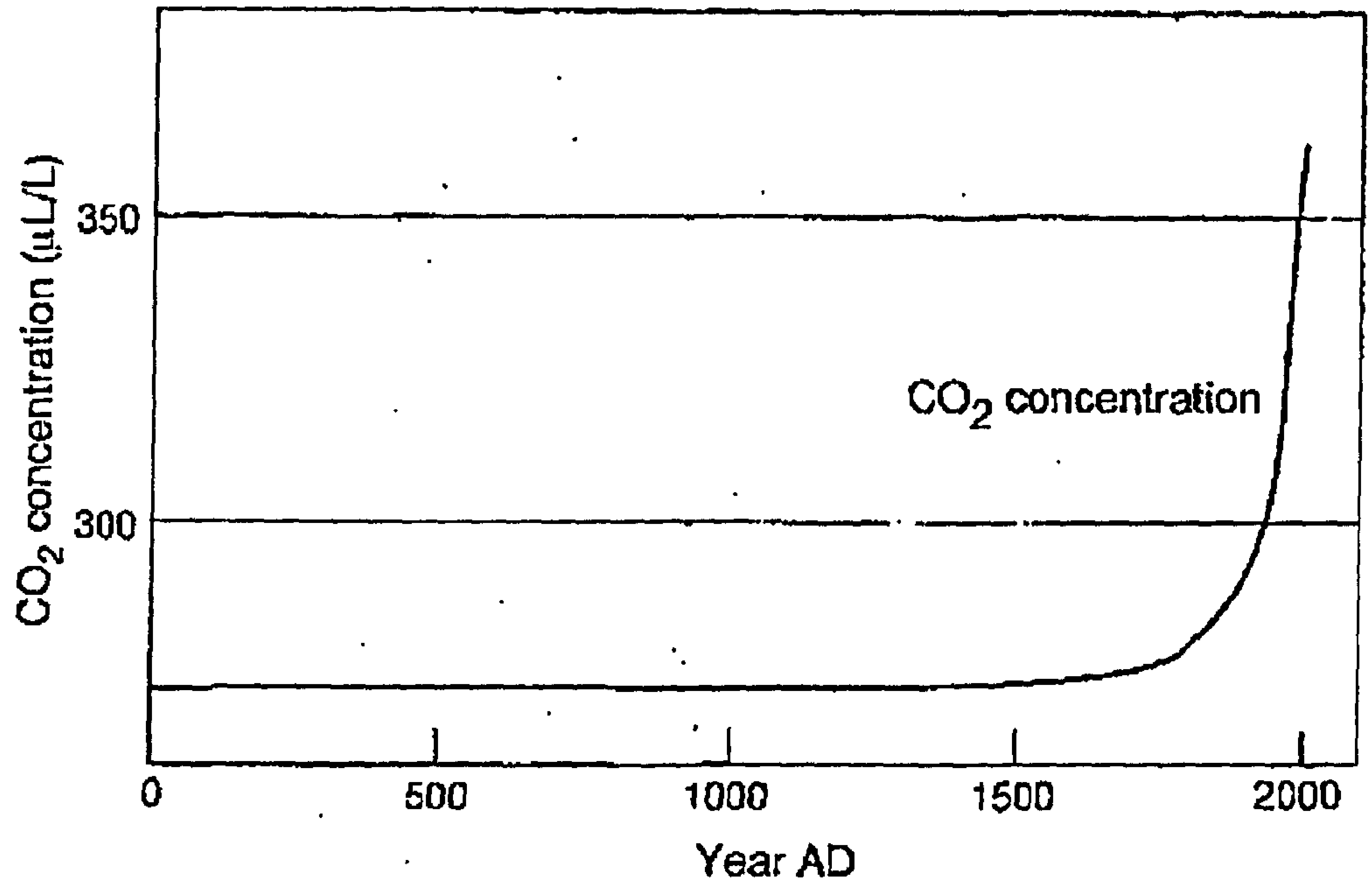


Figure 4.6. Concentration of CO_2 in the atmosphere over the past 2 000 years (source: Vitousek, 1994, cited in Walker and Steffen, 1999).

Salinger, 1982). Both, however, methods are based on climatic cause-and-effect processes that could be different from future greenhouse-gas radiative effects (Schneider, 1984, cited in Schneider *et al.*, 1992). Therefore, scientists have focused on large-scale models of the climate, general circulation models (GCMs), that attempt to represent mathematically the complex physical interactions among the atmosphere, oceans, ice, biota and land using scenarios of plausible future climatic changes. However, the complexities of the real climate system still vastly exceed the comprehensiveness of today's GCMs and the capabilities of today's computers (Schneider *et al.*, 1992). Furthermore, as Stone and Risbey (1990) pointed out, the meridianal transports of heat by the atmosphere, as predicted by GCMs for the present environment, differ from observations by as much as a factor of two. Thus, the reliability of any study which uses GCMs as the source for data needs to be taken into account.

Recent climate models calculate a potential rise of the global mean surface temperature of about 1^0 to 3.5^0C by 2100 (Watson *et al.*, 1996). This predicted change under future global warming conditions is faster than any natural warming during the past 18 000 years (Webb III, 1992). However, projected rises in temperature will not be equally distributed over the globe. Mean temperatures at the poles are expected to increase much more (0.8^{0}C per decade) than those in equatorial regions (0.1^{0}C per decade). The rise of global temperatures has been predicted to be accompanied by increased frequency and destructiveness of hurricanes, more protracted droughts, longer and hotter heat waves, more severe rainy periods and significant changes in the area of the great ice sheets of Antarctica (McNeely *et al.*, 1995). Nevertheless, there appears to be no hard evidence to substantiate all these assertions (Mahlman, 1997).

The UK Climate Impacts Programme (UKCIP) approach is to present four alternative scenarios of climate change for the UK spanning a reasonable range of possible future climates within the next 100 years. The UKCIP98 scenarios rely largely on one set of coupled ocean-atmosphere GCM experiments completed by the Hadley Centre during 1995 and 1996. They assume that by the 2080s CO_2 will be between 49% and 109% higher than the present average level of 334 ppmv and show a rise in mean annual temperature over the UK, slightly smaller than the global average, with larger increases in the south-east of the country than in the north-west (Figure 4.7) (Hulme and Jenkins, 1998). By the 2080s it is predicted that temperatures over south- east England may increase by 1.1^{0}C to 3.2^{0}C above the 1960-1991 mean whereas over Wales by 1.1^{0}C to 3^{0}C. Seasonal differences are minimal but, generally, warming may be slightly more rapid in winter than in summer and greater during the night. Changes in mean annual precipitation are more reserved. By the 2080s it is predicted that annual precipitation will increase by between 0 to 10 per cent over England and Wales and by between 5 and 20 per cent in Scotland (Figure 4.8). Throughout the UK, winters and autumns could become up to 20 per cent wetter.

Although carefully qualified, explicit scenarios of plausible future climatic changes are preferable to impact speculations based on implicit or casually formulated forecasts (Schneider *et al.*, 1992), some of the speculations are really interesting; for instance, that warmer weather over Greenland and the Arctic, due to global warming, could cause the North Atlantic Drift to effectively switch off and plunge parts of Northern Europe, such as the UK, into winters that resemble those experienced in Labrador and Siberia (Rahmstorf, 1997; Bunyard, 1999). More recent modelling work (Rahmstorf, 1999), however, indicates that despite quadrupling atmospheric CO_2

levels, and a decrease in the volume of water transported by the Atlantic conveyor belt by around 25%, it will not cause a total collapse.

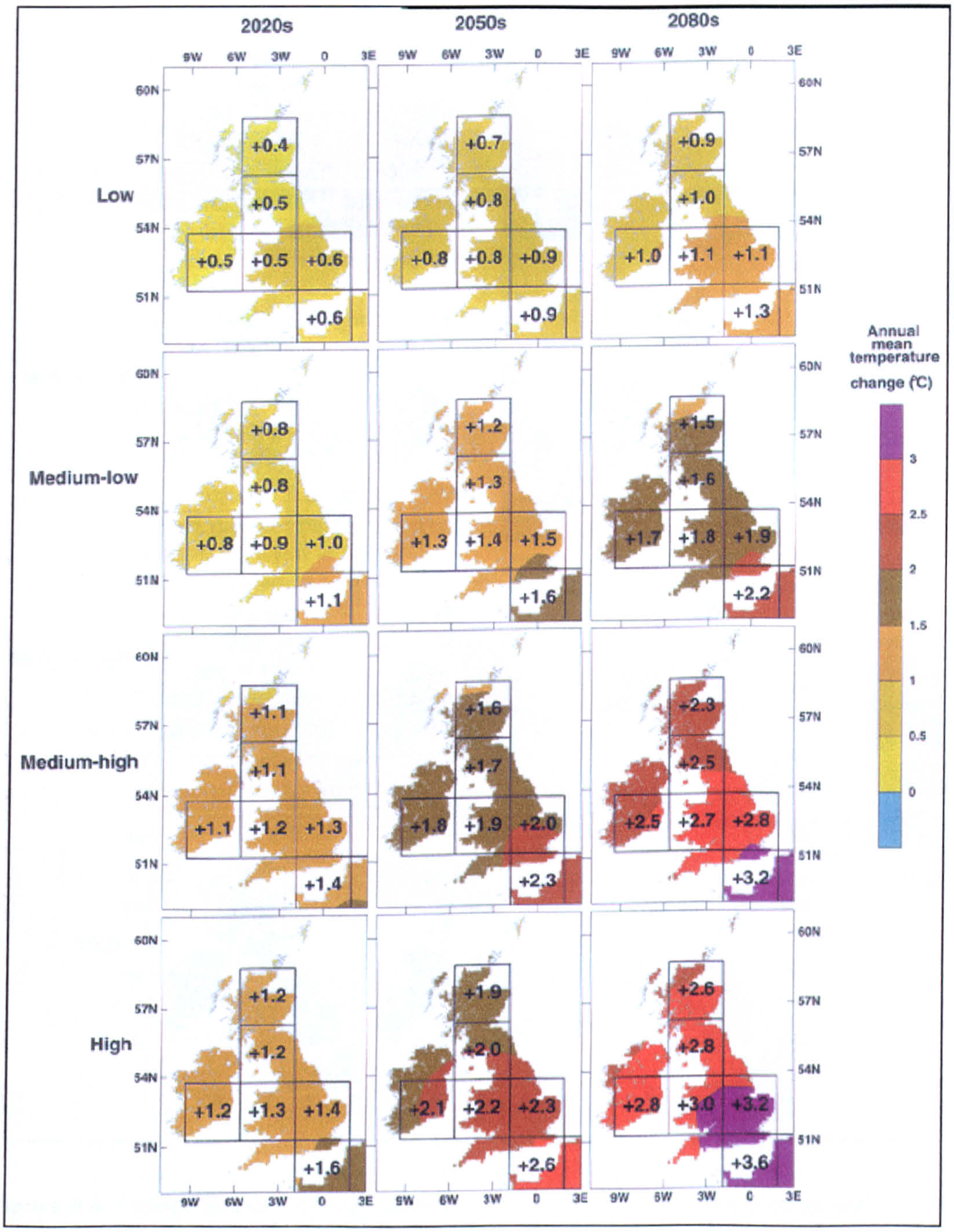


Figure 4.7. Change in mean annual temperature (with respect to the 1961-90 mean) for thirty year periods centred on the 2020s, 2050s and 2080s and for the four UKCIP98 scenarios based on the Hadley GCM experiments (source: Hulme and Jenkins, 1998).

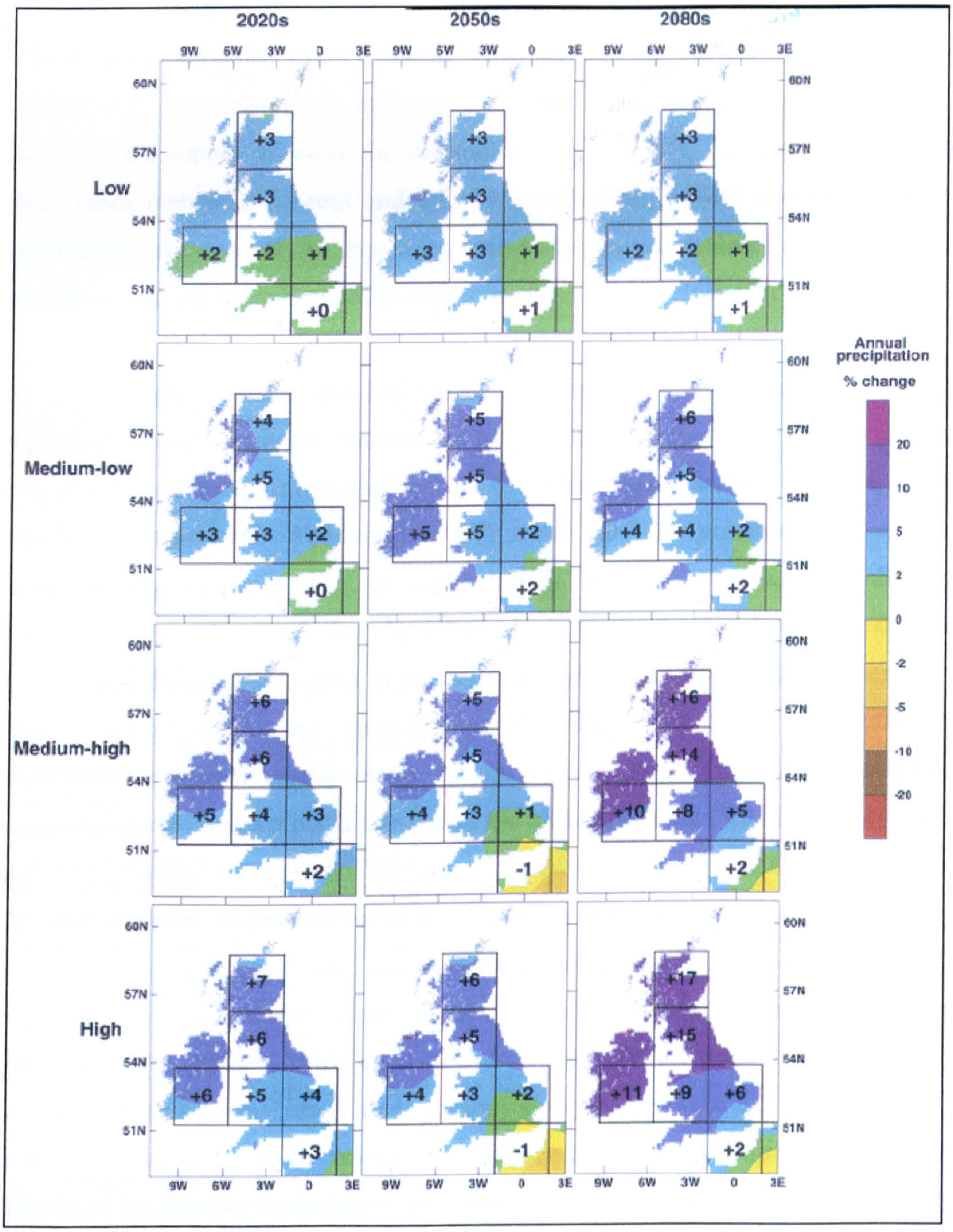


Figure 4.8. Change in mean annual precipitation (expressed as per cent change with respect to the 1961-90 mean) for thirty year periods centred on the 2020s, 2050s and 2080s and for the four UKCIP98 scenarios based on the Hadley GCM experiments (source: Hulme and Jenkins, 1998).

4.1.6 Climate and plant distribution

Abiotic relationships (*i.e.* physiological tolerances) are the primary factors determining whether any organism can exist in a certain environment. Many climatological variables exert a strong influence on the growth of plants, either directly, *e.g.* temperature, or indirectly, *e.g.* the combination of variables which determine the supply of water for vegetation (Grace, 1987). Temperature and light affect plant metabolic process and thereby germination, growth and reproduction. Species and ecotypes vary in their tolerances of low and high temperatures and light intensities, and therefore have different geographical distributions (Woodward, 1987).

On a geographical scale, the importance of climatic variables in moulding the vegetation is quite apparent. Boundaries to the distribution of plant life forms and species often coincide with isometric lines of climatological variables (Grace, 1987) especially temperature. Woodward (1987) stated that the poleward spread of a particular physiognomic type of vegetation is strongly controlled by absolute minimum temperature and the physiological ability to survive low temperatures. Larcher and Bauer (1981, cited in Grace, 1987) noted that low winter temperatures may be responsible for the northerly and altitudinal limits to the distribution of broadleaved evergreen woody plants, for the northern limit of temperate deciduous forests in North America and Eurasia and the altitudinal limits for survival of some species on tropical mountains. Trees are restricted to those areas of the world where the mean summer temperature exceeds 10^0C. Many species appear to be restricted by low summer temperatures. In *Tilia cordata* (small-leaved lime), individuals at the northern limit of distribution do not set seed unless the summer is an especially warm one (Pigott and Huntley, 1981, cited in Grace, 1987). Dwarf shrubs have life-cycles not very different from those of trees yet they always progress to higher altitudes and latitudes. The position of the treeline in continental climates is known to be strongly influenced by summer temperature although in oceanic climates, such as the British Isles, it is thought that the exposure at a site exerts a larger influence (Hale *et al.*, 1998).

Rodwell (1991a) stated that major contrasts in climatic factors are responsible for some of the most obvious floristic variations between the mixed deciduous and oak-birch woodlands of different parts of the country. First, there is the influence of temperature. The floristic divide between the regions corresponds crudely with the 26^{0}C mean annual maximum isotherm (Conolly and Dahl, 1970, cited in Rodwell, 1991a). The cooler, cloudier and shorter summers of the north and west adversely affect the sexual reproduction of a number of important species, such that Continental and Continental Southern elements in the flora of these woodlands are largely confined to the communities of the south and east. Second among the climatic factors is rainfall. In broad terms, the boundaries between the suites of communities coincide with the 1000mm mean annual isohyet (Climatological Atlas, 1952, cited in Rodwell, 1991a). Third, the consistency of surface and atmospheric humidity in the north-west, where there are rarely fewer than 160 wet days yr^{-1} (Ratcliffe, 1968), also encourages a greater profusion of ferns and bryophytes in all the woodland types. This abundance is often accentuated by the rockier terrain of north-western landscapes with a profusion of sheltered niches. Different groups of species can characterise each of the woodlands in this part of the country. Furthermore, sub-communities among these woodlands are related to further climatic effects, such as the minimum winter temperature or the incidence of frost, the oceanicity, and the windy climate. Finally, differences in soil and climate provide the best basis for understanding the major floristic variations among mixed deciduous and oak-birch woodlands but, as Rodwell (1991a) pointed out, very often, this diversity is overlain by the effects of silvicultural treatments, such as the removal or planting of timber trees, the selective coppicing of underwood crops, grazing and browsing by stock and wild animals. Treatments operate within the general constraints that edaphic and climatic conditions impose, although they do not always work in the same direction. Sometimes, treatments enhance patterns of floristic variation related to natural environmental factors; often, they work against them, blurring the variation.

4.1.7 Potential impacts of climate change on vegetation

A great deal of work has been undertaken to assess the potential consequences of climate change. This literature is summarised in Watson *et al.* (1996). A summary of the potential impacts, based on this work, is given in Table 4.1. This section has concentrated, however, on the potential effects of climatic change on vegetation only.

Table 4.1. Summary of potential impacts of climate change by sector (source: Wuebbles *et al.*, 1999, based on Watson *et al.*, 1996).

Sector	Area	Potential impacts
Terrestrial ecosystems	Forests	Large vegetation shifts, especially at high latitudes
		Increase in forest mortality rates during rapid transition time
		Loss of biodiversity
	Grass and shrub lands	Change in growing seasons and ecosystem boundaries
	Deserts	Becoming hotter, drier
		Increasing desertification
	Mountain Glaciers	Disappearance of one-third to one-half of existing glaciers over 100 years
	Mountain ecosystems	Vegetation shift to higher altitudes and possible extinction
		Disruption of recreational activities
	Polar ice sheets	Little change expected over next century
Aquatic ecosystems	Lakes and streams	Changes in water temperature, water flow and levels
		Extinctions at low-latitude boundaries of cold-water species
	Wetlands	Shift in geographical distribution
	Coastal systems	Shore erosion and higher tides
		Damage or loss of important coastal habitats such as coral reefs, marshes and river deltas
		Increased salinity of estuaries and aquifers
		Serious impacts of tourism, freshwater, fisheries and biodiversity
	Oceans	Increase in average sea level causing large land losses, particularly for small island states
		Possible changes in ocean circulation
		Reduction in sea ice cover
		Impacts on tourism, fisheries, transport, etc.
		Potential for triggering important climate feedbacks and/or abrupt climate change
Water resources		Intensification of global hydrological cycle
		Increased intensity of runoff, floods and droughts
		Change in water available for agriculture, domestic and industrial uses, hydropower, recreation, etc.
Agriculture	Crops	Large changes in crop yields & productivity on local and regional scales
		Increased risk of hunger and famine, especially in tropical and sub-tropical regions
	Livestock	Changes in available land, especially for pastoral systems
	Fisheries	National and local impacts as species and production centres shift
Human infrastructure	Energy, industry and transportation	Sudden changes, surprises, and extreme events would affect energy demand, transportation, etc.
	Housing	Increased vulnerability to flooding and erosion loss in coastal areas
		Higher potential for damage and disaster
	Property insurance	Higher risk of extreme events that will be difficult to detect or predict

Table 4.1. Continued.

		Could lead to higher insurance premiums, coverage withdrawal, or even insolvency
	Tourism	Loss of recreational locations will impact local economy
Human health	Direct	Increased illness and death from heatwaves and cold spells Death and injuries from altered frequency and intensity of extreme events such as floods or storms
	Indirect	Changes in range of vector-borne diseases such as malaria and dengue Effect of decreased water quality and agricultural changes on water-borne diseases and human health Respiratory and allergic disorders from climate-enhanced air pollution & pollens Social impacts of climate change on infrastructure and health

Because vegetation is a dominant factor in structuring ecosystems, a central part of understanding ecological effects of climate change is to understand how vegetation will respond (Woodward, 1992). Species may respond to changes in climate in many ways (DeGroot *et al.*, 1995). An overview of the main types of response features which determine the sensitivity of species to climate change is given in Table 4.2.

According to DeGroot *et al.* (1995) many physiological processes in plants are sensitive to changes in greenhouse gas concentrations (notably in CO_2) and climate (*e.g.* temperature and humidity). For example, photosynthesis by green plants and respiration are both influenced by CO_2 levels and temperature (Korner, 1993). When temperature and precipitation change, many phases in the life cycles of most plants

Table 4.2. Some response features of species to climate change (source: DeGroot *et al.*, 1995).

Physiology	Phenology	Inter-specific interactions	Abundance/distribution
Photosynthesis	Budburst	Symbiosis	Population dynamics (Increase/decrease/extinction)
Respiration	(De)foliation	Pollination	Range limits
Stress	Onset of flowering	Diseases/pests	
Dormancy	Growth pattern	Predation/herbivory	
	Seed setting/ripening		
	Breeding pattern		
	Reproduction success		
	Migration Pattern		

are affected, such as the timing of (de)foliation, leaf-burst and flowering, the timing of seed-setting and ripening, the length of the growing season, growth and timing of migration. Indications, for Britain, of the level of response between temperature and the timing of various biological events associated with woodland species are given by Sparks (1999). Changes in the balance between climate and life cycles of plants will have implications for inter-specific relationships such as symbiosis, diseases and pests, and competitive powers. Furthermore, physiological and phenological responses to climate change, in combination with changes in interactions between species, will influence the (relative) abundance and distribution of most species. There are numerous examples of correlations between the occurrence of a species and one or more climate parameters, such as snow-cover or temperature (Grace, 1987; Woodward, 1987). It should always be kept in mind, however, that it will depend on a set of factors, such as dispersal capacity, rate of migration and presence of barriers, as to whether a species ultimately will be present in its total potential range. In addition, changes in climate and concentration of greenhouse gases not only have direct-effects on species but also indirectly *via* climate-induced changes in other environmental conditions such as soil water deficit, soil chemistry, runoff and erosion. These abiotic effects, together with the direct response of plant species, determine the final impact of climate change on the structure and functioning of natural and semi-natural ecosystems and landscapes (DeGroot *et al.*, 1995).

When temperature and rainfall patterns change, species' ranges change. This is because species tend to track their climatic optima, retracting their ranges where conditions become unsuitable while expanding them where conditions improve (Peters and Darling, 1985). As the earth warms, species are generally expected to shift to higher latitudes (poles) and altitudes (peaks) (Peters, 1992). Certain areas of endemic and species-rich tropic alpine vegetation, under projected future global warming conditions, may be fully replaced by montane cloud forests presently found at lower altitudes (Halpin, 1994a; b). Changes in global vegetation cover and in the boundaries of the world's biomes (major vegetation zones) are expected to occur as entire vegetation types have shifted in response to past temperature changes (Peters and Lovejoy, 1992). However, it should not be imagined that because species tend to shift in the same general direction, existing biological communities move in synchrony. Conversely, because species shift at different rates in response to climate change and respond individually to various ecological factors, communities often dissociate into their component species and tend to fragment forming new assemblages as species shift their ranges in different directions (Figure 4.9) (Peters, 1992).

In addition to latitudinal changes in species ranges, a local increase in temperature may also cause vegetation to shift its altitude upward approximately 500 meters for a 3^{0}C warming (Peters and Darling, 1985). In particular, the authors stated that *'...species originally situated near mountain tops... may be entirely replaced by the relatively thermophilous species moving up from below'*. This prediction follows from observations on mountains that plants and vegetation zones have upper distributional boundaries that are strongly correlated with a low-temperature limit (Friend and Woodward, 1990). Therefore any increase in temperature should allow these boundaries to

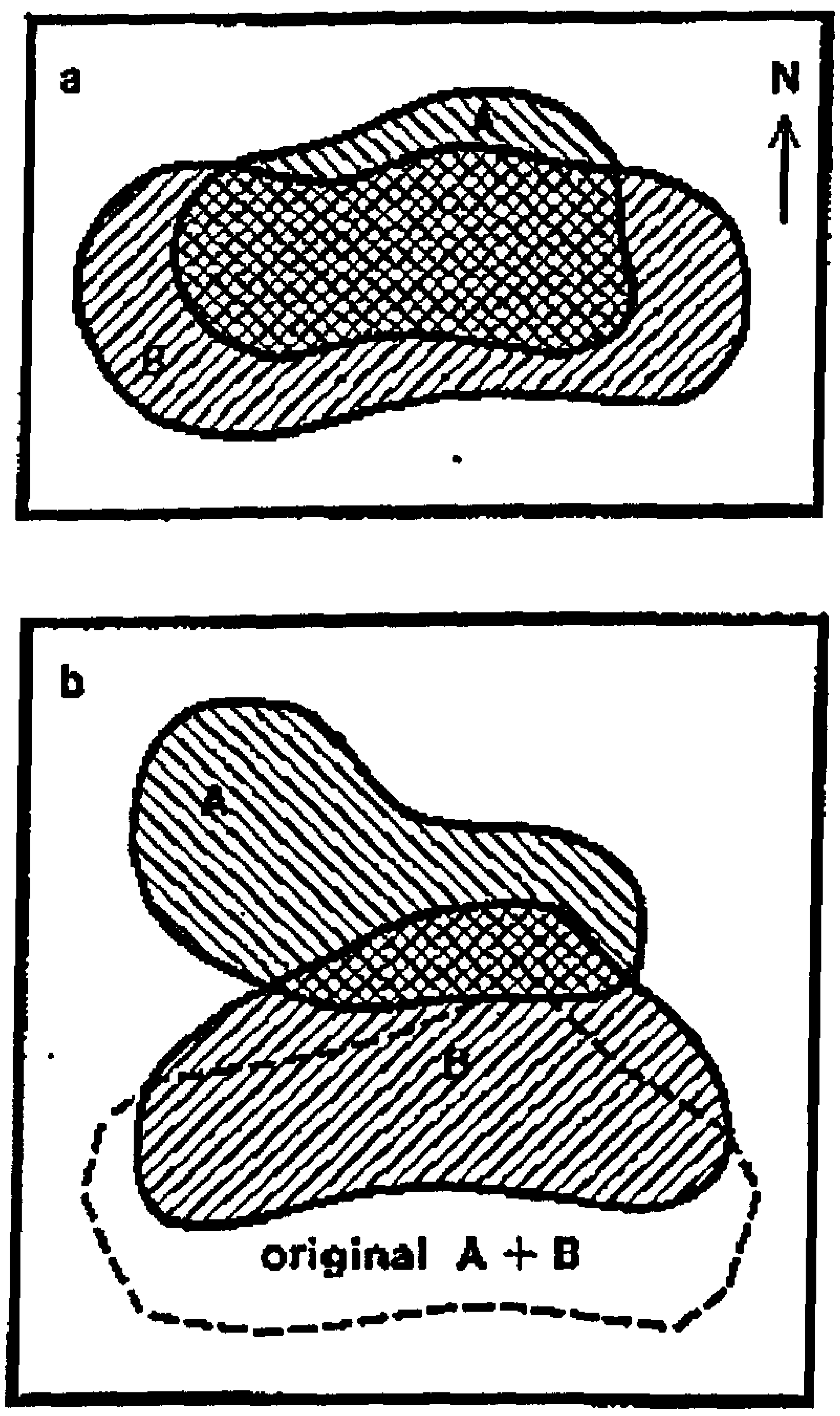


Figure 4.9. (a) Initial distribution of two species, A and B, whose ranges largely overlap. (b) In response to climate change, latitudinal shifting occurs at species-specific rates and the ranges disassociate (source: Peters, 1992).

increase in altitude. More recently, however, Woodward (1993) tested this hypothesis using results from published experimental studies. Investigations and models of the responses of leaf growth to temperature are in accord with the prediction but the individualistic responses of species to CO_2 enrichment indicate that this simple view is unlikely to be true for all species : growth is stimulated by CO_2 enrichment for some species but not for others. Wind speed generally increases with altitude on mountains and plants from high altitude tend to be more wind resistant than species from the lowland. Thus, it is expected that, particularly on wind-swept mountains, global warming will not necessarily be followed by the spread of lowland species into the uplands. Further evidence against the assertion is provided from the historical record. Payette *et al.* (1989) have shown for northern Canada over the last 1 000 years that, in spite of periods of significant warming, there has been little change in the altitude of the tree line. In this area of Canada, high wind speeds are an important determinant of the tree line. Just increasing temperature, with presumably little change in wind speed, fails to overcome the significant limitation for spread imposed by high wind speeds (Woodward, 1993).

Understanding the impacts of past climate change on plant life may throw light on how plants may cope with future climate changes (Wilkinson, 1999) and facilitate the development of models that predict future shifts in species, communities and ecosystems (Webb III, 1992). Studies in the Colombian Andes have shown the importance of Pleistocene (2 000 000-10 000 years BP) climate change for environmental and floristic dynamics along elevational gradients in tropical mountain regions (Van der Hammen, 1992); results depict strong altitudinal shifts in vegetation belts as a response to temperature changes. Dendrochronological studies in Chile show the sensitivity of trees to temperature changes over the last few hundred years (Szeicz, 1997). Furthermore, insight into long-term responses to large climatic changes can be gleaned from studies of fossil distributions of, particularly, pollen (Webb III,1992). In Europe, during the most recent glacial period, an ice sheet covered most of Britain and the frozen ground, or permafrost, extended far into France. This forced temperate trees southwards. Pollen evidence shows that they survived in refugia in the highlands of the Mediterranean peninsulas (Wilkinson, 1999). Such observations tell us that plants are very sensitive to climate. Their ranges move when the climate patterns change; species die out in areas where they were once found and colonise new areas where the climate becomes newly suitable. We can expect similar responses to projected global warming during the next 50 to 100 years, including disruption of natural communities and extinction of populations and species (Peters, 1992).

However, the rate at which the global mean temperature is predicted to rise under future global warming conditions is faster than any natural warming during the past 18 000 years (Webb III, 1992). A rise of about 1 to 3.5^{o}C by 2100 (Watson *et al.*, 1996) could be 10 to 50 times faster than the natural average rate of temperature change since the end of the last glaciation (McNeely *et al.*, 1995). This implies that many species are likely to be unable to move their ranges rapidly enough to keep up with the changing climate (Webb III, 1992; Peters, 1992). The ability of species to adapt will depend heavily on their ability to track shifting climatic optima by dispersing colonists. Survival of plants would therefore depend either on long-distance dispersal of colonists, such as seeds or migrating animals, or on rapid iterative colonisation of nearby habitat until long-distance shifting results. If a species' intrinsic colonisation ability is low, or if barriers to dispersal are present, extinction may result if all of its present habitat becomes unsuitable. Further, species are more likely to become extinct if their remaining populations are small or they occupy a small geographic range. Smaller populations mean fewer colonists can be sent out, reducing the probability of successful colonisation. Also, if a species has lost much of its range it is possible that remaining populations will be located in poor habitat and therefore be more susceptible to new stresses (Peters, 1992).

For many species, all of those conditions will be met by human destruction of habitat, which increasingly confines the natural biota to small patches of original habitat, patches isolated by vast areas of human-dominated urban or agricultural lands. Habitat destruction and fragmentation in conjunction with climate change sets the stage for an even larger wave of extinction than previously imagined, based on consideration of human enrichment alone (Peters, 1992). Fragmentation of habitats surrounded by cities, roads and farmland may also prevent species migration and dispersal towards more suitable habitats in response to climate change (Bierregaard *et al.*, 1997). In habitat fragments, survival of populations or species that need to adjust their geographic distribution to a changing climate will depend on their migration potential, but also on fragment size, quality and distribution (between-fragment distance, connectivity *via* corridors), and the character of the matrix surrounding fragments (physical barrier type) (Kappelle *et al.*, 1999).

Very little is known about migration rates of plant species. For trees, paleo-ecological as well as autecological studies show that dispersal rates vary roughly between 20 and 200 km/century (Huntley and Birks, 1983, cited in DeGroot *et al.*, 1995). Most of the European trees had maximum rates of movement of at least 500m a year and many moved even faster during the past 10 000 years (Table 4.3) (Wilkinson, 1999). A warming of 3^0C in 100 years corresponds with a latitudinal shift in bioclimatic zones of about 600 km. This would mean that the expected warming could be a factor 10 faster than the capacity of most plants to migrate and to invade simultaneously their distribution range (DeGroot *et al.*, 1995). At this rate of change even fast-migrating species may have difficulty in following the projected climate warming over the whole potential distribution range (Peters, 1992; DeGroot *et al.*, 1995). Species with low migration rates may become threatened by unfavourable climate conditions in their distribution range, if they are not able to tolerate the new conditions (DeGroot *et al.*, 1995). Understanding the way in which plants move in response to changing climate is, therefore, of great importance if we are to make accurate predictions on the effects of global warming (Wilkinson, 1999). However, the movement of trees may not be an issue in reality in the UK as species have been planted in the past outside their natural range. Examples are the beech trees planted in North Wales and Lake District.

Table 4.3. Maximum rate of movement of some European tree species during the past 10,000 years (source: Wilkinson, 1999).

Species	Movement (m/year)
Hazel (*Corylus* sp.)	1500
Beech (*Fagus* sp.)	300
Ash (*Fraxinus* sp.)	500
Oak (*Quercus* sp.)	500
Lime (*Tilia* sp.)	500
Elm (*Ulmus* sp.)	1000

The distribution of many plant species in Britain is largely determined by climatic variables which limit their ability to disperse. Species with a pronounced northern distribution are largely remnants from early past-glacial time. These are amongst the most endangered members of the British flora. On the other hand many plant species are restricted to the south of England by a requirement for higher summer temperature which limits plant development and seed production further north. If the climate changes radically, profound effects can be expected on the native flora (Fowler and Brown, 1993). Beerling and Woodward (1994) predicted that changes in the balance of precipitation and evapotranspiration will dominate the future prospects for ancient woodland in England and Wales, while in Scotland it is more likely that changes in temperature will be most important. The rate of vegetation change will depend upon habitat conditions, management and, most crucial of all, the lifespan and population dynamics of component species (*e.g.* dispersal and germination strategies) (Fowler and Brown, 1993). Furthermore, predicted increases in the frequency of such extreme climatic events as fires, hurricanes and droughts may be more important than temperature change itself in changing patterns of biological diversity (Wigley, 1985). Recent examples in Britain include the October gales of 1987 affecting the southern woodlands and the hot, dry summer of 1976 affecting heathlands, through heather death in 'accidental' fires (Marrs, 1986).

4.1.8 Modelling the potential response of vegetation to climate change

4.1.8.1 Introduction to models

Although plant response to varying environmental conditions has been investigated experimentally (both in the field and laboratory) from the leaf to the population and community level, the ability to extrapolate these observations directly to higher levels of organisation operating over much larger time and space scales is limited. Paleobotanical studies continue to provide observations of large-scale responses of vegetation to climate change in the past. However, their results cannot be directly applied to future conditions as they are not analogous in either the cause or potential time-scale of climate-change. This limitation makes it necessary to synthesise the current understanding of the relationship between plant pattern and climate within a conceptual framework which will allow for the prediction of plant patterns under novel environmental conditions (Smith *et al.*, 1993). Understanding how current vegetation will respond to transient patterns of global temperature, precipitation or solar radiation, requires reliance on computer models that can deal with some of the complexities of the vegetation and climate systems (Dale and Rauscher, 1994). Models provide a means of formalising a set of assumptions/hypotheses linking pattern and process, allowing for extrapolation beyond the range of observed phenomena (Smith *et al.*, 1993).

There have been a wide array of models developed to explore the response of vegetation to environmental variation. Because no one model encompasses all of the processes of importance or all of the biological levels of interest, the conceptual framework for assessing impacts of climate change on vegetation includes models that operate at different scales (Dale and Rauscher, 1994). Global vegetation dynamics models predict the kinds and rates of alterations in global vegetation biomes in response to climate change (*e.g.* Emanuel *et al.*, 1985). Landscape and regional scale models are used to predict the effects of climate change on the distribution of vegetation types and the potential for migration or extinction in the face of changing landscape patterns (*e.g.* Brzeziecki *et al.*, 1993). Community models are capable of simulating species changes by considering the differential birth, growth and death of individual trees as a function of species response to temperature, moisture, light, and nutrients (*e.g.* Dale and Franklin, 1989). The physiological models or individual tree models are used to predict the impact of climate change on the physiology of tree growth and development (*e.g.* Webb, 1991). The following sections of this review, however, will focus on the landscape and regional vegetation dynamics models only, because of the study area's extent.

Various approaches have been used to assess the likely response of forest ecosystems to climate change (Loehle and LeBlanc, 1996). The three primary approaches are ecological response functions, biogeographic correlations between climate and tree species or forest type distributions, and forest simulation models.

In ecological response surface models, the abundance of tree species is used to calibrate a multiple regression function of abundance versus climate variables (Webb III, 1992). They have been applied to paleopollen data to reconstruct forest history in response to past climate changes (*e.g.* Prentice, 1986). The biogeographic correlation type of predictive model for examining climate change effects uses correlations between regional climate conditions and the spatial distribution of vegetation types (Woodward, 1992). The approach is based on the premise that climate controls or exerts strong influence on the geographical distribution of vegetation. Thus, taking a classification that fits today's vegetation and applying it to the climate predicted for the future is straightforward. Several such studies (*e.g.* Emanuel *et al.*, 1985; Woodward, 1992) have found that major shifts in ranges of biomes or biotopes are likely. A more mechanistic, process-oriented modelling approach is the forest stand simulation (gap) models. These models simulate the establishment, growth and mortality of individual trees within small plots (approximately 0.1ha). They integrate species-specific information regarding the influence of age, light, nutrient availability, water availability, and temperature on tree growth (*e.g.* Dale and Franklin, 1989). A critical review of the difficulties that arise in each of the three approaches is provided by Loehle and LeBlanc (1996).

Because of the availability of data, this review will focus only on biogeographic correlation type of models. In particular, it will describe the methods employed to model responses of vegetation to climate change at the landscape-regional scale with emphasis given on the use of geographic information systems (GISs). A brief report of the usefulness of GISs in order to study the potential impacts of climate change is provided at the beginning while the limitations of using this type of model-approach are presented at the end of the section.

4.1.8.2 Geographical Information Systems

A geographic information system (GIS) is being increasingly used to bridge the gap between theoretical and applied aspects in ecology. Wadsworth and Treweek (1999) highlighted the effectiveness of GIS in the visualisation and communication of what is known about the distribution of particular species or phenomena, the audit and inventory of how much of a resource is present and how it might be changing, and for analysis, predictions, modelling and decision making. For instance, shifts in geographic distributions of individual species and in the composition of species assemblages can be identified by long-term monitoring studies using GIS (Kappelle *et al.*, 1999).

The ability to integrate vast amounts of data, from the natural and socio-economic sciences, in one common methological approach, makes GIS a vital tool in the assessment of impacts of climate change. According to Din (1992) the limitations of GIS in not possessing adequate modelling capabilities to measure such effects can be easily overcome by combining GIS with other expert modelling techniques.

4.1.8.3 Linking GIS with vegetation-site models

The study of large regions implies manipulation and analysis of great amounts of geo-referenced data. Quick access to geo-referenced data and the possibility of generating numerical maps are important but not, however, the only benefits of using GIS in ecology (Wadsworth and Trewick, 1999). One very interesting application of GIS technology in environmental studies is to link GIS with static or dynamic simulation models of varying character and complexity.

Brzeziecki *et al.* (1993) interfaced a simple probabilistic vegetation-site model, based on empirical data from 7500 phytosociological *relevés* (data points), to a GIS in order to simulate the geographical distribution of 71 forest community types, representing the potential natural vegetation (PNV) of Switzerland. The main prerequisite of such a GIS-assisted modelling effort is the existence of suitable digital data for the study area. For Switzerland this requirement has been largely fulfilled by several digitised maps of similar resolution and accuracy, covering the entire country and representing the most important environmental parameters (climate, topography, soil). From the 12 environmental parameters used the most important was a digital elevation model (DEM), providing information on elevation, aspect and slope. GIS was used to create a complete environmental data set for each DEM-point by overlaying the elevation data with digital climatic maps (temperature and precipitation) and a digital soil suitability map. The generated numerical vegetation map enabled the simulation of the occurrence of various vegetation types as a function of different site factors.

The ability of GIS to handle spatially explicit data of large regions enabled Brzeziecki *et al.* (1994) to follow the former study of Brzeziecki *et al.* (1993) and use GIS technology to predict the potential impacts of a changing climate on the vegetation cover of Switzerland. The same numerical map of potential natural vegetation was used in a simulation experiment, involving a rise in annual mean temperature of 2^0C, to determine the potential impact of climate change on the ecological potential of forest sites. The analysis was simplified by considering in the study only two major groups of communities, differing significantly according to their species composition, environmental conditions, productivity and silvicultural treatment. As they pointed out, the interface of the vegetation-site model to GIS enabled various quantitative characteristics and spatial aspects of the potential vegetation response to be determined.

Kienast *et al.* (1996) developed a spatially explicit forest community model also based on the work of Brzeziecki *et al.* (1993) that generated estimates of the potential natural vegetation for the entire potential forest area of Switzerland under today's as well as under altered climate regimes. As in the study of Brzeziecki *et al.* (1993), the dependent variable in this study was forest community type. However, the model had some differences. First, the number of communities was reduced to 33 zonal types which were primarily dependent on climate and did not occur on sites with very special site conditions in terms of topography or geomorphology. Second, instead of using 12 independent variables, the model included only geographical region to account for continentality, temperature and/or precipitation depending on model version, soil acidity and aspect. The study generated two different model versions in which the quotient between July temperature and annual precipitation (model version A) or mean annual temperature (model version B) were used as bioclimatological variables. In contrast to the simulation experiment of Brzeziecki *et al.* (1994), that involved a simple rise in mean annual temperature, in this model two different regionalized climate scenarios were designed based on GCMs. GIS was used, in addition, to compare expected and observed forest composition on the basis of leading tree species and to assess the adaptation potential of the sites to climate change.

Kienast *et al.* (1998) further integrated GIS with the Kienast *et al.* (1996) model to evaluate the potential climate-induced vegetation changes in mountain forests of Central Europe and possible impacts on species richness. The study included, in addition to the spatially explicit forest community simulator of Kienast *et al.* (1996), a conceptual model of the movement of climatic ranges along altitudinal gradients as a result of global warming.

4.1.8.4 Statistical analysis of environment-vegetation relationship with GIS

The spatial resolution of the global climate data sets is sufficient to represent broad continental features of ecoclimatic transitions but it is entirely inappropriate for use at a regional scale, where questions concerning land management areas are being considered. In order to correct this, Halpin (1994a) developed a regional database, for the entire country of Costa Rica, of climate, topography, soils , potential vegetation, vegetation cover and land use using GIS. The lapse-rates, sea-level temperatures and precipitation regimes were interpolated from climate station data. This base climate model was then modified to create two regional climate change sensitivity scenarios, based on an increase of temperature and precipitation, to predict the changes in the distribution of ecoclimatic zones for the country as a whole.

Li Xia (1995) applied elevation and quaternary geology as indices of topography and parent materials, along with a climatic index of moisture (MI), to classify vegetation and then predict its response, in a North-East China Transect, to six climate change scenarios, involving increases in temperature and precipitation. All the data used in the statistical analysis of environment-vegetation relationships were manipulated by a GIS. The model offered a general picture of vegetation patterns during doubling of CO_2 but as the author pointed out it could be more effective if quaternary geology was combined with more detailed topographical characteristics, such as slope and aspect.

A BIOCLIM-type approach was adopted by Eeley *et al.* (1999) to define the physical correlates of indigenous forest in a province of South Africa and develop a model, based on climatic parameters, to predict the potential distribution of forest subtypes in the province. The bioclimatic profiles of eight different forest subtypes were defined from a series of grid overlays of current forest distribution against nineteen climatic and geographical variables (altitude, geology, soil type), using GIS grid-based processing. A principal components analysis was performed on a selection of individual forests to identify those variables most significant in distinguishing different forest subtypes. The study generated five models to predict the distribution of forest subtypes from their bioclimatic profiles. Maps of the potential distribution of forest subtypes predicted by these models under current climatic conditions were produced. The model accuracy was assessed by overlaying the predicted distribution maps on the actual present-day distribution of forest in the province. To explore the impact of palaecoclimatic change on forest distribution, one model was applied to two palaecoclimatic scenarios, the Last Glacial Maximum (LGM) (≈18 000 BP) and the Holocene altithermal (≈7 000 BP). This provided an insight into the regional-scale/historical forces shaping the pattern and composition of present-day forest communities. The potential future shifts in forest distribution associated with projected climate change are investigated by applying the same model to a doubling of atmospheric CO_2 scenario.

4.1.8.5 Statistical models interfaced with GIS

Developing predictive models for the geographic distribution of vegetation requires extensive data management with GIS and use of statistical packages. With advances in the use of GISs and the increased abundance of data available for landscapes, several techniques can be used to model spatial plant distribution from mapped environmental variables. For continuous data, these include regression models, general linear models (GLMs), general additive models (GAMs), direct and indirect gradient analysis (CA, CCA) and regression tree models (Franklin, 1995).

Proe *et al.* (1996) interfaced a regression model with a GIS to predict and map the GYC (General Yield Class-maximum mean annual volume increment) of Sitka spruce (*Picea citchensis*) across Scotland under a number of climate change scenarios. The model used measured values of GYC recorded at 487 sites across Scotland and related these to estimated values of mean monthly temperature and rainfall derived by interpolation of data recorded by a network of meteorological stations across Scotland. Dominant soil type was also included in the model that provided an estimate of the growth rate of Sitka spruce for each 1km^2 within Scotland under current climatic conditions. The climate change scenarios used were based upon those considered to be the most likely to occur in Scotland according to the United Kingdom Climate Change Review Group. GIS enabled changes in GYC to be predicted for each 1km^2 in Scotland given assumed temperature changes and increased summer precipitation.

GIS and two types of GLMs were used by Guisan *et al.* (1998) to investigate the relationship between the distribution of the alpine sedge *Carex curvula* ssp. *curvula* and selected environmental variables in Switzerland. The modelling approach consisted of four models. The first model was a binomial GLM and included only the mean annual temperature as explanatory variable, which was adjusted to species presence/abundance data in the entire study area. The second was a logistic model restricted to stands occurring within the *a priori* defined temperature range for the species. This model was developed by regressing field observations, sampled over a wide range of conditions, on environmental predictors. The environmental data, including slope angle, slope aspect and curvature (generated from the DEM), annual mean temperature, geology, solar radiation, potential permafrost, and snow cover index (obtained by combining two aerial photographs) were gathered for the whole study area and stored in a grid format, in the GIS. The two models were combined in the GIS to generate a map of the species potential abundance in the study area (third model). Finally, the model predictions were filtered by the classes of the qualitative variables under which the species never occur (fourth model). An evaluation of the model with the *y*-measure of association in an ordinal contingency table showed satisfactory results.

Gottfried *et al.* (1998) developed a predictive model to examine the distribution pattern of individual plant species and plant communities at the transition between the alpine-nival ecotone where the environment is likely to be drastically affected by climate change. To explore the vegetation structure and to detect possible changes, their study applied spatial modelling to predict vegetation patterns over a high alpine mountain of Austria, combined with dynamic modelling techniques. Direct and indirect analyses were combined with GIS-techniques, based on a fine-grained DEM. Vegetation data from 1 000 field samples distributed over the alpine-nival ecotone of the mountain and topographic descriptors, derived from the DEM as habitat characteristics of the samples, were used as data input in the model. Correlations between the vegetation samples and habitat characteristics enabled single plant species and community distribution to be predicted for the whole model area. The study showed a general trend of decline of biodiversity with altitude, but with a maximum of species richness at the ecotone itself. Since the relief modifies the high mountain climate remarkably, the differentiated relief dependency of vegetation supported the view that this type of environment will be affected significantly by climate change.

Iverson and Prasad (1998) developed models to evaluate potential shifts for 80 individual tree species in the eastern United States. GIS in conjunction with regression tree analysis (RTA) were used to assess environmental factors associated with the current ranges of tree species. In the study climate, soils, land use, elevation, and species assemblages were analysed for >2 100 counties and data for >100 000 forested plots provided information on tree species range and abundance. RTA was used to devise prediction rules from current species-environment relationships, which were then used to replicate the current distribution as well as predict the future potential distributions under two scenarios of climate change with twofold increases in the level of atmospheric CO_2 . Validation measures proved the utility of the GIS-RTA modelling approach for mapping current tree importance values across large areas and led to increased confidence in the predictions of potential future species distributions.

Iverson *et al.* (1999) followed the former study of Iverson and Prasad (1998) to predict the future transient distribution of Virginia pine (*Picea virginiana*) in the eastern United States under a 2x CO_2 climate change scenario using a deterministic regression tree analysis model and a stochastic migration model. As in the work of Iverson and Prasad (1998), the current distribution of species abundance was estimated by GIS using range maps and data from the regional Forest Service plots. In addition, the deterministic model was used to predict potential suitable habitat and future species abundance by relating current climate and other environmental variables to its present distribution and abundance and then project these values onto future climate scenarios. For the development of this model more than 100 predictor variables were gathered at the beginning and then reduced with RTA analysis to 33 variables, including climate, soil, elevation, land use and landscape pattern. In contrast to the Iverson and Prasad (1998) study, this work included an additional stochastic model to examine likely scenarios of species migration over the next century through fragmented landscapes. Simple intersection of the results from both models yielded maps where constraints on future distribution were provided by each model. RTA outputs represented the potential environmental envelope shifts required by species, while the migration model predicted the more realistic shifts based on colonisation probabilities from species abundance within the fragmented landscape. The workers noted that these tools provided mechanisms for evaluating the relationships among various environmental and landscape factors associated with tree-species importance and potential migration in a changing climate.

4.1.8.6 GIS in conjunction with principle components analysis (PCA)

GIS and remote sensing have been used to relate vegetation structure and composition to environmental variables as well as population parameters. Baker and Weisberg (1997) used GIS to map population parameters indicating potential change throughout the forest-tundra ecotone of the Rocky Mountain National Park. Seedling density and annual krummholz height growth were measured in a total of 125 sampling locations in the field over 36 elevational transects across patch forest and krummholz zones. DEM-derived and photogrammetric data were used to create GIS maps for 11 environmental variables for the Park. Due to high multicollinearity among the variables, principal components analysis (PCA) was used to derive uncorrected principal components (PCs) from the set of original environmental variables. The PCs were then used as independent variables to develop predictive equations for seedling density and krummholz height growth. The GIS was used to extrapolate the resulting predictive equations to the entire Park, generating maps of expected seedling density and krummholz height growth. Potential responses in the ecotone to climate change were evaluated in the context of species-specific differences in how tree seedling density and krummholz height growth were associated with the present environment. As the authors pointed out, present population parameters extrapolated spatially may provide a useful guide to where future change is likely.

4.1.8.7 Limitations of biogeographic correlation approach

The biogeographic correlation type of predictive model for examining climate change effects uses correlations between regional climate conditions and the spatial distribution of vegetation types (Woodward, 1992). Several models mentioned before have found that major shifts in ranges of specific types of vegetation are likely. The projected rates of geographic shift are greater than the likely migration rates of constituent species, suggesting a potential for significant dieback in these communities.

The biogeographic correlation method suffers, however, from a fundamental difficulty (Loehle and LeBlanc, 1996). The method uses correlations based on the realized niche when the fundamental niche is needed. Plant species are often capable of growing far outside the range of conditions where they are abundant. This is the difference between the fundamental and the realized niche: the fundamental niche is where the plant can grow in the absence of competition, whereas the realized niche is where the plant is found in communities when competition is active (Figure 4.10). The fundamental niche is what governs the actual growth of plants, whereas the realized niche is a part of it obtained by correlating species or communities with abiotic factors. All the models assume that both niches are equal. This has resulted in an overly rapid local elimination of species or communities whose fundamental limits to growth are (falsely) exceeded by the rapidly changing climate (Pacala and Hurtt, 1993). Hence, there is reason to suspect, according to Loehle and LeBlanc (1996), that the models may exaggerate the direct impact of climate on tree growth and mortality.

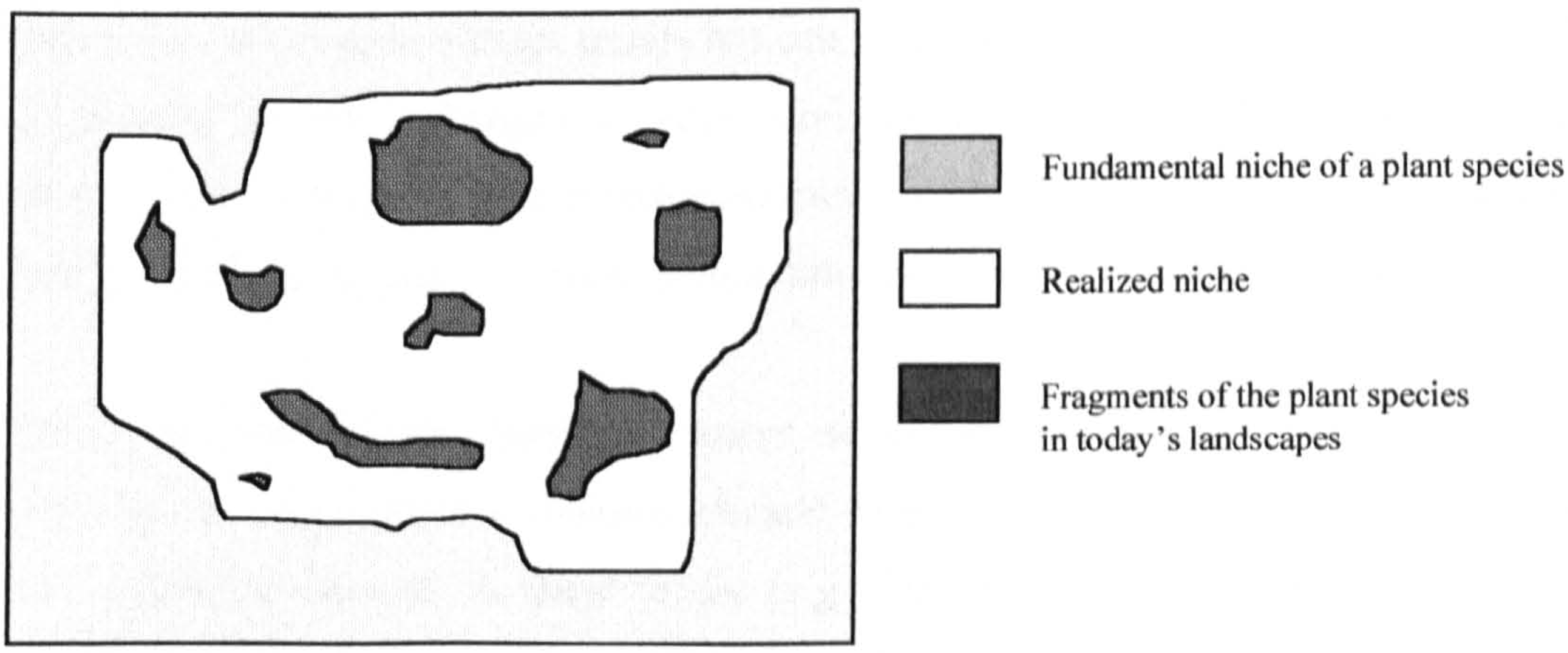


Figure 4.10. If we imagine the fundamental niche of a plant species as a square then its realized niche is smaller because of the presence of competition in communities where the plant is found. Human destruction and fragmentation of habitats results, in addition, in small fragments of the species within its realized niche.

There are other problems with this type of approach. First, simulated patterns of shifts of biotopes or vegetation communities as complete entities are not very realistic, because they do not take into account the individual responses of species to changes in climate factors (*e.g.* section 4.1.8.3) (Peters and Lovejoy, 1992). In the models (*e.g.* Brzeziecki *et al.,* 1993), biotope range changes are analogous to species range changes, which means that when a biotope is replaced by another, all the species in the biotope change. In reality, many species overlap between adjacent biotopes. In a zone experiencing warming, for example, many of the species that will dominate in the new biotope may already be present in specialised habitats within the current biome (*e.g.* if the transition is from woodland to prairie, many prairie species are already present in the woodland understory). Thus, a change in biotope does not represent a complete replacement of all species, as it might appear to do at first glance (Loehle and LeBlanc, 1996).

Second, the outcomes of models are often presented as potential vegetation maps based on future equilibrium climates (*e.g.* section 4.1.8.3), without an indication of the time required for landscapes to possibly reach new equilibrium patterns following climate-induced changes (Halpin, 1997). Paleoecological evidence suggests that continental changes in vegetation pattern are often the result of hundreds to thousands of years of complex ecological change, and that novel associations of independent species populations are to be expected (Davis and Zabinsky, 1992). In addition, simulation mapping of expected changes in potential vegetation regions can yield insights on ecosystem-change trends but can be easily misinterpreted as deterministic predictions of exact changes in vegetation pattern (Halpin, 1997). The approach shows what community type is expected under a given climate but does not indicate what is likely to happen to existing community types under a shifting climate.

Third, the non-overlap between current vegetation community types and those predicted to occur under a changed climate seems to imply that the old ecosystems will suffer catastrophe in these zones (*e.g.* Brzeziecki *et al.*, 1994) (Loehle and LeBlanc, 1996). The data on fundamental niche widths and on species tolerance of climatic fluctuations, however, suggest that catastrophic consequences do not necessarily follow. For example, a grassland system under a wetter climate will not suffer extinction but may be replaced by trees following a long lag period.

Fourth, if biotopes are defined by annual average climate (*e.g.* Kienast *et al.*, 1996), but warming is likely to be greater in winter (as projected by GCM calculations), then predictions from biogeographic analyses will overestimate the effect on the distribution of life zones (Rowntree, 1985) particularly in northern regions. Changes in seasonal temperature distributions may also invalidate existing life zone classifications.

A final point, as Loehle and LeBlanc (1996) pointed out, is that projections of correlational approaches to predicting vegetation response to climate change are, at best, first approximations of vegetation response to climate change. The dangers of extrapolating statistical association beyond the range of data used to derive them are well known. These dangers are of even more concern when there is limited knowledge of the biological and ecological mechanisms that are believed to cause the statistical association. Furthermore, direct extrapolation of observed species distributions in relation to present climate, as a means for projecting future responses, is inappropriate; such projections must include consideration of physiological tolerances, competition, and dispersal mechanisms (Halpin, 1997).

4.2 Generation of temperature and precipitation estimates

4.2.1 Data and general methodology

Temperature and precipitation data for 14 stations in North Wales were compiled from the published monthly weather records of the Meteorological Office (Meteorological Office, 1993) for the period 1961-1990. In addition, long term rainfall data were provided by the Environment Agency, Wales. This gave a total of 14 recording stations with temperature data and 58 with precipitation data. The temperature records of these stations were either complete for the 1961-90 period and had been averaged from direct readings over the full 30-year period or were weighted against the 1951-1980 period average data and adjacent stations with complete records in instances where breaks occurred in the 30-year record (Botwnnog station).

Mean daily temperature at all stations was the mean of the daily maximum and minimum thermometer readings taken from once-daily inspection. The temperature reading used in calculations was the daily mean averaged over the 30-year period. Mean monthly precipitation was the total monthly rainfall reading taken at each station, averaged over the recording period.

The general procedure performed to predict the spatial distribution of temperature and precipitation in Snowdonia for the 1961-90 period was the following:

a) geographical and topographic variables for each data point (station) were quantified. The distribution of the stations is shown in Figure 4.11 and full station details are given in Appendix 2;
b) multiple linear regression models were built using the data from the stations;
c) the validity of each model was determined by exploring the residuals;
d) the models were used to predict the spatial distribution of temperature and precipitation in north Wales and climatic maps were generated for the Snowdonia National Park.

This procedure was performed for the whole year (annual means) and for two seasons, winter season (December to February) and summer season (June to August).

4.2.2 Temperature

The temperature regime is one of the most distinctive features of the climate of the British Isles. It is generally recognised that these islands, situated as they are between approximately 50^0N and 60^0N latitude, are very favoured with regard to their range of temperature, experiencing winters which are exceptionally mild for such a northerly position and summers which are never unbearably warm (Tout, 1976).

In the British Isles the temperature lapse-rates with altitude are among the sharpest in the world (Manley, 1970, cited in Taylor, 1976). Consequently, the British upland climates may be clearly, if variably, differentiated from their lowland counterparts at least on the regular patterns of temperature and the immediate effect they have on the growing season (Taylor, 1976).

a)

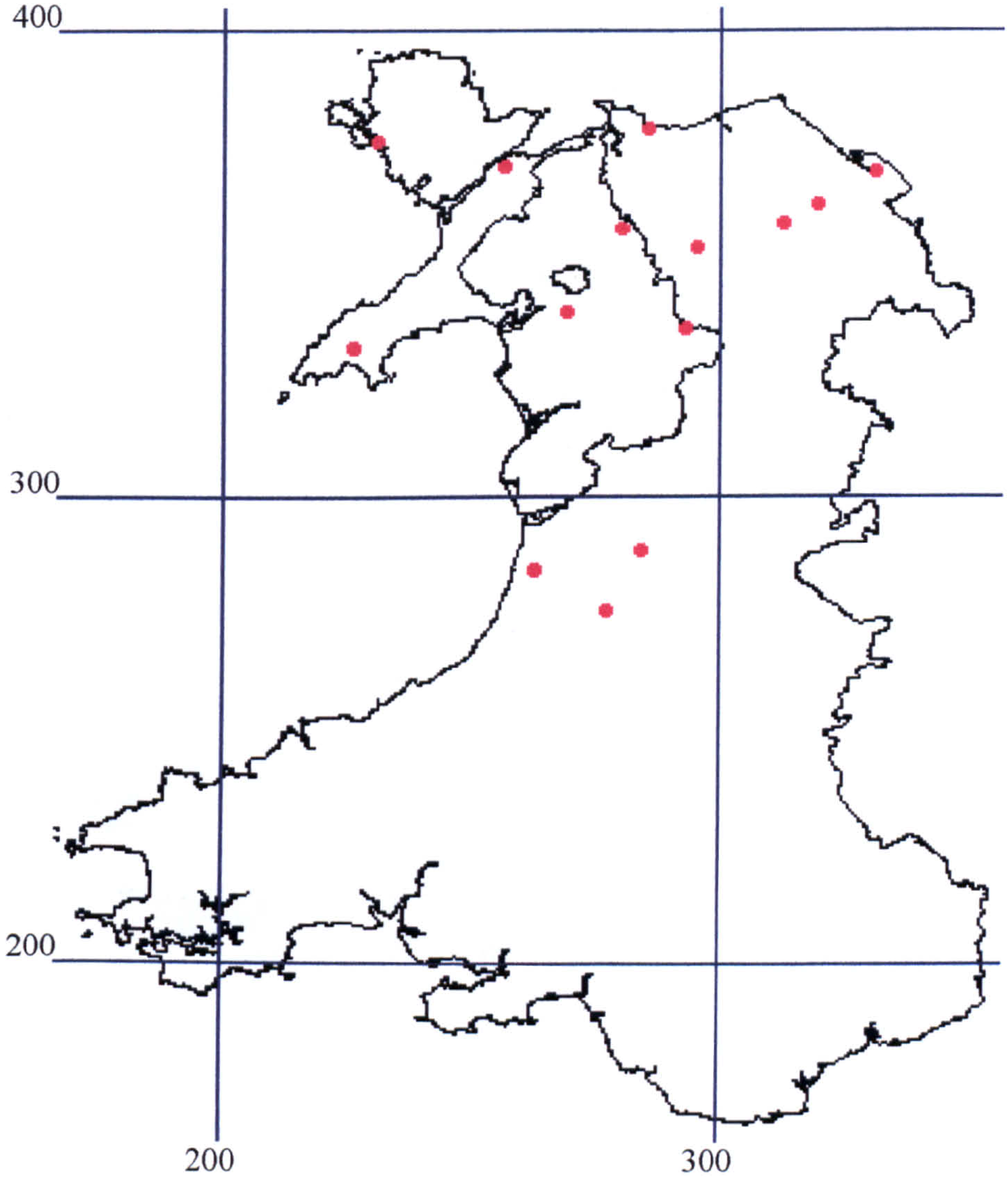


Figure 4.11. Distribution of the a) temperature recording stations. Gridlines orientated to the National Grid at 100 km spacing; top of page points north.

b)

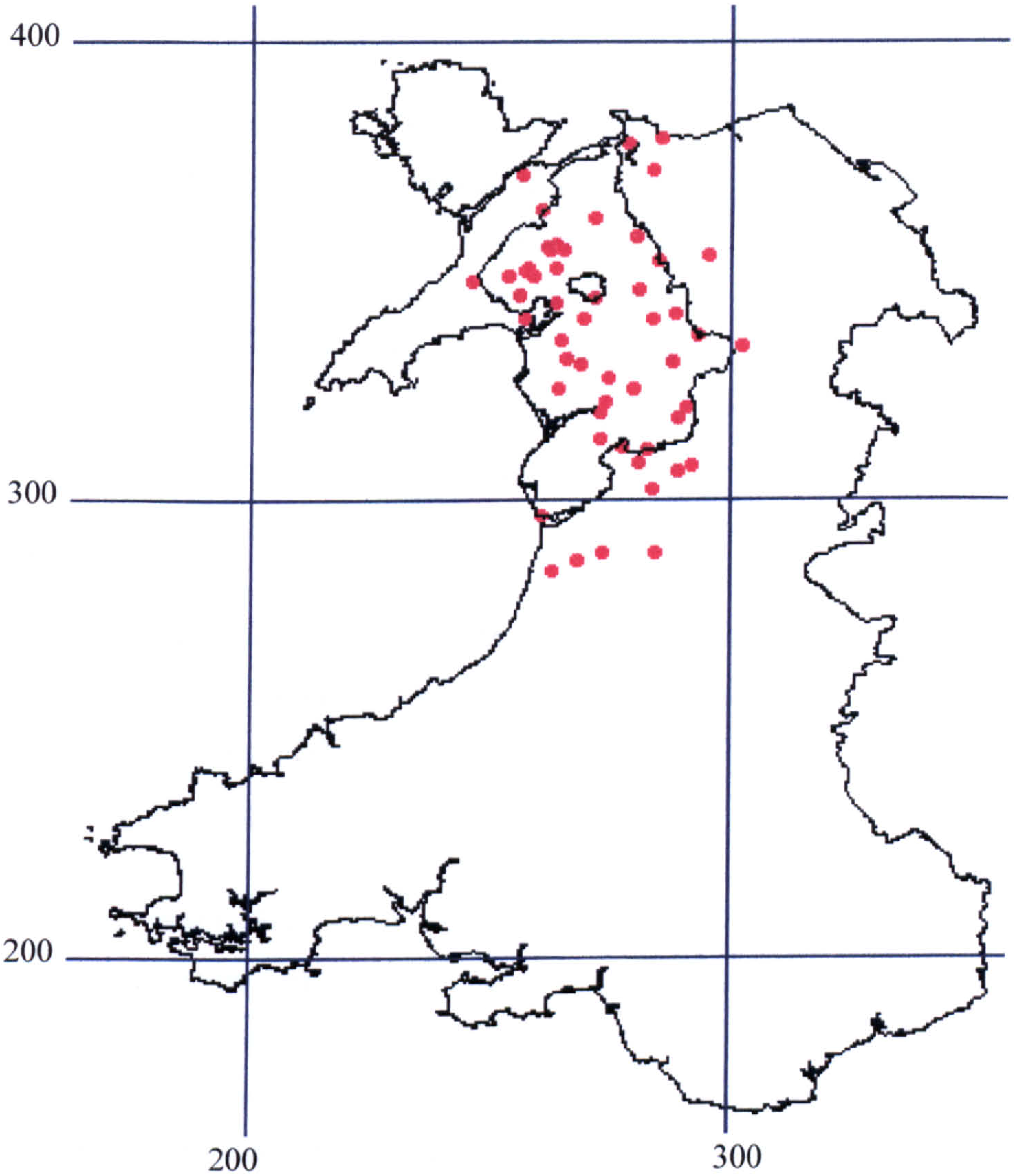


Figure 4.11. Continued. Distribution of the b) rainfall recording stations. Gridlines orientated to the National Grid at 100 km spacing; top of page points north.

The relatively high sea temperatures off the west and south-coasts as compared with the eastern coasts (particularly in winter and spring) and the high frequency of polar-maritime air masses (with inherently large temperature lapse rates) are factors which promote a rapid fall of temperature with altitude on the relatively steep, exposed, maritime westerly slopes. Temperatures fall as the air rises over the uplands and temperature lapse rates are generally substantial (Taylor, 1976).

Harrison (1973, cited in Taylor, 1976) examined mean temperature data (1931-60) for seventy stations for a west-east transect of varied relief across England and Wales between 50^0 and 55^0 north. He concluded that altitude was the vastly more significant factor in temperature variation than either distance from the west coast or latitude, both of which played very minor roles. This contrast was also shown in a study of temperature data for the slope transect between the coast of Cardigan Bay and the Plynlimon plateaux where altitude was responsible for more than 98% of the temperature gradient (Taylor, 1976).

Temperature lapse rates vary with latitude, longitude, altitude, aspect, slope, proximity of the sea (eastern or western), type of air mass, type of day or night, season and year (Taylor, 1976). They are therefore subject to extreme variability over short distances and brief time periods.

The Meteorological Office has adopted a standard lapse rate of 6.0^0C/1000m rise in elevation for mean temperatures. Regional or local lapse rates are subject to variation. Manley (1943, cited in Francis, 1978) estimated a rate of 6.9^0C/1000m for the northern Pennines while Smith (1950, cited in Francis, 1978) derived a rate of 6.7^0C/1000m for the Aberystwyth hinterland and Oliver (1960, 1964, cited in Taylor, 1976) a rate of 7.3^0C/1000m for part of south Wales. Furthermore, data from the Ben Nevis observatory yielded a rate of 6.4^0C/1000m (Taylor, 1976).

The evidence for seasonal fluctuations in temperature lapse rates is varied and conflicting. Measurements *in situ* by Smith (1950, cited in Francis, 1978) showed an annual variation in monthly mean lapse rates on the western slopes of the Welsh mountains. Values ranged from 4.8^0C/1000m in March to 7.2^0C/1000m in October. Manley (1943, cited in Francis, 1978), Pearsall (1950) and Oliver (1960, 1964, cited in Taylor, 1976) diagnosed that the greatest lapse rates occurred in spring; Harrison (1973, cited in Taylor, 1976) discovered, however, for the Aberystwyth-Plynlimon slope transect, that lapse rates were least in spring and at a maximum in autumn and winter. These apparent contradictions suggest great variability over time and space in temperature lapse rates.

Despite the sharp control that changes in relief exert upon gradients of climate, the altitudinal component has never been comprehensively studied and is less well understood. Descriptions of the British upland climate must be probablistic at best since the meteorological data available are so localised and fragmentary. Taylor (1976) demonstrated that the location and distribution of operational meteorological stations in 1974 showed concentrations at low elevations, and near the coasts to the particular neglect of the uplands. Furthermore, in Tout's (1976) study the lack of adequate coverage of temperature conditions at even moderate altitudes was shown by the fact that 77%, of the 217 meteorological and climatological stations used to prepare temperature maps for the 30-year period from 1941 to 1970, were at less than 100m, 94% were at less than 200m and only one station was at an altitude of more than 350m. As Taylor (1976) pointed out this is continuing testimony to the extreme paucity of primary information on the upland climates which necessitates the substitution of crude and unavoidable upslope extrapolation from lowland stations.

The prediction of mean monthly temperature from place to place, given that, inevitably, there is a limit to the number of climate recording stations is of increasing importance in ecology. However, there has been doubt over the best method for producing a complete climatic surface from a limited set of stations. White and Smith (1982) used a regression model to predict assorted climatic variables including temperature from a set of topographic and location variables. The attempt was severely criticised by Gregory (1983) not for its objectives and underlying approach but for the presentation and the actual content of the study. A recent gridding of the accumulated seasonal temperatures for England and Wales used a three-variable regression equation (Meteorological Office, 1989, cited in Lennon and Turner, 1995). A more generally accepted method is to use an interpolation to fit a surface between the recorded points; traditionally this has consisted of drawing isopleths on the map by hand (Meteorological Office, 1952) and recently of using thin plate splines

(Wahba and Wendelberger, 1980, cited in Lennon and Turner, 1995). More recently, four categories of model, simple interpolation, thin plate splines, multiple linear regression and mixed spline-regression, were tested by Lennon and Turner (1995) for their ability to predict the spatial distribution of temperature on the British mainland. The models were all tested by external cross-verification. The mean daily temperature was predicted with the greatest accuracy by using a mixed model: a thin plate spline fitted to the surface of the country, after correction of the data by a selection from 16 independent topographical variables (such as altitude, distance from the sea, slope and topographic roughness), chosen by multiple regression from a digital terrain model (DTM) of the country. The next most accurate method was a pure multiple regression model using the DTM. In the absence of a thin plate spline a multiple regression with a DTM was used, in this study, for plotting mean annual and seasonal temperature surfaces for Snowdonia.

To construct the regression model, a total of 6 independent geographical and topographic variables, listed with abbreviations in Table 4.4, were chosen for inclusion in the present study. Quantification of these variables was achieved using the IDRISI for windows v2.0 GIS system (Eastman, 1997). The DTM used for Snowdonia was obtained from the National Park Authority with a 50m pixel resolution. The GIS converted the DTM into slope and aspect maps for the Park (SURFACE routine in IDRISI). For the four stations included in the DTM the slope and aspect were estimated using the slope and aspect maps derived from the DTM. For the other ten stations, these variables were calculated using 1:25,000 First Series, Ordnance Survey (OS) maps. The distance from the sea was calculated from a coastline of Wales (DISTANCE process in IDRISI). Having the grid references of the meteorological stations, the stations were digitised as points and overlayed on the distance map to compute the distance from the sea of each station in kilometres. In the derivation and verification of the regression model, the actual grid east and grid north positions (to six figures) of the climate recording stations were used as variables. For the construction of the climate maps the variables were converted into distance maps from arbitrary lines to the west and south of the National Park. The correlation of each variable with the mean annual, mean winter and mean summer temperature of the stations is shown in Table 4.5.

Table 4.4. Geographical and topographic variables chosen for inclusion in the multiple linear regression analyses.

GRIE	Longitude, as 6-figure Ordnance Survey grid reference (eastings)
GRIN	Latitude, as 6-figure Ordnance Survey grid reference (northings)
ALT	Altitude of meteorological station (metres)
ASP	Aspect of meteorological station (degrees)
SLOP	Slope of meteorological station (degrees)
DIST	Shortest distance to the sea (km)

Table 4.5. Pearson correlation of temperature model variables.

	Mean annual temperature (^{0}C)		Mean winter temperature (^{0}C)		Mean summer temperature (^{0}C)	
Variable	r		r		r	
Grid easting (GRIE)	-0.341	NS	-0.507	NS	-0.104	NS
Grid northing (GRIN)	0.461	NS	0.387	NS	0.507	NS
Altitude (ALT)	-0.962	*	-0.922	*	-0.961	*
Aspect (ASP)	-0.049	NS	-0.079	NS	-0.002	NS
Slope (SLOP)	-0.335	NS	-0.276	NS	-0.356	NS
Distance to the sea (DIST)	-0.808	*	-0.786	*	-0.741	*

* = significant at P<0.05; NS = not significant at P<0.05.

All the variables in Table 4.5. were entered into a stepwise regression analysis in MINITAB for windows rel.12.1 software (MINITAB, 1997). The multiple regression model, having the form $Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_n X_n$, with β_o being the intercept, and $\beta_1, \beta_2, \ldots, \beta_n$ the coefficients of $X_1, X_2, \ldots, X_n$ model variables respectively, was then evaluated. The regression models fitted were:

i) for mean annual temperature,

$$TEMP = 11.0476 - 0.006391*ALT - 0.028035*DIST - 0.000003*GRIE - 0.001234*ASP \quad (1)$$

$R^2 = 0.988$ (S = 0.1396), F = 180.93

ii) for mean winter temperature,

$$WINTEMP = 8.6766 - 0.006632*ALT - 0.021967*DIST - 0.000011*GRIE - 0.002054*ASP \quad (2)$$

$R^2 = 0.987$ (S = 0.1572), F = 169.17

iii) for mean summer temperature,

$$SUMTEMP = 13.8079 - 0.006505*ALT - 0.022733*DIST + 0.000005*GRIE - 0.039*SLOP \quad (3)$$

$R^2 = 0.976$ (S = 0.1851), F = 91.93

where TEMP, WINTEMP, SUMTEMP are mean annual, mean winter and mean summer temperature respectively in ^{0}C, ALT is altitude above sea level in m, DIST is distance from the site concerned to the nearest point on the coastline in km, GRIE is 6-figure Ordnance Survey grid reference (eastings), and ASP/SLOP are the aspect and slope of the site concerned in degrees (^{0}). With [F, p=0.95, df=4, 8]=3.84 it can be concluded that all three models fitted to the data are significant.

The validity of each model was determined by exploring the residuals. The models fit the data very well with no station being misclassified and the residuals ranging from 0 to less than 0.3 of a degree (Figure 4.12). It seems that there are no consistent overall geographical trends in the distribution of the residuals. The computation of annual and seasonal temperature maps was straightforward. Maps based on the three regression models were produced by multiplying the altitude, distance from the sea, eastings and aspect/slope maps with the β_1, β_2, β_3 and β_4 model coefficients respectively (SCALAR routine in IDRISI), overlaying all the maps (OVERLAY process in IDRISI) and adding (SCALAR module in IDRISI) the β_0 intercept. The mean annual temperature map predicted for the 1961-1990 period is shown in Figure 4.13 whereas the mean winter and summer temperature maps for the same 30-year period in Appendix 2. The maps compare very well with those for the observed 1961-90 baseline climatology (10km grid) produced by UK Climate Impacts Programme, with greater detail for temperature around the mountainous areas of Snowdonia.

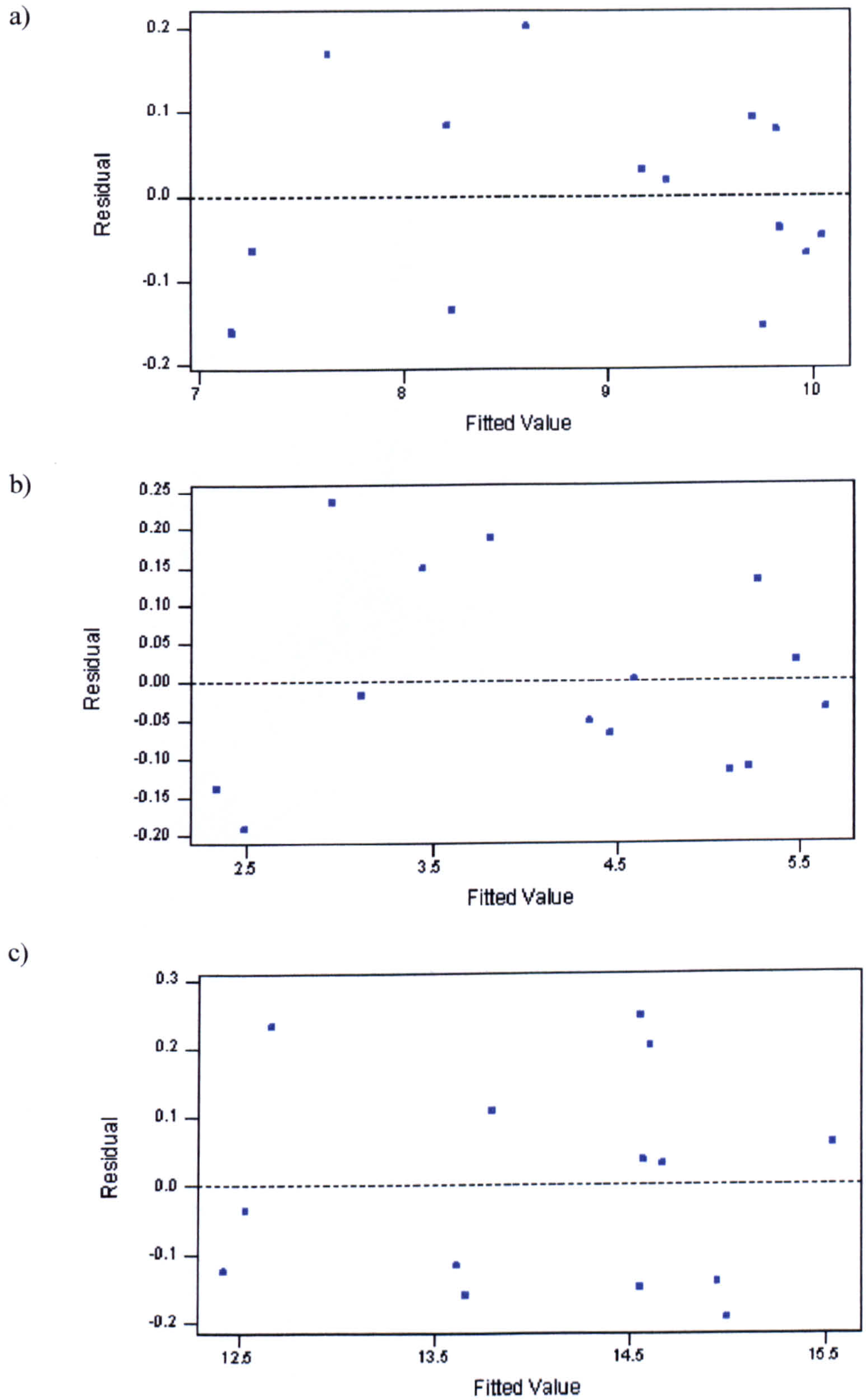


Figure 4.12. Plot of the residual differences between the model value and the actual station value, plotted against the fitted model values for a) mean annual, b) mean winter and c) mean summer temperature.

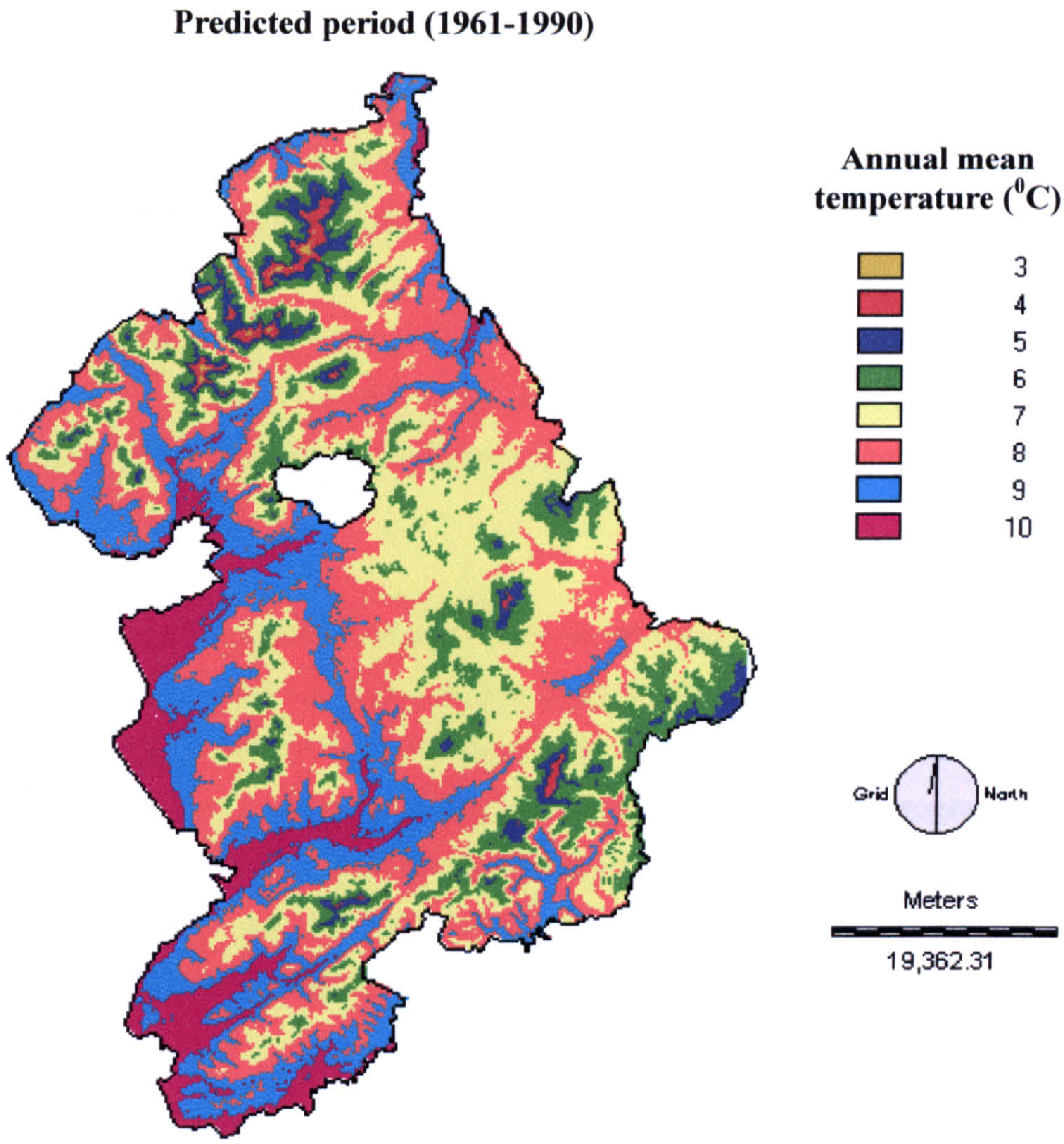


Figure 4.13. Annual mean temperature (^{0}C) predicted for the period (1961-1990).

The temperature models for north Wales identified altitude, distance from the sea, longtitude and aspect/slope as the work of Lennon and Turner (1995) for the whole of Britain. Altitude was more significant in predicting temperature variation than any other factor which, was also shown by Harrison (1973, cited in Taylor, 1976) and Taylor (1976). The temperature lapse rates are comparable with those of Smith (1950, cited in Francis, 1978) and Oliver (1960, 1964, cited in Taylor, 1976) despite differences in climatic data used and in areas studied. The evidence for seasonal fluctuations in lapse rates, in this work, is in agreement with the fact that there is great variability over time and space in temperature lapse rates. However, as not all the seasons of the year were examined, it was not possible to diagnose the season with the greatest lapse rate and compare that with other studies.

4.2.3 Precipitation

It is widely recognised that the uplift required to produce precipitation may occur as a result of one or more of three basic mechanisms: first, low level convergence, usually at fronts in cyclones, providing wide-spread uplift with magnitudes of the order of 5-10 cm s^{-1}; secondly, buoyancy, resulting from local atmospheric static instability giving upward motion of up to 30 m s^{-1} but extending over fairly restricted areas; and thirdly, forced uplift by orography, an effect which may trigger or intensify the other two mechanisms. All three mechanisms frequently operate simultaneously (Atkinson and Smithson, 1976).

The increase of precipitation with altitude, for all heights in the British Isles, has long been recognised and is an effect that dominates the distributions portrayed on monthly and annual maps and not infrequently on daily maps (Atkinson and Smithson, 1976). Since Salter's (1921, cited in Taylor, 1976) pioneering study of orographic rainfall gradients (increases of 169.3-254 mm/100m) in west Wales, a number of specific local studies have indicated, with one exception (Harrison, 1973, cited in Taylor, 1976), that British average rainfall gradients are approximately linear with altitude (Table 4.6.).

Table 4.6. Rainfall gradients with altitude, in millimetres of rainfall per 100m rise of altitude (source: Taylor, 1976).

Source		Area	General gradient	West slope gradient	East slope gradient
Pearsall	(1950)	Central Pennines	-	188	98
Gloyne	(1958)	Scottish Highlands	-	253	83
Rodda	(1962)	Ystwyth Catchment N. Ceredigion	-	167	-
Unwin	(1969)	Snowdonia	458	-	-
Harrison	(1973)	Slope-Plynlimon to Cardigan Bay	-	228	-

Rodda (1962) studied the amounts of areal rainfall within the River Ystwyth Catchment in Wales and established the following relationship between the rainfall totals recorded at 19 sites in 1958 and two topographic parameters, altitude and exposure, using regression analysis:

$$P = 1190.75 + 1.67h - 3.29e$$

r = +0.97, s.e. of estimate = ± 61.98 mm, where P is amount of annual rainfall in millimetres, h is height above sea level in metres and e is exposure in radians. The author noted that all the topographic factors governing the distribution of rainfall had not been accounted for and suggested that further parameters could be introduced such as slope or distance from the sea.

Using data from over 6500 stations, Bleasdale and Chan (1972, cited in Atkinson and Smithson, 1976) established the following relationship between average annual precipitation and altitude in Britain:

$$P = 714 + 2.42h$$

where P and h are as above. Mapping the 6500 plus anomalies from this regression line revealed positive anomalies exceeding 600mm in north and south Wales.

Preliminary analysis of rainfall data to the east of Plynlimon by Taylor (1976) for the 1970-74 period provided the following relationship:

$$P = 1530 + 1.71h$$

r = + 0.80, where P and h are as in previous examples, and suggested a linear relationship between rainfall and altitude. In contrast, Harrison (1973, cited in Taylor, 1976) indicated that rainfall gradients, at least for one maritime slope analysed over a 2-year period, may be curvilinear with rainfall increasing exponentially with altitude.

In the Pennines it was found that mean precipitation was mainly a function of mean relief and that factors such as aspect were relatively unimportant (Lockwood, 1979). For the period 1916-50, the mean rainfall in the eastern Pennines (P in mm) is related to the mean elevation (h in m) within a 8 km radius by the following relationship:

$$P = 564.27 + 2.023h.$$

The equation for the western Pennines is:

$$P = 916.29 + 1.890h.$$

Seasonal values for the eastern Pennines are given by:

November to February	$P = 187.31 + 0.957h$
March to April	$P = 73.98 + 0.265h$
May to August	$P = 206.80 + 0.467h$
September to October	$P = 93.82 + 0.425h.$

There are two main reasons why precipitation values are greater over upland than lowland areas. First, the hills act as a barrier to moist airstreams which are therefore forced to rise; and secondly, the hills act as high-level heat sources on sunny days so that convective clouds tend to form preferentially over them giving showery precipitation (Atkinson and Smithson, 1976). Maximum monthly totals, as a result, occur in the mountainous areas of the west. Rain gauges are relatively sparse in these locations, especially at higher altitudes where totals would be expected to be greater. Consequently the highest totals recorded are partly a function of gauge siting and frequency rather than the maximum which has fallen at some spot in the British Isles.

While it is true that rainfall gradients on west-facing slopes are generally greater than on east-facing slopes in Britain (Salter, 1921, cited in Taylor, 1976), it should be remembered that west slopes are generally steeper and shorter themselves than the gentler and longer easterly ones. This helps to explain the substantially higher rainfalls normally found on west slopes than at comparable altitudes on east slopes, as many isohyetal maps demonstrate (Taylor, 1976).

There are a number of established techniques for the derivation of areal rainfall totals (Jones, 1983, cited in Wong (1992); Shaw, 1988). Jones (1983, cited in Wong, 1992) reviewed many of the more commonly used methods and found that they all have problems when applied to areas with only a few, irregularly spaced gauges. Wong (1992) investigated and judged against their performance a variety of methods for derivation of areal rainfall for the Glaslyn catchment in north Wales. Methods such as the Theissen polygon method and trend surface analysis were examined but found to be not better than the multiple regression analysis finally used to generate an areal rainfall estimate.

Simple and multiple regression analysis of rainfall against independent variables such as altitude, exposure, slope and aspect have been used in rainfall analysis for some time at the Ystwyth (Rodda, 1962) and Glaslyn (Wong, 1992) catchments in Wales, Plynlimon (Taylor, 1976) and the Pennines (Lockwood, 1979). A number of variables have been used or suggested in multiple regression analysis. Unwin (1969) found that altitude and latitude explained 79% of rainfall variability over Snowdonia and suggested that aspect and distance from the watershed may improve the multiple regression model. Kirby *et al.* (1991, cited in Wong, 1992) reported altitude and slope gave the best model for Plynlimon. Similar work at Balquhidder (Johnson *et al.*, 1990, cited in Wong, 1992) found longitude and altitude to be best with little further improvement gained by adding either slope or aspect. The factors chosen for inclusion in the present study were the same as in the temperature surface estimates (Table 4.4.). However, preliminary analysis of the rainfall data showed that an additional variable had to be added in order to get a better predictive rainfall model. This was the distance from Snowdon (SNOWDIST) in km, the highest peak (H=1085m) in Snowdonia. The correlation of each of these variables with the annual, winter and summer total average of rainfall of the stations is shown in Table 4.7.

All the variables in Table 4.7. were entered into a stepwise regression analysis in MINITAB for windows rel.12.1 software (MINITAB, 1997). The regression models fitted were:

i) for mean annual rainfall,

$$RAIN = 10414 + 1.6288*ALT + 16.751*DIST - 0.023731*GRIN + 25.641*SLOP - 41.992*SNOWDIST \quad (4)$$

$R^2 = 0.782$ ($S = 434$), $F = 37.37$

ii) for mean winter rainfall,

$$WINRAIN = 3071.5 + 0.3714*ALT + 7.581*DIST - 0.007039*GRIN + 8.474*SLOP - 12.037*SNOWDIST \quad (5)$$

$R^2 = 0.752$ ($S = 135.1$), $F = 31.46$

iii) for mean summer rainfall,

$$SUMRAIN = 2293.4 + 0.4695*ALT - 0.005257*GRIN + 6.46*SLOP - 9.714*SNOWDIST \quad (6)$$

$R^2 = 0.763$ (S = 111.7), F = 42.75

where RAIN, WINRAIN, SUMRAIN are mean annual, mean winter and mean summer precipitation respectively in mm, ALT is altitude above sea level in m, DIST is distance from the site concerned to the nearest point on the coastline in km, GRIN is 6-figure Ordnance Survey grid reference (northings), SLOP is the slope of the site concerned in degrees (^{0}) and SNOWDIST is distance from the Snowdon peak. With [F, p=0.95, df=5, 40]=2.45 it can be concluded that all three models fitted to the data are significant.

Table 4.7. Pearson correlation of rainfall model variables.

Variable	Mean annual rainfall (mm) r		Mean winter rainfall (mm) r		Mean summer rainfall (mm) r	
Grid easting (GRIE)	-0.383	*	-0.300	*	-0.452	*
Grid northing (GRIN)	0.263	*	0.225	NS	0.293	*
Altitude (ALT)	0.660	*	0.627	*	0.657	*
Aspect (ASP)	0.360	*	0.371	*	0.344	*
Slope (SLOP)	0.592	*	0.599	*	0.588	*
Distance to the sea (DIST)	0.196	NS	0.263	*	0.118	NS
Distance from Snowdon (SNOWDIST)	-0.593	*	-0.547	*	-0.614	*

* = significant at P<0.05; NS = not significant at P<0.05.

The mean annual, winter and summer precipitation maps were created in the same way as the temperature maps. Figure 4.14 shows the annual mean total precipitation predicted for the period 1961-1990 whereas the seasonal rainfall maps are provided in Appendix 2. The three models fit the data reasonably well with the majority of residuals being 10-30% of actual rainfall (Figure 4.15). It seems that there are no

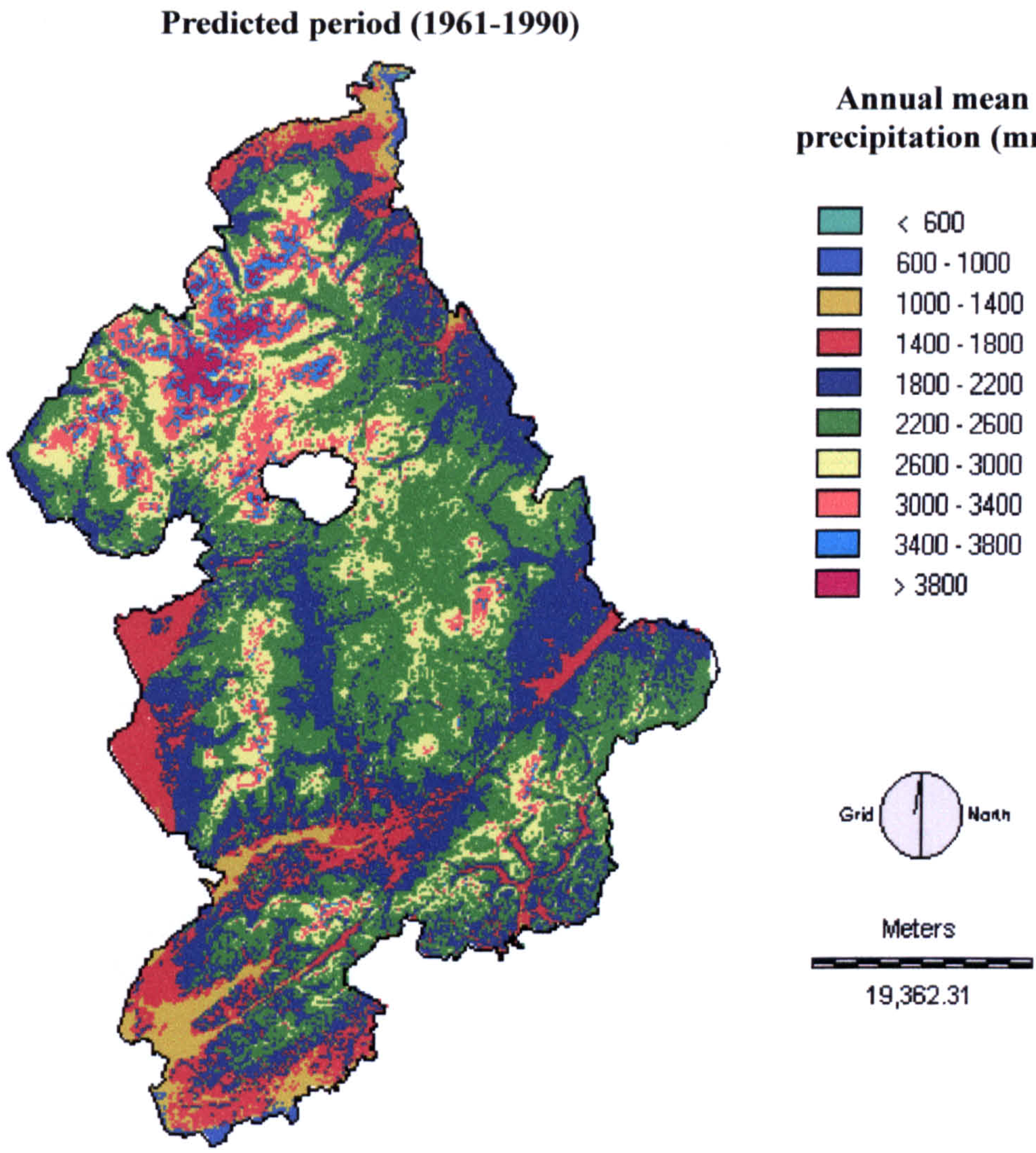


Figure 4.14. Annual mean precipitation (mm) predicted for the period (1961-1990).

consistent overall geographical trends in the distribution of the residuals. The multiple correlation coefficients ranging from 0.867 to 0.884 indicate that the prediction equations are reasonably efficient ones. Wong (1992) analysing data from the Glaslyn catchment and Unwin (1969) using data from gauges in the northern part of Snowdonia, including the catchment found altitude and latitude explained 90% and 79% respectively of rainfall variability. This suggests a great variability of rainfall in an area of very complex topography such as the Snowdonia National Park. The rainfall maps compare favourably with those of the Meteorological Office (1996) and for the observed 1961-90 baseline climatology (10km grid) produced by UK Climate Impacts Programme, with greater detail for rainfall around Snowdon.

a)
b)
c)

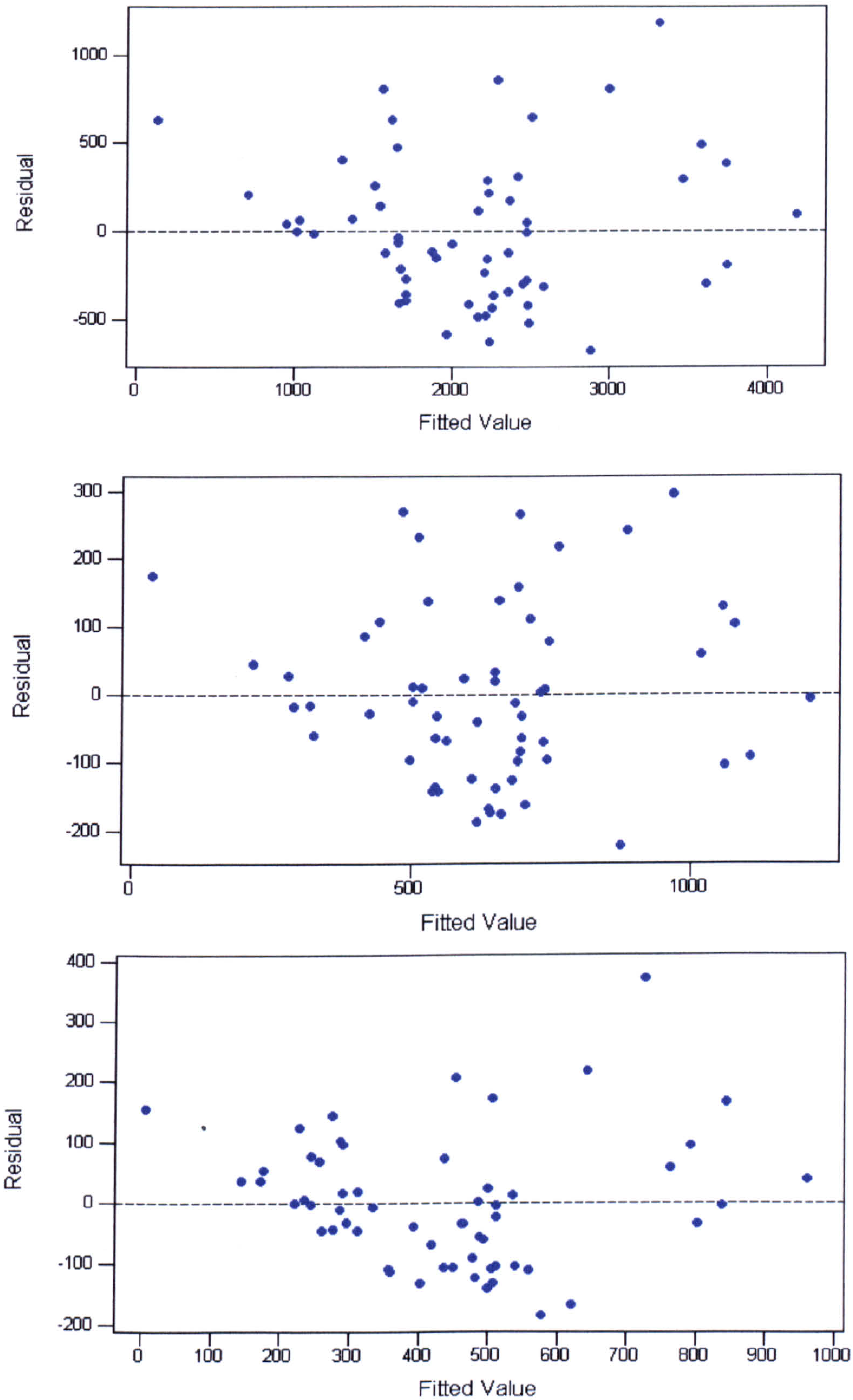


Figure 4.15. Plot of the residual differences between the model value and the actual station value, plotted against the fitted model values for a) mean annual, b) mean winter and c) mean summer precipitation.

The rainfall models for the Snowdonia National Park identified altitude, latitude, slope, and distance from the sea and Snowdon also suggested in studies by Rodda (1962) and Kirby *et al.* (1991, cited in Wong, 1992) but not longitude which was found to be important at Balquhidder (Johnson *et al.*, 1990, cited in Wong, 1992).

Since Unwin (1969) and Wong (1992) also identified altitude and latitude in Snowdonia, this could be a reflection of topography. The addition of factors such as slope and distance from the sea or Snowdon substantially improved the multiple regression models. However, the r^2 values, even after including all these factors, remained low (75.2-78.2%). This may be a result of the mountain area chosen for the analysis and the fact that it is a difficult area with relief variations more marked than in other places and the paucity of gauges at higher elevations. The Snowdon variable further emphasised the role the extreme topography in this small area plays in rainfall variability.

4.3 Present and future distribution of semi-natural woodland

4.3.1 Data and methods

The data available for Snowdonia to implement this study comprises of the 1980s land cover map of the entire National Park and a set of eleven environmental parameters related to climate, topography, soil and geology conditions and also to climatic seasonality (Table 4.8). The approach taken to predict the spatial distribution of temperature and precipitation in north Wales and how climatic maps for the Park were generated is described in section 4.2. In addition, the UK Climate Impacts Programme (UKCIP98) scenarios for the same climatic variables in the environmental dataset for the next 100 years were made available after the UKCIP 98 Climate Scenario CD-ROM was supplied by the Climate Impacts LINK Project (Hadley Centre).

As section 4.1.8 illustrated, many choices are involved in the methods used to construct the models that match the environment and species/entity distribution data and define the relationship between them. In studies using climate-space models to

Table 4.8. Environmental variables used in the analysis.

Variable	Unit	Comments
1 Elevation (DEM)	m	50m pixel resolution
2 Aspect	degrees	Derived from DEM
3 Slope	degrees	
4 Geology	Categoric	Geological Map of Wales at 1:250 000 scale. Digitisation by Luo (1998)
5 Soil	Categoric	Soil Survey of England and Wales map at 1:250 000 scale. Digitisation by Luo (1998)
6 Mean annual temperature	^{0}C	All climatic variables were produced using multiple linear regression modelling with data from meteorological stations covering the 1961-90 period
7 Mean winter temperature	^{0}C	
8 Mean summer temperature	^{0}C	
9 Mean annual rainfall	mm	
10 Mean winter rainfall	mm	
11 Mean summer rainfall	mm	

*All variables were with a 19.89279m pixel resolution.

simulate species distributions, there are differing objectives that influence the choice of the model. There are those, such as the Australian studies using the BIOCLIM model (Nix, 1986, cited in Dockerty, 1998) which use a sample of species records from an unknown species range, to predict the species potential distribution, and there are those, such as the European studies (Huntley *et al.*, 1995), that use records from a known species range to develop models that will faithfully replicate that range. Sparks *et al.* (1995a) examined a variety of methods for linking the geographic distribution of species in Britain to climatic data. A rectangular climate envelope (as used in the BIOCLIM package; Nix, 1986, cited in Dockerty, 1998), a climate envelope based on a convex hull (as used in the HABITAT package; Walker and Cocks, 1991), linear discriminant analysis (LDA), logistic regression and a grid-based approach were used. Sparks *et al.*, (1995a p518) state '*...of the examined methods, logistic regression and the grid method most satisfactorily modelled the current distribution*'.

From all these methods reviewed it would appear that logistic regression offers the potential for defining a model with demonstrated ability to simulate known distributions. In addition, IDRISI GIS has a function that can be used for this type of modelling approach. This study, therefore, will follow this approach and attempt to simulate the recorded distribution of broadleaved and scrub woodland to establish

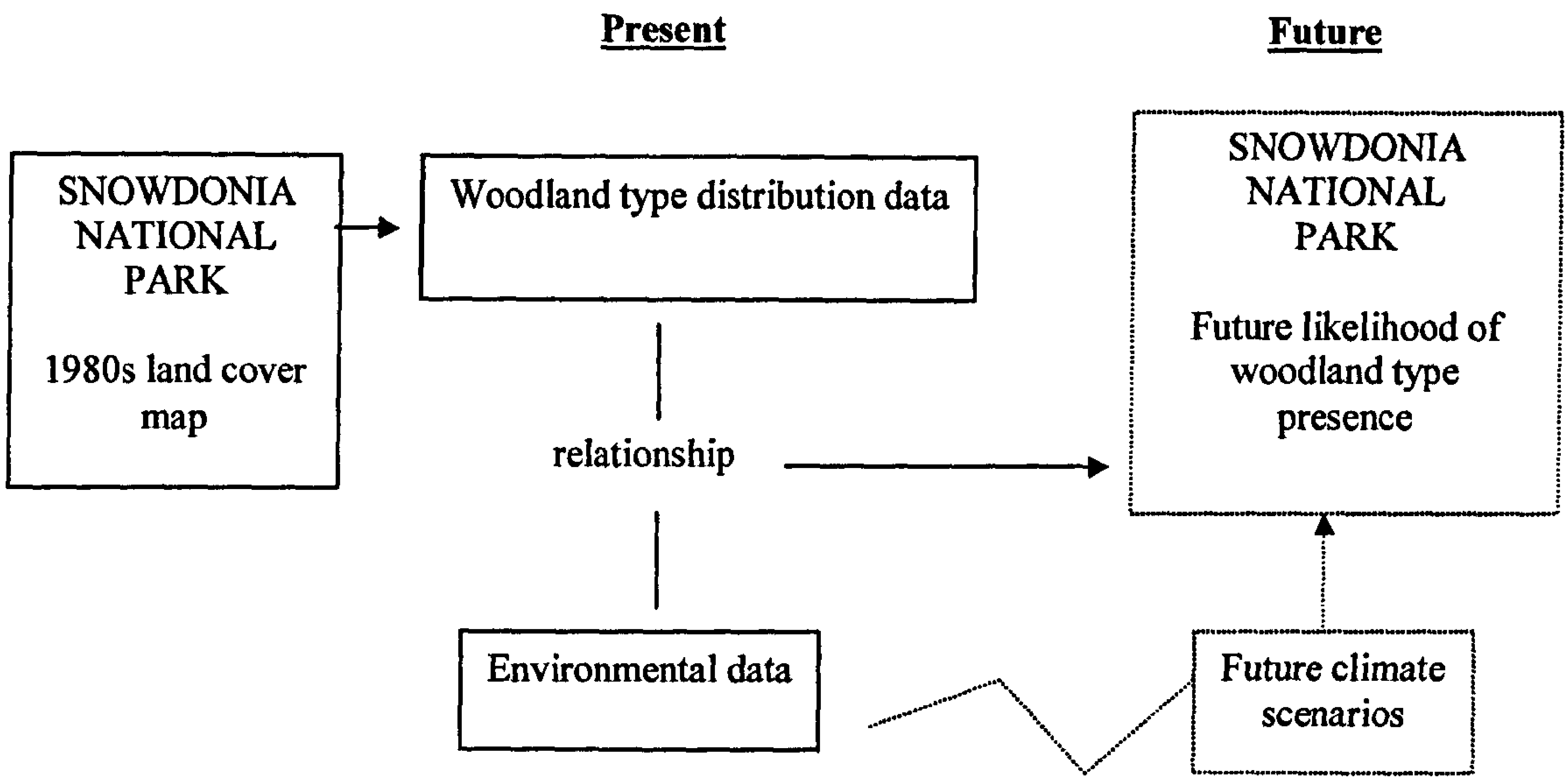


Figure 4.16. Diagram showing the modelling process followed in this study.

whether there is a relationship between their distribution and the variables in the environmental dataset. Figure 4.16 illustrates the modelling process.

Logistic regression is a special case of multiple regression in which the dependent variable is discrete, such as land cover types (*e.g.* forest, pasture, urban). If the dependent variable is dichotomous (presence/absence nature), Y_i takes on only two values: 1 and 0. In predicting forest change, for example, $Y_i=1$ represents the event that the forest has changed, and $Y_i=0$ represents the event that the forest has remained unchanged.

In the case of three independent variables, the logistic regression equation can be expressed as follows:

$$logit\ (p_i) = ln\ (p_i/(1-p_i)) = a + b1*x1 + b2*x2 + b3*x3$$

where p is the dependent variable expressing the probability that $Y_i=1$, a the intercept, $b1$, $b2$ and $b3$ are the regression coefficients and $x1$, $x2$, $x3$ are the independent variables. The relationship between the dependent variable and independent variables follows a logistic curve. The logit transformation of the equation effectively linearizes the model so that the dependent variable of the regression is continuous in the range of 0-1.

Binary presence/absence data of broadleaved and scrub woodlands were related to the environmental parameters using stepwise logistic regression in IDRISI. From the Boolean images of both woodland types probability images were created with probabilities ranging from 0 to 1. In most cases, probability is obtained from the frequency of the event in its sample. In this case, however, there was only one case for each pixel (*i.e.* either woodland or not). Thus, a surrogate method for calculating the probability was needed. Furthermore, events are spatially autocorrelated meaning that if one pixel is forest, for instance, the adjacent pixels would tend to be forest as well due to their similar conditions. In this case, for each pixel we considered its surrounding pixels as its sampling points and calculated probability from this sample. The module FILTER was used for this task. A 3x3 mean filter was used in the GIS to produce the probability images for the woodlands. The probability images used 9 pixels as the approximate sample for the centre pixel in the filter kernel. Thus, the sample size was 9. The selection of the filter type and/or size depends on the data resolution and the purpose of the analysis. A 3x3 filter kernel was selected with the understanding that it represented better the small patches, the majority of broadleaved and scrub woodland patches.

Each probability image was entered with a set of independent image files (parameters) into the LOGITREG module that undertakes logistic regression from image files. The maximum number of independent variables IDRISI v.2.0. allows the user to enter in the module is eight. IDRISI Macro Language (IML) was used to write programmes for each time the module was run. The module also requires to set a confidence level which represents the confidence that future events will occur according to the probability image. If the user states 100% confidence, the process would exclude areas that did not experience such an event in the probability image from having such an event in the future (Eastman, 1997). To acknowledge the uncertainty of future events, in this work, a confidence level of 0.9 was stated (representing a 90% likelihood that the simulated distribution of woodlands will follow exactly the same pattern as in the probability image).

The output images from the models, continuous within the range of zero to one, indicated the probability of suitable environmental conditions for the development of these woodlands communities. The summary statistics produced, such as the R^2 and t-test for each independent variable, were used as a measure of goodness of fit for the logistic regressions and for comparison among variables.

Models simulating known distributions can be evaluated by comparison of the modelled and recorded distributions, for example by cross-tabulating observed and predicted presences, and applying some statistical test to access the degree of similarity. The test most frequently encountered in this regard is the Kappa statistic.

The Kappa statistic (Cohen's Kappa coefficient of agreement) gives the measure of agreement between two given maps. Monserud and Leemans (1992 p282) pointed out the importance in distinction between agreement and association, stating '*...the distinction between agreement and association for nominal data is that for two responses to agree they must fall into the identical category, while for two responses to be perfectly associated it is only necessary to be able to predict the category of one response from the category of the other*'. The same authors pointed out that it is possible to have a situation of high association (*i.e.* high positive or negative correlation coefficients) along with either high or low agreement.

The Kappa statistic is defined as follows:

$$K = P_o - P_e / 1 - P_e$$

P_o – is the overall proportion of observed agreement
P_e – is the observed agreement expected by chance.

A Kappa value of one indicates perfect agreement, and a value close to zero indicates that the observed agreement is the same as would be expected by chance. Negative values are possible and indicate no real agreement. Monserud and Leemans (1992) suggested the following thresholds for separating the degree of agreement for the Kappa statistic:

Degree of agreement		Kappa value
None	up to	0.05
Very poor		0.20
Poor		0.40
Fair		0.55
Good		0.70
Very good		0.85
Excellent		0.99
Perfect		1.00

The Kappa statistic can be used to assess the overall agreement between maps and the agreement between particular classifications (*e.g.* areas of a particular vegetation type under different climate change scenarios – as illustrated by Monserud and Leemans (1992). Lenihan (1993), Shao and Halpin (1995), Huntley *et al.* (1995) and Dockerty (1998) used Kappa to assess agreement between modelled and observed distributions. In this study, to assess the performance of the models, all models were evaluated using this statistic. The simulated woodland distributions were overlain with the maps showing their present-day distribution (CROSSTAB process) and the Kappa Index of Agreement (KIA) statistic was computed for each woodland type.

The predicted present-day distribution maps of broadleaved and scrub woodland types, in combination with the UK Climate Impacts Programme (UKCIP98) scenarios for the next 100 years based on the Hadley GCM experiments, were used to assess the probability of presence for these habitats under scenarios of future climate change. LOGITREG module in IDRISI has the ability to use the regression result to make new predictions in a time series if there are independent variables for the new time periods. In this case, climatic variables identified as important from the logistic regression were adjusted according to the climate change scenarios (Table 4.9) and for all other variables it was assumed they remained unchanged. The new prediction images were in the same format as those produced from the logistic regression.

Table 4.9. Alterations made to current climatic variables under scenarios of future climate change.

Variable	Future predictions*			
	Low scenario		High scenario	
	2020	2080	2020	2080
Mean annual temperature	Present+0.5°C	Present+1.1°C	Present+1.3°C	Present+3.0°C
Mean summer temperature	Present+0.6°C	Present+1.3°C	Present+1.4°C	Present+2.9°C
Mean annual rainfall	Present+2.0%	Present+2.0%	Present+5.0%	Present+9.0%

*Based on the UKCIP98 scenarios for the next 100 years (Hulme and Jenkins, 1998).

4.3.2 Results

The logistic regression identified seven variables important for broadleaved distribution from the initial set of eleven variables. These were elevation, aspect, geology, soil type, rain, mean annual and summer temperature. A significant model was also obtained for scrub with elevation, aspect, slope, geology and temperature identified as important for its distribution. The logistic regression models fitted were:

i) for broadleaved woodland,

*logit(broad) = 3.107796 + 0.000015*rain - 0.0000732*snpasp - 0.0012043*snpdem + 0.0067674*snpgeolt - 0.0024485*snpsoil - 0.0872066*sumtemp - 0.0434877*temp*

R^2=0.669, $F_{7,209048}$=60368.07, $p<0.001$

ii) for scrub woodland,

*logit(scrub) = 3.296583 – 0.000198*aspect – 0.0013702*elevation + 0.0089583*geology + 0.0019574*slope – 0.1959565*temp*

R^2=0.614, $F_{7,34678}$=11052.16, $p<0.001$.

The summary statistics for each woodland type (R^2 and t-test for each independent variable) are given in Appendix 2.

One feature of distributions simulated from regression models is that the probability values (representing predictions of vegetation presence) returned by the regression operation (zero to one) are continuous, thereby 'stretching' the predicted dependent variable by a degree depending on the level of precision (number of decimal places) specified for the output. Some means must therefore be used to determine which probability values best represent 'presence' and 'absence'. As there are only two possible classes, it would be reasonable to regard values of up to 0.5 as 'absent' and values greater that 0.5 as 'present'.

In the work of Huntley *et al.* (1995) the allocation of values to presence and absence classes was determined through the identification of a probability 'threshold' which provided the best match between the probability-simulated distributions and the recorded distribution. The purpose of identifying this threshold was to use it to constrain simulated distributions produced under future climate scenarios. A specially written computer program was used to remove the lower probability values from the simulation in increments of 0.01 until the best match (maximum Kappa value) between recorded and simulated distribution was achieved. This provided a threshold value for presence/absence classification which could be applied to simulate future distributions of each species under changed climate scenarios. The best simulation was achieved using thresholds ranging from $p>0.30$ to $p>0.50$ for the eight species studied.

In the present study, visual inspection of the probability-simulated distributions for both woodland types indicated that a good match at $p>0.50$ threshold would be achieved in the linear models. In IDRISI, p values above the selected threshold ($p>0.50$) in the probability-simulated distribution maps were assigned (RECLASS module) a value of 1 and below this threshold ($p<0.50$) a value of 0. The resulting maps were compared with those of recorded distribution, and the number of true and false presences and the Kappa statistic were recorded. The cross-tabulation tables for both woodland types giving the Kappa statistic and also showing the number of cells classed as present or absent in the recorded and simulated distributions can be found in Appendix 2.

The simulated distributions for broadleaved and scrub woodlands showed a very good and good agreement respectively with their recorded distribution (KIA=0.74 for broadleaves and KIA=0.66 for scrub) after selecting a probability threshold $p>0.50$ for presence. The probability-simulated present-day distributions of broadleaved and scrub woodland are presented in Figures 4.17 and 4.18.

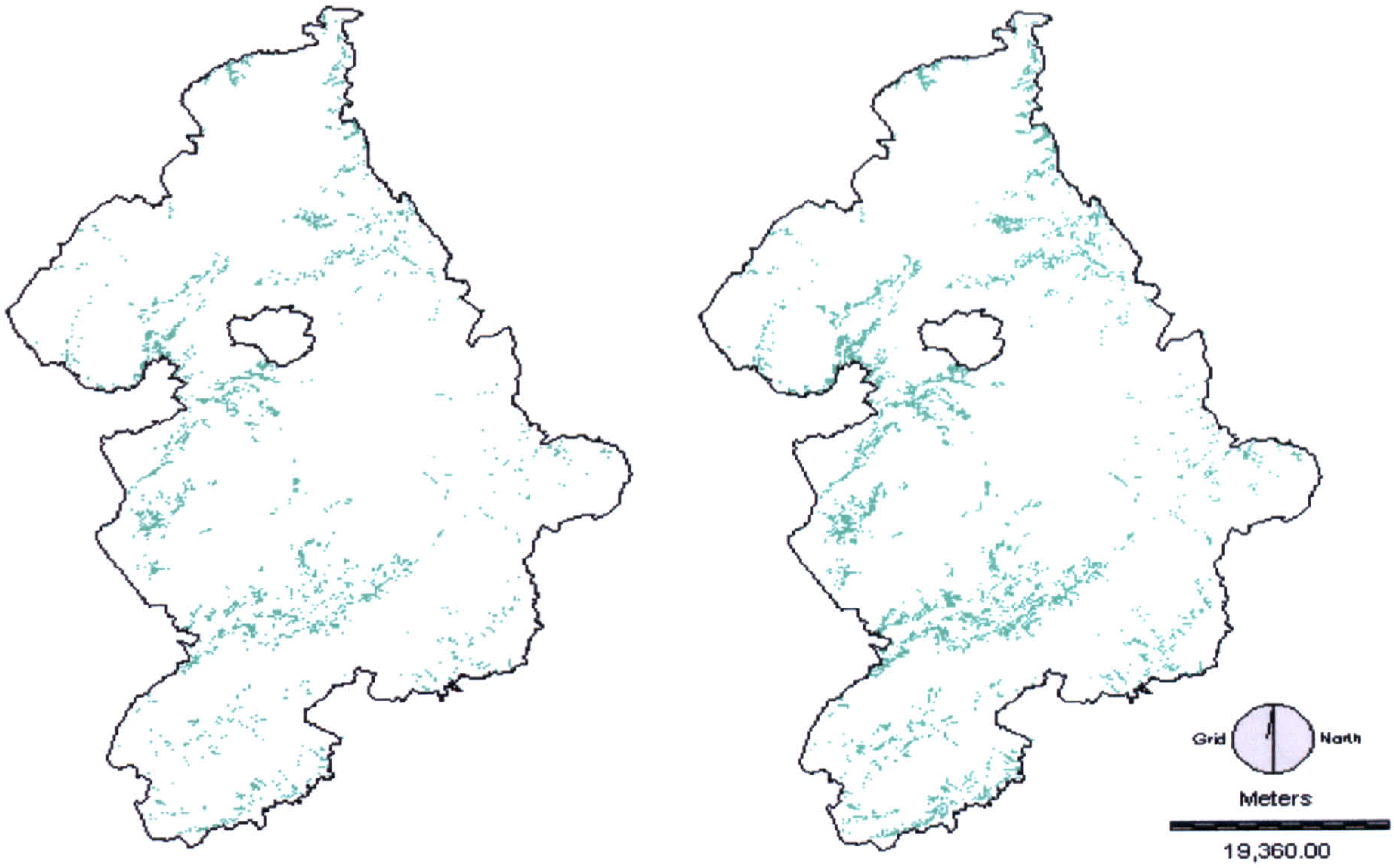
It is most likely that the methods that will be most useful for predicting the future distribution of a species or community will be those that most accurately model the current distribution (Sparks *et al.*, 1995a). This would suggest that the regression equations which showed a satisfactory agreement with the present distribution of broadleaves and scrub could be applied to simulate distribution under future climatic scenarios. Figures 4.19-4.22 show logistic regression predictions for broadleaves and scrub after applying the 2020 and 2080 UKCIP98 low and high scenarios which represent the range of possible responses for each time slice.

The situation appears to be of 'no change' for broadleaves with a slight decline in probability of presence for scrub in the 2080s for the sites examined under the low scenario (Table 4.10). Under the 2020 high scenario, there is only a small decline in probability of presence for scrub. The 2080 high scenario, however, shows a declining trend in probability of presence for both woodland types, potentially leading to the eventual loss of these woodlands from these sites. Scrub, in particular, shows a decline of 63% in sites of Snowdonia having probability of presence $p>0.50$.

Table 4.10. Actual and future modelled area (probability of presence $p>0.50$) of woodlands in Snowdonia.

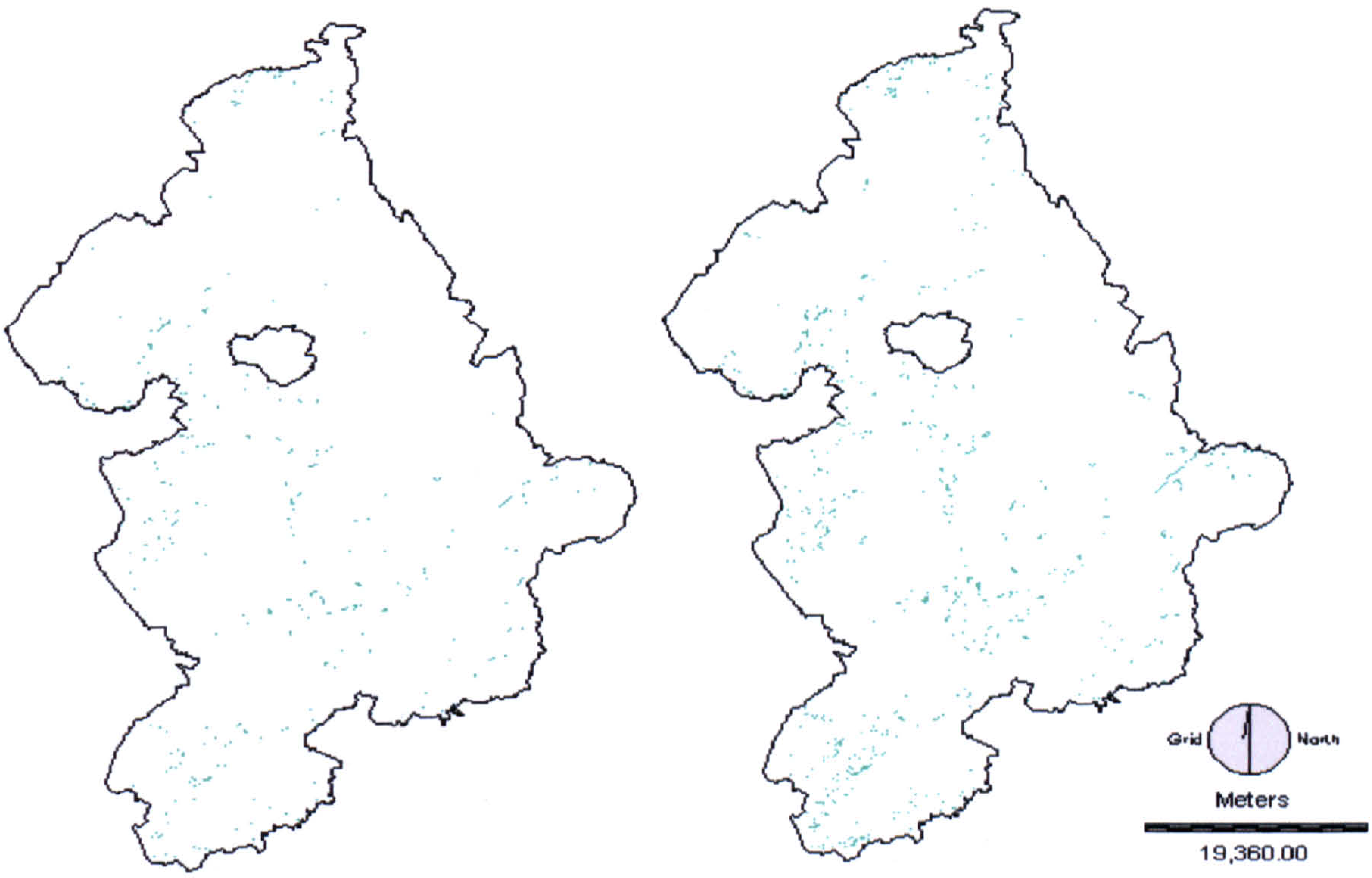
Area (ha)		Broadleaves	Trend	Change (%)	Scrub	Trend	Change (%)
Current		8273			1373		
Current modelled		13888			2760		
Future modelled							
Low scenario	2020s	13888	↔		2760	↔	
	2080s	13888	↔		2676	↓	-3.04
High scenario	2020s	13888	↔		2539	↓	-8.00
	2080s	12858	↓	-7.42	1008	↓	-63.48

Trend: ↑ = increasing probability of presence; ↓ = decreasing probability of presence; ↔ = no change in probability of presence.



Current Modelled-current

Figure 4.17. The current and modelled-current distribution of broadleaves in Snowdonia (KIA=0.74).



Current Modelled-current

Figure 4.18. The current and modelled-current distribution of scrub in Snowdonia (KIA=0.66).

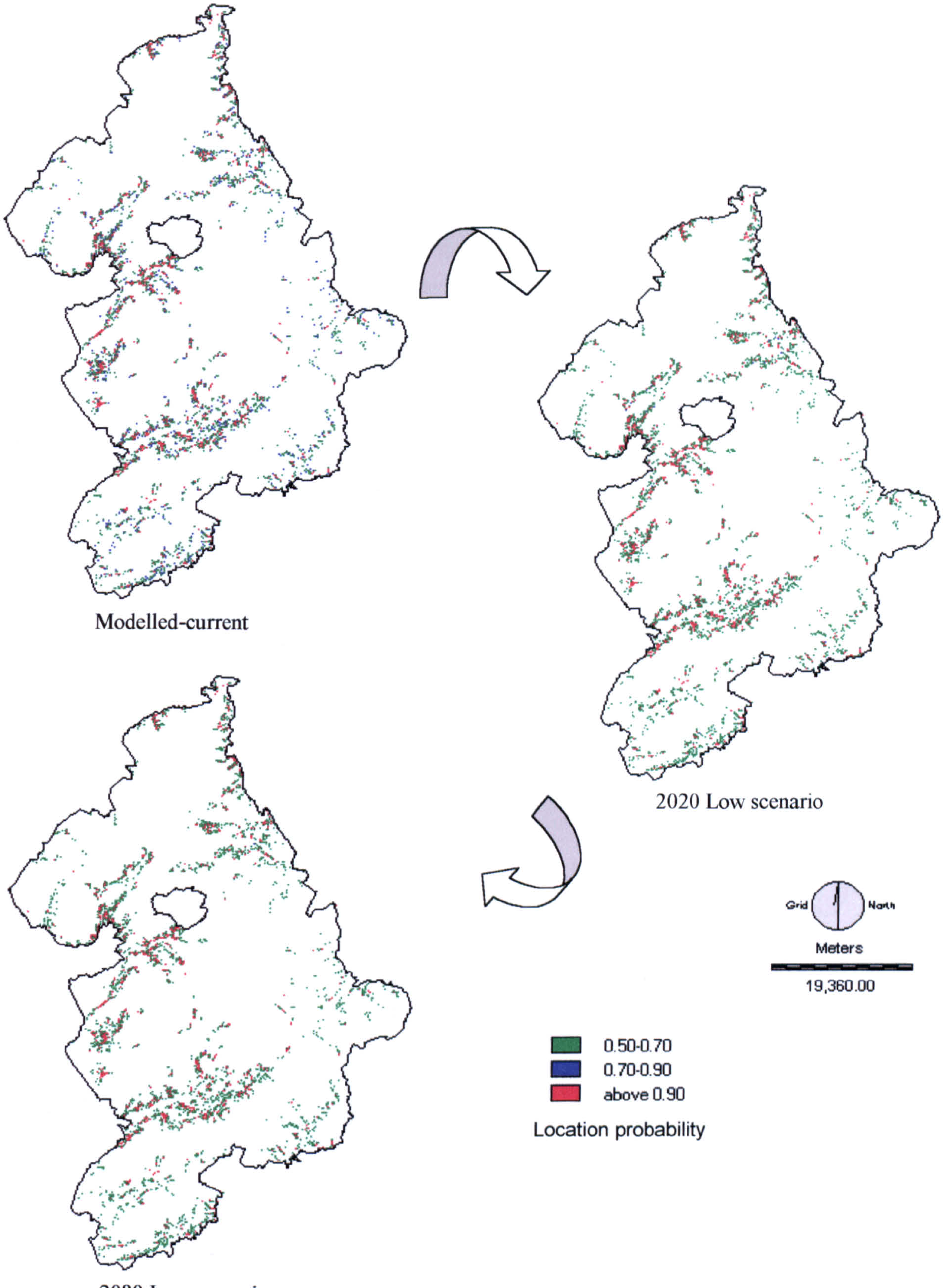


Figure 4.19. Logistic regression predictions for broadleaves in Snowdonia using the 2020 and 2080 Low UKCIP98 scenarios.

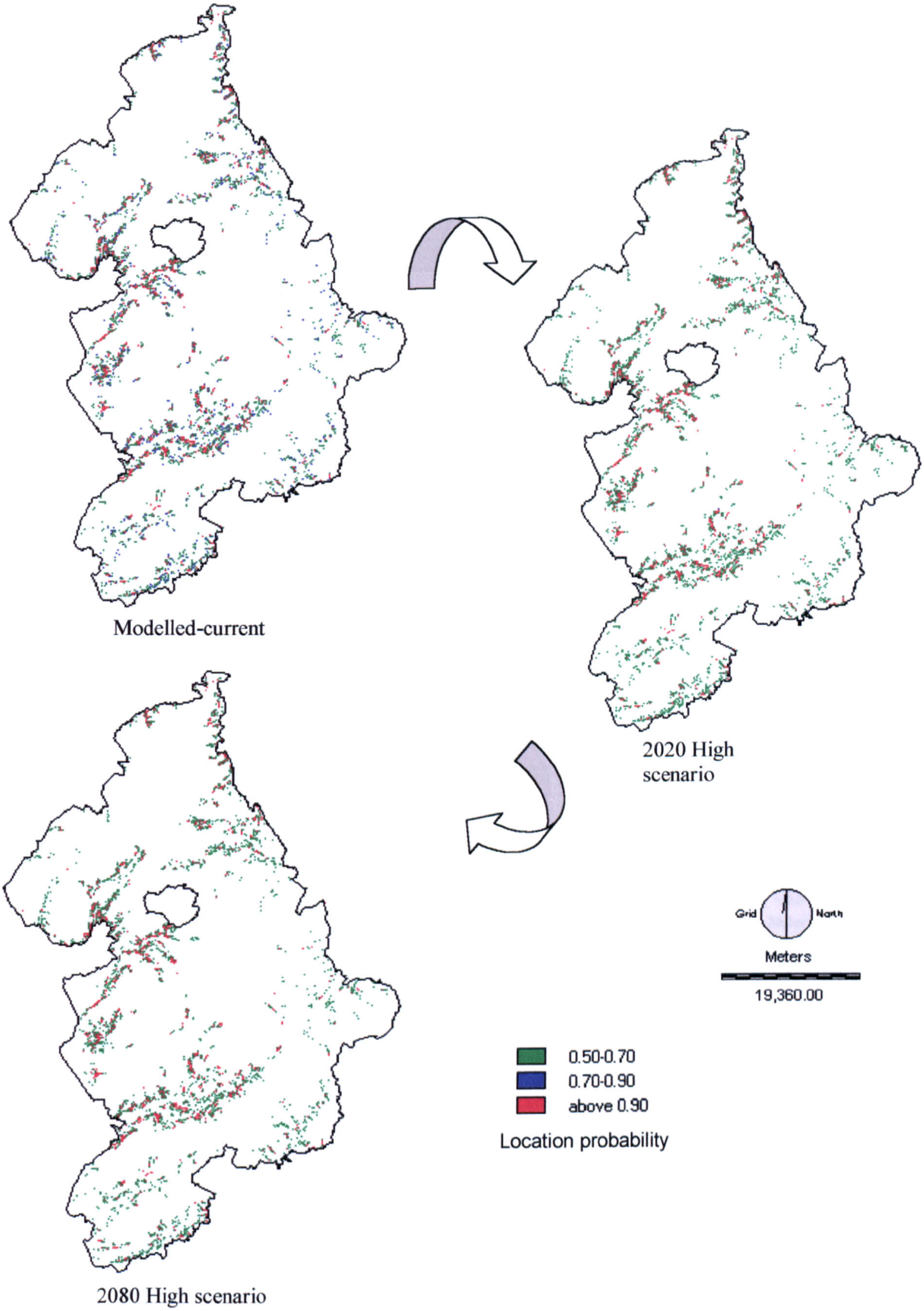


Figure 4.20. Logistic regression predictions for broadleaves in Snowdonia using the 2020 and 2080 High UKCIP98 scenarios.

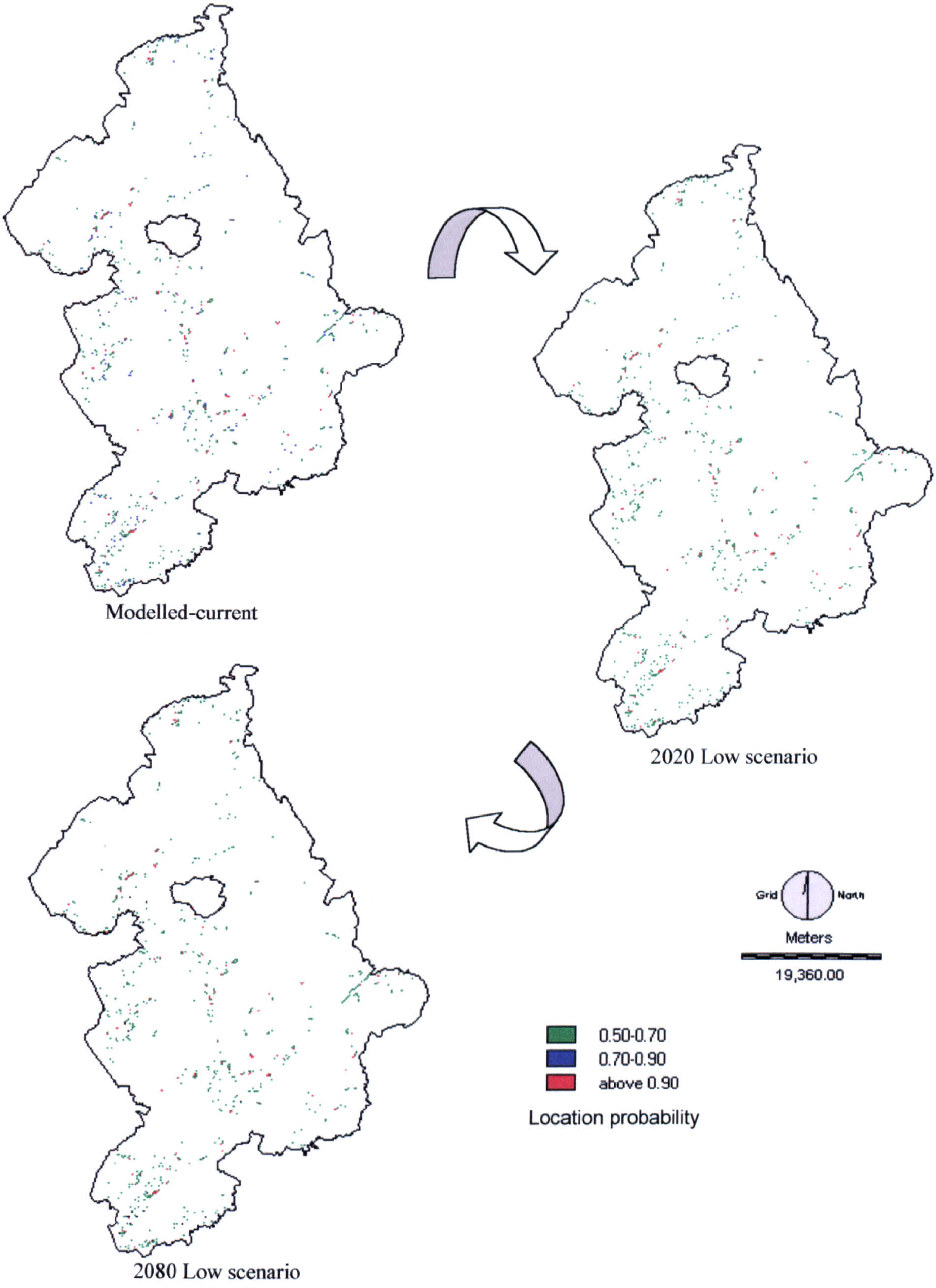


Figure 4.21. Logistic regression predictions for scrub in Snowdonia using the 2020 and 2080 Low UKCIP98 scenarios.

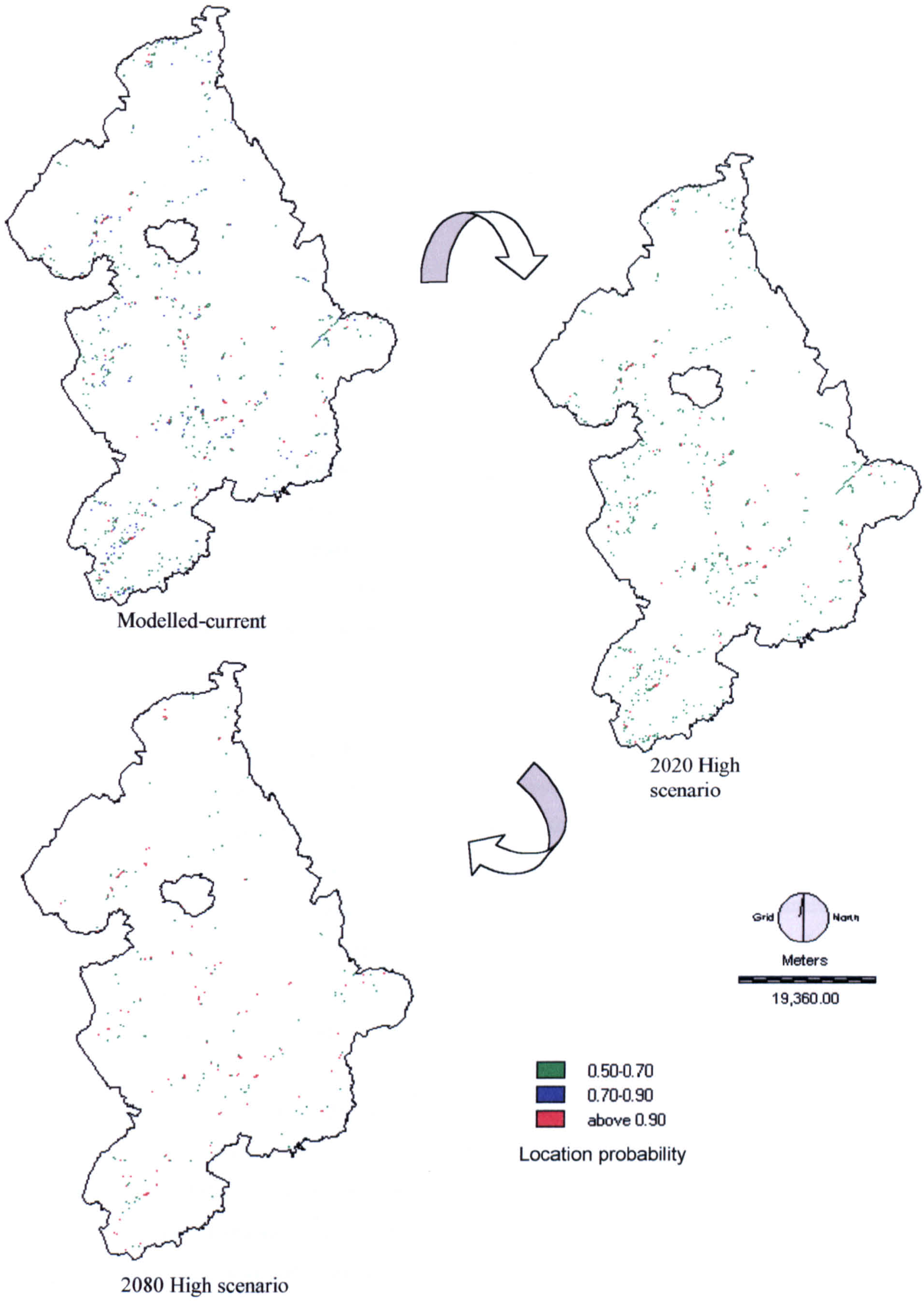


Figure 4.22. Logistic regression predictions for scrub in Snowdonia using the 2020 and 2080 High UKCIP98 scenarios.

4.3.3 Discussion

The IDRISI GIS proved to be a powerful tool for creating an environmental database for Snowdonia and producing logistic regression predictions for broadleaved and scrub woodlands in the Park. The GIS was able to cope with the large data volume used in the study. In addition, it helped to extend the model to make predictions in anticipation of climate change. This scenario analysis and further studies of this nature could be very helpful in initial strategic planning for future management responses.

Recent publications have proposed using logistic regression for linking the geographical distribution of plant and animal species to environmental data (Le Duc *et al.*, 1992; Sparks *et al.*,1995a; b; Augustin *et al.*, 1996; Dockerty, 1998). Sparks *et al.* (1995a), in particular, compared alternative methods for linking the geographical distribution of three species in Britain to climatic data and found that logistic regression was one of the methods that most satisfactory modelled the current distribution.

In this study, the potential for linking woodland data for Snowdonia to a set of eleven environmental variables was examined. Using regression models at $p>0.50$, it has been possible to obtain satisfactory simulated distributions for both broadleaved and scrub habitants. Furthermore, by using a broad number of environmental parameters, it was made possible in the analysis to identify particular aspects of environment (such as climate) that correlate with their current distribution. This is considered to demonstrate that distribution of broadleaved and scrub woodlands in Snowdonia is related to factors such as climate.

The geographical distribution of species/entities is the result of many inter-relating factors. These include historical, geological and economic reasons. It is not uncommon for different factors to appear to be of primary importance at different scales of interest (Sparks *et al.*, 1995a). Topography (elevation, aspect), soil and geology type, rain, and mean annual and summer temperature were those factors found most important for broadleaved woodland type distribution in Snowdonia. For scrub woodland, the situation appears to be similar. Topography (elevation, aspect, slope), geology and temperature are the parameters identified as important for its distribution.

The declining trend in probability of presence for broadleaved and scrub woodlands shown under the high scenario may be interpreted by considering the exact conditions found on the present woodland sites. Under the predicted conditions of the UKCIP98 high scenario, increases in temperature and rainfall have the consequence of reducing the areal extent of sites with exact current climate specifications. If the climate over the next years of the century, changes following the high scenario predictions, there is the potential of the eventual loss of semi-natural woodlands from some sites in Snowdonia, according to the analysis results. However, this is not perhaps what is likely to happen in the future. The distribution modelling reported here, is based on a small geographic area of Britain and the tolerances of each species or community in the woodlands are not examined (fundamental niche 4.1.8.7 subsection). Expert ecological knowledge predicts that these woodland types have broad environmental tolerances. Historical information, in addition, suggests that most of the land in Snowdonia was covered by woodlands over the past before alternations in the landscape by man began (Linnard, 2000). Furthermore, if the management of the land alters, with a reduction of grazing in particular, this seems quite possible after the foot and mouth disease outbreak, a notable expansion of most woodland types is likely.

The MONARCH (Modelling Natural Resource Responses to Climate Change) project evaluates the impacts of climate change on wildlife and geomorphological features in Britain and Ireland through an integrated methodology linking established impact models to coherent climatological zones (Cook and Harrison, 2001). The impacts of climate change on the distribution of suitable climate space were modelled for 33 plant, four insect, two amphibian, one mammal and 10 bird species associated with 12 habitats of conservation concern. Responses were highly variable, with some of each category losing and some gaining climate space. Oak woodlands themselves were predicted to grow vigorously enough under warmer conditions, and may colonise mountain sides that are currently too cold for them. But the other vegetation of these woodlands is likely to suffer seriously as soils dry out in summer.

The broader scale impacts on the potential distribution of natural ecosystems within England and Wales are being modelled, using BIOME-UK (Berry *et al.*, 2000). This is a regional version of the global BIOME3 vegetation model, which was developed to assess the impacts of climate change on the distribution and biogeochemistry of natural ecosystems. The model output consists of a quantitative vegetation state description including the dominant part functional type (PFT). At the global scale, BIOME3 shows the dominant PFT in Britain to be temperate deciduous forest, with a small area temperate conifer forest in northern Scotland. BIOME-UK was run at the finer scale for current climate conditions, and with actual soil data to see whether the dominant PFT changed in distribution and whether any new ones were recorder. It was then run with the changed climate parameters for 2020 and 2050 in order that potential changes in dominant PFT could be identified. The results showed that the potential dominant PFTs over much of England and Wales are temperate deciduous and temperate coniferous woodland, and that forest could remain as the potential vegetation type over much of Britain.

Forests, however, are composed of individual species and modelling work of others has shown that each species responds differently to changing climatic parameters (Huntley *et al.*, 1995; Sykes *et al.*, 1996). Sykes *et al.* (1996) and Cook and Harrison (2001) studies, for instance, suggest that *Fagus sylvatica* (beech) could be lost in East Anglia and parts of southern England, due to failure for chilling requirements to be met, whereas *Quercus robur* (an Oak species) ought to be able to survive in Britain, including Wales. Sykes *et al.* (1996) concluded that changes like these imply a major re-organisation of the dominant forest ecosystems of northern Europe. This would have important implications for those concerned with the management of habitat, especially those of designated conservation status (Berry *et al.*, 2000). In Britain, Dockerty (1998) constructed two climate-space models for 241 plant species occurring from a sample of 86 natural reserve communities in the country to estimate the impacts of climate change on natural reserves. Results indicated that the warming climate will lead to a declining trend in probability of presence in the case of *Betula pubescens* (birch), whereas the opposite trend was shown for *Quercus petraea* (oak) in Nantporth, a small reserve on the shore of the Menai Strait (Gwynedd, Wales). Overall, the situation appeared to be one of 'no change' for the majority of species of Welsh reserves and those further north in England.

4.3.4 Critique of the approach followed

There are a number of issues, which apply to the modelling approach used in this study.

- All species have different climatic tolerances and will respond independently to change (Woodward, 1987). However, for the purpose of this analysis the distribution of woodland types, and thus the community level organization was examined. As a result, predicted changes in vegetation communities as complete entities are not very realistic (section 4.1.8.7).
- In the models, only climatic parameters and physical geography were used and it was assumed that these are the most important factors controlling the distribution of broadleaved and scrub vegetation types at the landscape level. Anthropogenic factors, for example, which can result in land-cover changes were not taken into account, although their importance is recognised for determining the present day distribution of woodlands at regional and local levels.
- The models used correlations based on the realised niche, the range of conditions under which a plant actually occurs while subject to competition (Figure 4.10). It might be preferable to use the fundamental niche.

These issues are important considerations in relation to the use of the models constructed in this work. Parr and Etherall (1994 p11, cited by Dockerty, 1998) state '*Predictions based on these relationships are best seen as indicative of the kind of changes that might occur and must be viewed with caution, particularly if they extent into climates not currently represented in Europe*'. However, one can see the observed distribution of species/entities as an initial guide to the likely impact of climate change (Kirschbaum, 2000).

4.3.5 Future research

The research which has been carried out in this study illustrates a methodology and how it can be applied. Although this study has focused on a small geographic area of Great Britain, the Snowdonia National Park, the methodology could be used to assess the potential changes for woodland types at any location. Perhaps, an ideal approach might be to apply the method to the entire Britain or even to Europe and then apply the results to Britain. It would be interesting to see if modeling of distributions at such scale confirm the results found in this work. However, studies of such scale are computationally intensive. The IDRISI GIS coped well with the data volume used in this work but it was very time consuming. A compromise should be made with the number of environmental parameters used and the resolution of the images if the distribution of woodland types at this scale is to be studied.

Although this study examined the distribution of broadleaved and scrub woodland in the National Park, it may be better to model the distribution of more specific woodland classification types, such as the National Vegetation Classification (NVC) woodland communities in relation to environmental parameters. Maps of potential native woodland cover could be produced, representing the NVC woodland communities and their potential natural extent in Snowdonia under current environmental conditions. An attempt to extend the NVC models in order to make predictions in anticipation of climate change and examine the consequences could be also examined. This approach is taken forward in a subsequent chapter.

In addition, the study could be extended to examine the distribution of individual species, for example, in relation to the long-term conservation potential of rare species in Snowdonia. It would be beneficial to identify particular species that could act as climate change indicators and study the trends in probability of presence. Studies like these would provide an evaluation of 'which habitats' might be least or most affected by climate change. Dockerty's work (1998), for instance, has shown that the warming climate appears to favour oak rather that birch species, which could lead, in the long-term, to changes in woodland communities.

4.3.6 Concluding remarks

One of the main advantages of the logistic regression approach is that it can readily be extended to include information such as soil type and local climate (Le Duc *et al.*, 1992). Following the approach in this study, it was possible to model the present-day distribution of broadleaved and scrub woodland in Snowdonia using factors such as topography, soils, geology type and climate, and extend the models to make predictions in anticipation of climate change.

It is important that we begin to adopt a long-term and regional perspective to forest ecology, biogeography and conservation. It is clear that forest ecosystems are spatially and temporally dynamic and that they respond relatively rapidly to climatic change (Eeley *et al.*, 1999). Understanding how woodland distribution is governed in the present, and how it may change in the future, will enable us to make more enlightened management decisions and to develop flexible conservation strategies to accommodate the fluctuating pattern of native woodland distribution, to protect their habitat and the biodiversity they support.

4.4 Summary

This chapter has reviewed a number of issues which relate to the various aspects of climate change, in addition, has described the way an environmental database for Snowdonia was created using GIS, and how the physical characteristics of semi-natural woodland were defined in order to model the present distribution of broadleaved and scrub habitats in the National Park. Furthermore, the potential of using climate change scenarios for extending the models produced to make predictions in anticipation of climate change was also discussed.

The next chapter examines the priority areas for native woodland expansion in Snowdonia.

CHAPTER 5

'The future does not just lie ahead; it is
something that we create.
More precisely, the future is produced by
natural processes and human
modification thereof'.

Forman and Collinge (1997).

5.0 PRIORITY AREAS FOR NATIVE WOODLAND CREATION AND RESTORATION

The native woodlands in Snowdonia are of national and European conservation importance because of the multiple and diverse benefits which they provide. These include diverse wildlife habitats set in characteristic landscapes, a source of timber and places for recreation.

These woodlands have been reduced and fragmented over the centuries and this issue has been recognised within the *UK Biodiversity Action Plan* (BAP) (HMSO, 1994). This BAP is the UK's commitment to *Agenda 21* (Earth Summit, 1992), and contains native woodland Action Plans with explicit expansion targets for native pine woodlands and upland oakwoods. The local Biodiversity Action Plan for Snowdonia identified the need to expand the area of upland ash and oak woodlands and encouraged the restoration of these habitats where possible. In addition, Tir Gofal, a new all-Wales agri-environment scheme, recognises the need to maintain and create traditional habitats on farms wherever possible and identifies a number of prescriptions including the planting of new woodland (CCW/FC Wales, 1999).

A local accord between the Snowdonia National Park and the Forestry Commissin in Wales has set a target of increasing the area of native woodland within Snowdonia by 50% within 50 years (SNPA, 1995). However, there has been no comprehensive study of the priority areas for the establishment of new native woodland to enhance woodland habitat networks in the National Park as envisaged in the *Wales Woodland Initiative-Strategy* (Anon., 1998a), although Purdy and Ferris (1999) and Good *et al.* (2000) did study objective approaches to the development of forest habitat networks in England and mid-Wales accordingly.

The present study takes forward, develops and attempts to integrate the ideas developed in studies by Good *et al.*, (1997), Purdy and Ferris (1999), Good *et al.*, (2000), and Gkaraveli *et al.* (2001) for the establishment of a methodological approach to woodland creation and restoration modelling responsive to the regional conditions and taking account of the needs of non-woodland habitats.

To help guide native woodland expansion in the Snowdonia National Park, this work aims to achieve the following:

1. to combine all the available data for Snowdonia to provide the basis for identifying priority areas for the establishment of woodland habitat networks;
2. to provide an objective way for prioritising sites for native woodland creation and restoration, taking account of the needs of non-woodland habitats.

5.1 Possible futures for the Welsh forests

The results of Chapter 3 confirmed the important role that afforestation and deforestation have played in recent decades in determining current landscape composition in the Snowdonia National Park. Forestry will continue to have an impact in the future, but perhaps in different ways. A threefold vision for the future of forestry in Wales is proposed in the *Woodlands for Wales* document (National Assembly for Wales, 1999); woodlands for rural development and the wider economy, for the environment, and for people. Due to the predicted retirement or death of a large proportion of Welsh farmers over the next 15 years, and the absence of successors to many of these farmers, it is likely that increasing amounts of land will come up for sale (Stevens, 2000). Some of this may become available for large-scale plantings of one form or another. If so there may be new opportunities to join up and expand existing farm woodlands, which are mostly very small (<1ha) and isolated (Stevens, 2000; Gkaraveli *et al.*, 2001). Unfortunately the Tir Gofal agri-environment scheme in Wales, while including farm-woodland management as part of its prescriptions for environmental maintenance and enhancement, is limited in its consideration to individual farms within the scheme. There is currently no means of providing financial assistance for the integrated management of woodlands on different farms, although this is what is required to enhance the development of effective woodland habitat networks.

In practice the future nature and size of the Welsh forest estate will depend very much on the economics of land use options in Wales in general and of forestry within those options in particular (Stevens, 2000). This has been appreciated and four scenarios were set out and presented by FC in *Woodlands for Wales* discussion document (National Assembly for Wales, 1999), which offer a range of options for the future of Welsh woodlands and the timber industry of Wales. All were based on assumptions about future policies and budgets, and were designed to inform debate on future policy directions. The scenarios vary from 'Business as usual' to 'Market forces led' at one extreme and 'Environmental scenario' at the other. The 'Integrated rural economy scenario' is that which is most likely to appeal across the board. It would encourage the development of multi-use forestry with agriculture, community woodlands and local wood-based cottage industries as part of an integrated rural economy (Stevens, 2000).

5.2 Wales Woodland Strategy

In 1997, CCW and the FC commissioned the report on the *Wales Woodland Initiative-Strategy* (Anon., 1998a) to advise how the target of a significant increase in the area of woodland in Wales by 2050, set in the 1996 White Paper *A Working Countryside for Wales,* could be met. A new initiative was clearly necessary since at 1996 planting rates[1] it would take some 50 years to achieve a modest 20% increase in woodland cover (Good *et al.*, 2000). Both CCW and FC considered that the initiative should focus on the creation of woodland that delivers a combination of environmental, social and economic benefits, which are the three main components of integrated rural development. Its specific role should be to draw in additional funds that stimulate the creation of such woodland, especially on privately owned land. It was envisaged that while timber production would often be one of the objectives of such woodland creation, the initiative would generally not encompass new forestry planting designed primarily for commercial objectives.

The *Wales Woodland Initiative-Strategy* (Anon., 1998a) emphasised that an initiative focused on woodland creation would need to relate strongly to existing woodlands, since the expansion, linking and buffering of such woods would be a primary objective. One of the key elements of the strategy developed in the report was the development of a forest habitat network. The arguments given for this may be summarised as follows:

- Forest was the natural matrix within which most other Welsh habitats occurred in prehistoric times;

[1] The term 'planting' was used throughout the report to include natural regeneration as well as planting *per se*.

- Millennia of human activity have eliminated much woodland cover and fragmented what remains;
- This has led to population fragmentation and ecological isolation of woodland flora and fauna;
- Population isolation may lead to local extinction which can have damaging effects on a wider scale;
- The general importance of habitat connectivity for wildlife conservation is recognised in the concept of 'habitat networks';
- Such networks enable re-establishment of connectivity between existing habitat fragments with minimum land take.

The *Strategy* (Anon., 1998a) recommended the following approaches to developing a forest habitat network:

- Retain existing woods to provide the foundation upon which the initiative can build;
- Create native woods on sites which have been cleared of ancient woodland cover in the recent past;
- Expand existing woods by creating new woodland adjacent to existing woods where possible;
- Generate core forest areas comprising large blocks of woodland that form the 'nodes' within the network and provide habitats for species requiring large territories, large home ranges, or protection from the competition of non-forest species;
- Generate large-scale wooded 'links' to provide long distance connectivity between core forest areas;
- Integrate plantation forests and semi-natural woodland;
- Create and maintain 'normal' forests (*i.e.* forests which contain the full range of age classes);
- Manage forests to link critical age classes as some species depend on particular phases within the forest cycle;
- Maintain and where necessary restore semi-woodland habitats (wood pasture, parkland with trees, bracken banks, stream-sides, ungrazed outcrops, hedges, cliffs and railway embankments) to link isolated small woods and provide corridors for movement of woodland species;

- Manage open spaces within core forest areas and wooded links as semi-natural habitats;
- Recognise the complementary needs of other habitats.

A recent development in Wales which builds upon woodland habitat networks is CCW's suggestions for a woodland management framework (Latham, 2000). This proposes a framework to co-ordinate management in woodland SSSIs throughout Wales but it is envisaged that it could be extended to embrace woodlands in the wider countryside. The overall objective of the framework is to guide management for the benefit of as many woodland organisms, communities and structures as possible. This would be achieved through:

- An increase of woodland diversity through the representation of all woodland structural states (natural woodland, high forest, coppice, wood pasture) in each ecologically representative area and every appropriate woodland type throughout Wales;
- Location of management to give maximum benefit, for example by arranging coppiced woods so that they are close together and movement of species between them is facilitated;
- Options to dedicate the whole of an individual woodland to a particular structural state, thus maximising its size and ecological value;
- Clarification of management aims, so that for individual sites a statement of desired structural state can be made and appropriate attributes selected for monitoring;
- Guidance for management in non-statutory sites, for example through Tir Gofal, to complement the management taking place within the SSSIs;
- Guidance on the location of productive sustainable management, so that non-productive conservation management can be better focussed on SSSIs and other key sites;
- Guidance for woodland expansion. The framework could be used to propose suitable sites within a unit for the establishment of new woodland, so that existing woodlands have increased areas or are ecologically linked. The future management of new woodlands could be recommended, and this may influence their location, design and choice of any planted species.

It is proposed that the management framework would be based on units of ecologically linked woodland SSSIs, defined by criteria such as proximity and connectivity, woodland types and hydrological catchments. The aim would be to develop a management system for each unit, which would result over time in the achievement of a desired mix of the four basic structural states (natural woodland, high forest, coppice and wood pasture). These desired mixes would vary depending on Habitat Action Plan (HAP) woodland types predominating within the units. In combination they would cover the full range of HAP woodland types in Wales (Latham, 2000).

In 2001, the National Assembly for Wales produced the *Wales' Woodland Strategy* (National Assembly for Wales, 2001) to help the UK Government to deliver its international commitments to sustainable forestry, as set out in the *UK Forestry Standard* (Forestry Authority, 1998). A key priority of the strategy was the management of existing woodlands with key objectives for woodland management the following:

- To promote best practice in woodland management;
- To move to a greater use of continuous-cover systems; and
- To find appropriate sites for new trees and woodland.

The draft strategy recommended the following approaches to find appropriate sites for new woodland. New woodland could:

- Link and protect the irreplaceable remnants of ancient semi-natural woodlands;
- Provide shelter on farms and help diversify agricultural businesses;
- Contribute to a sustainable supply of timber for large and small industries;
- Make a valuable contribution to the restoration of the landscapes left by mineral extraction or other past industrial activities, re-establishing the links with surrounding natural habitats.

Another key priority of the strategy was to deliver a diverse and healthy environment having as key objectives the following:

- To conserve and enhance the biodiversity of woodlands;
- To conserve and enhance the landscapes of Wales; and

- To better integrate woodlands with other countryside management.

In response to these key objectives, the strategy emphasized the high existing or potential biodiversity values of ancient semi-natural woodlands, upland oakwoods and more recently planted woodlands with remnant semi-natural vegetation, and the fact that if the strategy was to succeed the quality of these woodlands should be improved by linking and expanding their habitat networks without compromising other valued habitats or historic features. Furthermore, the strategy set as objectives the following:

- To prevent further loss of ancient and semi-natural woodland;
- To continue the restructuring of existing plantations, encouraging owners to look for opportunities to restore natural vegetation removing non-native woodland where appropriate;
- To increase the quality of native woodlands for wildlife and implement the Biodiversity Action Plan targets for their restoration and extension, creating links between fragmented woodlands;
- To increase the area of native woodlands, targeting extension and connection of existing woods and incorporating the concept of increasing the core area of native woodland habitats; and
- To develop appropriate links between woodlands and wider countryside management through Tir Gofal and other environmental schemes.

This study considers the requirements for successful woodland expansion from the nature conservation point of view as set out in the *Wales Woodland Initiative-Strategy* upon which are superimposed the more detailed CCW proposals for a management framework for woodland SSSIs in Wales and the more recent *Wales' Woodland Strategy*, and attempts to integrate all these ideas in order to identify priority areas for woodland creation and restoration in Snowdonia.

5.3 Objectives and priorities of nature conservation in British woodlands

Nature conservation is an expression of concern that man should have a sensitive relationship with his environment which can be sustained indefinitely, but it must be expressed practically in the way in which land (*i.e.* soils and vegetation) and populations of individual species are utilised (Peterken, 1993). The aims of nature conservation in British woods according to Peterken (1993) are:

(1) To maintain naturally self-perpetuating populations of all native plant and animal species throughout their range;
(2) To maintain adequate examples of all semi-natural woodland communities, including communities of trees and shrubs, field layer, epiphytes, animals and the soils and other physical features upon which they depend;
(3) To maintain other features of interest;
(4) To contribute to maintaining an element of wilderness in the British landscape.

These aims can be achieved by the following general approaches (Peterken, 1993):
(1) Maintaining or restoring traditional low-intensity forms of management and the semi-natural features they incorporate;
(2) Maintaining or restoring the few woods whose characteristics are almost natural;
(3) Directly protecting threatened species;
(4) Persuading foresters to limit the intensity of management for timber production;
(5) Maintaining a mature structure in existing woodlands and zoning the distribution of future afforestation in order to preserve an element of wilderness.

In response to the second practical objective of woodland nature conservation, the maintenance of adequate examples of all semi-natural woodland communities, Peterken (1993) suggested the following five categories, collectively termed 'special woodland types', as a top priority for nature conservation:
(1) Ancient semi-natural stands surviving from medieval wood-pasture management;
(2) Ancient semi-natural high forest stands, notably pine- and birch-woods in the Highlands;
(3) Ancient semi-natural coppices and high forest stands which were formerly coppiced;
(4) Ancient semi-natural stands which have not been managed; and
(5) Secondary stands originating before 1800 which have not been managed, and have therefore a natural structure.

5.4 Biodiversity and forestry

At the Rio Conference the responsibility was put on all nations to respond to threats to the environment, in their own potential self-interests as well as for moral and cultural reasons. The UK response included the publication in 1994 of the *UK Biodiversity Action Plan* (HMSO, 1994). This lists 59 actions which were to be taken, of which several are of direct interest to foresters (Kirby, 1999). These include:

- Continuing to protect ancient semi-natural woodlands and encouraging forms of management which conserve their special characteristics;
- Continuing to encourage the regeneration of woodland;
- Encouraging the restructuring of even-aged forests with a mixture of types and the creation of more varied forests with a mixture of types and ages of trees, including the implementation of forest design plans in State forests;
- Continuing to encourage a steady expansion of woodland and forest cover;
- Encouraging the extension and creation of native woodlands including extending the area of Forestry Commission Caledonian Forest (native pine and broadleaves);
- Supporting the creation of community woodlands near population centres.

The national and international biodiversity commitments will be achieved in part, according to Kirby (1999), by applying the principles of nature conservation management which have been set out by Peterken (1993), through the existing system of protected sites, particularly SSSIs and National Nature Reserves (NNR) and through a new way, the development and implementation of Habitat and Species Actions Plans (HAPs and SAPs).

Selected habitats (both wooded and non-wooded) have been identified by the UK Biodiversity Steering Group as priorities for action under the biodiversity programme (HMSO, 1995). These habitats are those for which the UK has international obligations; or are habitats at risk, such as those with a high rate of decline over the last 20 years; or are habitats which may be functionally critical (*i.e.* areas which are part of a wider ecosystem but which provide feeding areas for particular species); or are important for priority species. Various species were identified as priority species, based on our international commitments to their protection, rarity, whether threatened in the UK or globally, and the degree to which their populations have declined over the last 25 years (Kirby, 1999).

For each of these habitats and species, an Action Plan has been prepared which considers the current status of the habitat and species, what threats it may be under and what is already being done for its conservation. Five types of woodland in Wales are recognised as priority habitats in the *UK Biodiversity Action Plan* (Upland Oakwoods, Upland Mixed Ashwoods, Lowland Parkland and Wood Pasture, Wet Woodland and Lowland Beech and Yew Woodland). Of the 188 rare and declining species in Wales listed in the *UK Biodiversity Action Plan*, 55 are associated with broadleaved woodland (CCW/FC Wales, 1999). The local Biodiversity Action Plan for Snowdonia, in particular, prioritised Upland Oak Woodland, Upland Mixed Ash Woodland and Lowland Wood Pastures and Parklands as those of the highest conservation concern (SNPA, 1999).

The Action Plans set targets for what should be achieved in order to conserve the habitat or species in the long term. For the habitats, the targets are generally concentrated on maintaining the area of existing habitat, restoring areas that have been damaged in the past, and creating new areas, particularly to help off-set the effects of habitat fragmentation (Kirby, 1999). The BAP for Snowdonia emphasised the need to expand the area of Upland Ash and Oak Woodlands and encourages the restoration of their habitats (SNPA, 1999).

To meet the targets set by the *UK Biodiversity Action Plan*, Kirby (1999) recommended the following:

- The condition and management of existing semi-natural woods need to be improved;
- Some ancient broadleaved woods which were replanted with conifers should be restored to native broadleaves; and
- New woods of native species should be created to help buffer existing small sites, provide links between woods and create new patches in areas where are scarce.

5.5 Ancient woodlands

Ancient and natural woodlands in Great Britain were recognised as distinct from recent plantations in the early 19th century (Watkins, 1990) and legislation was enacted to protect them. Rackham (1980) and Peterken (1993) have stressed the distinctive nature of woods that have existed since medieval times, termed ancient woods, some of which may be direct descendants of the former natural forest. These authors contrasted ancient with recent woods that have grown up naturally or been planted on land that was open fields, moor or heath at some time in the last few hundred years. They showed that sites that had been continuously wooded for at least a few centuries (and possibly longer) were more likely to be richer in native plants and animals, and contain more rare and uncommon species than woods of recent origin. This was particularly true for stands that were still semi-natural (composed predominantly of native trees and shrubs) compared to those that had been replanted this century, usually with introduced conifers.

Ancient woodlands are defined as those sites that are believed to have remained under some form of woodland cover continuously since at least AD 1600. They may (and usually have) been cut over many times, for example through treatment as coppices; some have been planted with non-native conifers this century (Spencer and Kirby, 1992). The threshold date of AD 1600 marks the time at which cartographic evidence of the existence of woodland begins to be more widely available and the beginning of the period in which the planting of trees and woods became widespread (Spencer and Kirby, 1992). Recent woods are those that have developed naturally or been planted on land that has been grassland, moorland, heathland or some other type of open vegetation, at some time in the last four hundred years. Semi-natural woods are those composed predominantly of trees and shrubs that are native to the site and have grown up from stump regrowth (as in coppices) or have regenerated naturally as opposed to being planted; they may be on either ancient or recent sites (Spencer and Kirby, 1992).

The continuity of ancient woodland cover makes ancient woodlands very important for specialised woodland plants and animals. Woods that are both ancient and semi-natural have been identified as the most important for nature conservation (Peterken, 1993). Less than half of the broadleaved woodland in Wales is considered to be ancient, and more than half of that present in 1900 has since been cleared or converted to conifer plantation (CCW/FC Wales, 1999).

Ancient woodland in Wales is highly fragmented; 89% of sites are less than 20ha (Table 5.1), whereas less than 0.6% is greater than 100ha (Spencer and Kirby, 1992). The effect of fragmentation, and the typically long narrow valley side woodlands, is that there is very little real woodland interior habitat for specialist woodland species. The size class distribution for ancient woodland in Wales in Table 5.1 graphically illustrates the fragmentation of most ancient woodlands (CCW/FC Wales, 1999).

In the 1980s, there were 6608ha of ancient woodland in the county of Gwynedd (Spencer and Kirby, 1992), and at that time all of the Snowdonia National Park was within Gwynedd. The distribution pattern for Gwynedd (Figure 5.1) is typical of the upland landscapes of the north and west Britain. Ancient sites are concentrated along major river valleys and there are few on the adjacent hills and mountains. The Isle of Anglesey has few ancient woods compared with the rest of Wales or with other low-lying parts of Gwynedd, which may reflect the better agricultural soils found on the island (Spencer and Kirby, 1992).

Ancient woodland is irreplaceable, having taken many centuries to evolve. Many species with poor powers of dispersal have now been identified as characteristic of ancient woodland. Some occur in almost no other habitat, particularly epiphytic lichens (Hodgetts, 1992; cited in Woodland Trust, 2000), saproxylic beetles (Harding and Rose, 1986; cited in Woodland Trust, 2000) and woodland flies (Marren, 1990, cited in Woodland Trust, 2000). A significant number of vascular plants are associated with ancient woodland to a lesser or greater degree (Peterken and Game, 1984). The presence of various other species, including the dormouse (*Muscardinus avellanarius*) (Bright, 1996), can also be correlated more weakly with ancient woodland.

While plantations on ancient woodland sites include stands planted so closely that any semi-natural under storey is suppressed, these woods often continue to support some species characteristic of ancient woodland, particularly along rides, ride margins and in glades as well as dormant within the seed bank (Radford, 1998).

Table 5.1. Size class distribution for ancient woodlands in Wales (source: Spencer and Kirby, 1992).

	Size category (ha)						
	1-5	6-10	11-20	21-50	51-100	101+	Total
Total area of sites (ha)							
Ancient woodland	8 849	8 647	11 524	15 075	6 996	5 484	56 575
ASNW	6 959	5 994	6 712	7 313	2 414	1 266	30 658
Ancient woodland within conservation areas	484	741	1 499	2 237	706	-	5 667
ASNW within conservation areas	447	660	1 394	2 031	584	-	5 116
No. of sites							
Ancient woodland	2 957	1 284	868	519	109	33	5 770
No. of ASNW	2 486	1 072	714	446	96	29	4 843
No. of sites within conservation areas	144	97	102	77	12	-	432

ASNW = ancient semi-natural woodland.

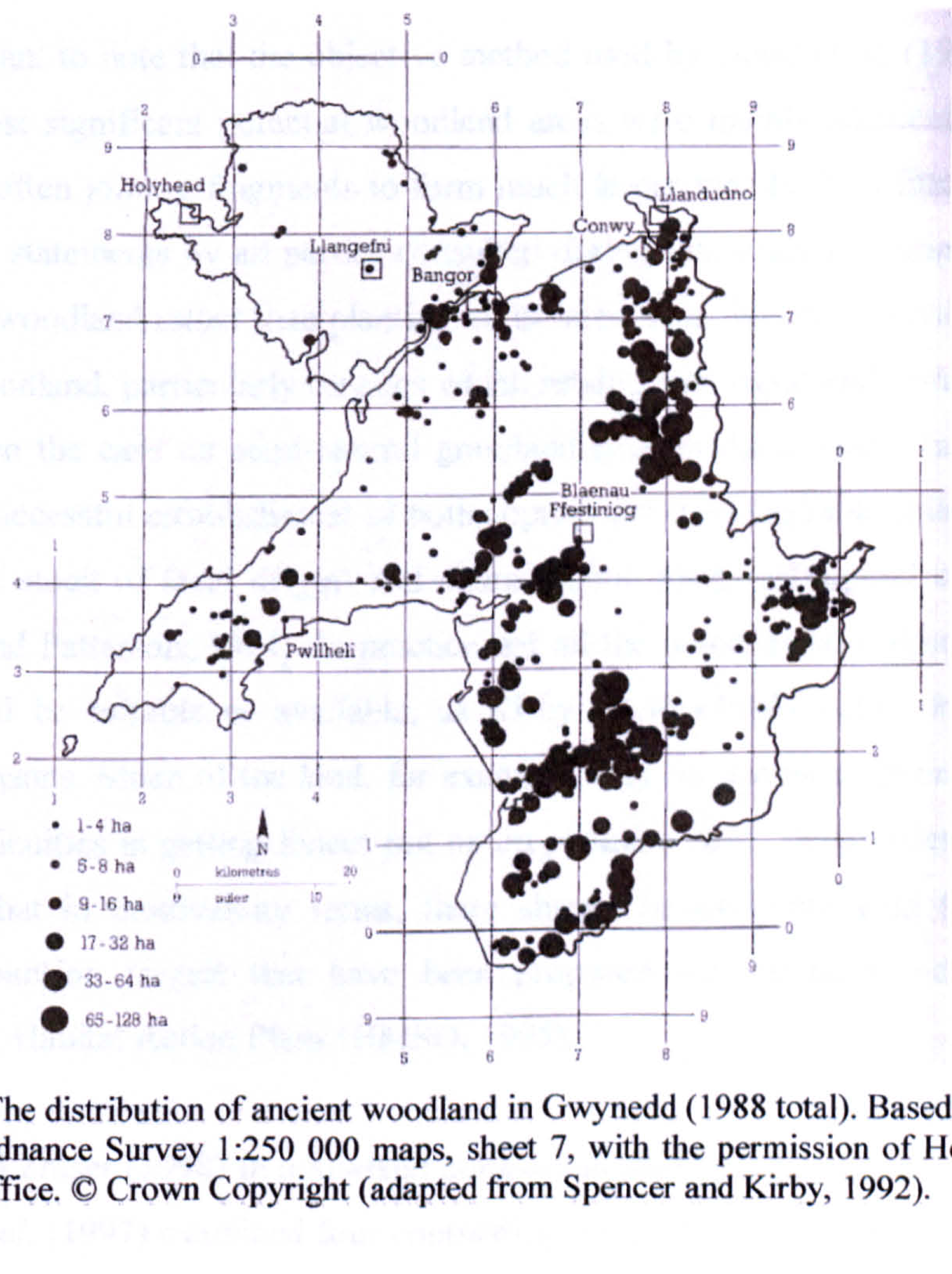


Figure 5.1. The distribution of ancient woodland in Gwynedd (1988 total). Based on the 1984 and 1988 Ordnance Survey 1:250 000 maps, sheet 7, with the permission of Her Majesty's Stationery Office. © Crown Copyright (adapted from Spencer and Kirby, 1992).

5.6 Creating forest habitat networks

5.6.1 Possible approaches

In the English uplands, Good *et al.* (1997) used a land cover map and environmental variables such as aspect, slope, altitude and soil type to identify potential sites for new woodland. The land cover types considered to have some potential for conversion to new woodland, if on suitable soils and between 200 and 600m contours, were: grass heath, moorland grass, mown/grazed turf, meadow/verge/semi-natural grass, ruderal weeds, felled forest, rough/marsh grass, saltmarsh, bracken, tilled land, plus small patches of other semi-natural vegetation such as open/dense shrub heath and open/dense shrub moor less than 5ha in extent. These potential areas for upland woodland expansion were identified from the Institute of Terrestrial Ecology (ITE) land cover map data for two study areas each in four National Parks and one Area of Outstanding Natural Beauty (AONB).

It is important to note that the objective method used by Good *et al.* (1997) showed that the most significant potential woodland areas were mainly adjacent to existing woodland, often joining fragments to form much larger woods. This fitted in ideally with policy statements by all parties consulted during this study favouring extension of existing woodland rather than planting on isolated sites. Woods planted adjacent to existing woodland, particularly on sites which retain some woodland flora and fauna, as it is often the case on semi-natural grassland sites in the uplands, have the best chance of successful establishment of both appropriate trees (suitable soils, seed trees available of stock of local origin) and characteristic plant and animal communities (Rodwell and Patterson, 1994). In practice not all the potential land identified in the study would be suitable or available, as Kirby *et al.* (1999) noted, for social or practical reasons. Much of the land, for example, may be common grazing and there may be difficulties in getting fences put up on common land. Nevertheless, the work suggested that in biodiversity terms, there should be sufficient land to meet the various expansion targets that have been proposed for upland wood under the Biodiversity Habitat Action Plans (HMSO, 1995).

Buckley and Fraser (1998) in a lowland companion study to that done in the uplands by Good *et al.* (1997) examined four contrasting lowland regions of England in order to test their relative capacity to absorb new woodland planting. In each region the main current land use was improved grassland or arable. The woodland cover was fairly low, but the pattern and size of the existing woods varied. They explored how adding a fixed amount of new woodland in different ways (*i.e.* random allocation, corridors between woods and buffer planting) to the four different regions affected landscape measures such as inter-wood distance, mean wood size, total woodland edge and woodland core area.

In a project of the Joint Nature Conservation Committee (JNCC), Purdy and Ferris (1999) demonstrated how a variety of GIS-based woodland datasets can be integrated to improve the ability to respond for advice, under the UK BAP on reversing woodland fragmentation, through the development of 'habitat networks'. Working with the datasets available, they developed a set of criteria to measure the desirability for new woodland creation at a given location, in a 100 x 100 km trial area in England. Criteria were developed that gave higher priority to woodland creation close to existing woodland, so that isolated patches would not be created, and the fragmentation of existing woods was also reduced. Broadleaved ancient semi-natural woodland in SSSI sites and woodlands >5ha were among those criteria which received much higher weighting. Constraints were also applied to exclude those areas where woodland creation could not occur. These included SSSI sites and existing woodland, but the authors suggested that other designated areas, land cover types such as valuable heathland or grassland habitats, and spatial parameters could also be used.

In the same study (Purdy and Ferris, 1999), replanted woodland patches on ancient woodland sites were identified as the priority areas for woodland restoration. For these areas, criteria were developed to measure desirability for restoration of each replanted patch, with an emphasis on being close to existing ancient semi-natural woodland, so that isolated patches would not be prioritised for restoration. Criteria receiving the highest weighting were distance from ancient semi-natural woodland (<30m) and patch size of the replanted patch (>5ha). As Purdy and Ferris (1999) noted, it is necessary to establish priority areas for restoration. In order to do this, existing woodland areas need to be classified on the basis of a number of factors such as species, site type, size, proximity to other woodland patches and conservation status.

For Wales, Good *et al.* (2000) attempted to devise an objective map-based procedure for developing woodland habitat networks as envisaged in the *Wales Woodland Initiative-Strategy* (Anon., 1998a). The study concentrated on the Ystwyth Valley in West Wales, one of Tir Coed's proposed development areas. The main objectives were to assess the extent and connectiveness of ancient woodland and other semi-natural habitat throughout the Ystwyth Valley, develop guidelines for the expansion of woodland taking account of the needs of non-woodland habitats, and provide a means of identifying core woodland areas and assessing the effect of a specific woodland expansion proposal in enhancing the habitat network.

In the Welsh study (Good *et al.* 2000), a brief familiarisation visit was made to the study area at the start of the study to assess the nature of the terrain and of existing woodland cover. Phase I Habitat survey, Nature Conservancy Council (NCC) Upland Survey and Ancient Woodland Inventory (AWI) data were included to produce a land cover map for the Ystwyth Valley. The valley was divided into three distinct zones; the lower, the middle and the upper. In the first two zones, an objective GIS approach was used to define 'core' areas of woodland. These comprised existing deciduous woodland, mixed woodland, conifer woodland on former ancient woodland sites, and areas of ancient woodland which had been lost. Ancient woodland areas which had been lost were included, regardless of the current land cover because it was assumed that it would be considered useful not only to know where these areas were, but also to return them to native woodland cover, where possible. Buffer zones of 25m, 50m and 100m were then created around these core areas. By overlaying the buffer zones with the land cover map, it was possible to assess the area and land cover types which would be affected by each buffer zone scenario. After consultations, these land cover types were divided into potentially suitable or unsuitable for conversion to woodland. The division was primarily based on presumed conservation constraints. The 'potential suitable' category included improved grassland, semi-improved grassland, habitats dominated by bracken and other scrub communities, and Molinia-dominated vegetation land cover types. The 'unsuitable' category included the existing core woodland areas and such habitats as unimproved acid and neutral grassland, Molinia blanket bog, and modified valley mires.

For the upper part of the Ystwyth Valley, however, because of the little existing broadleaved woodland cover, a different approach to creating woodland expansion scenarios was used (Good *et al.* 2000). First, the most suitable areas for woodland expansion were identified. Then, a synoptic assessment was produced based on OS maps, geology and soil maps, the ITE land cover map and maps relating to significant policy and relevant landscape conservation designations. This provided a framework for determining areas appropriate and not appropriate for woodland expansion from the landscape standpoint which subsequently formed the basis for the planning of potential woodland expansion.

It is noteworthy that the approach used by Good *et al.* (2000), involving the drawing of buffer zones of different widths around existing woodland areas, resulted in considerable increases in core woodland area and reduction of fragmentation. In addition, using this method the landscape impacts would be less, as the new woodland would expand upon existing woodland areas rather than creating new visual impacts in currently unwooded terrain.

For Snowdonia, as far as the author of this Thesis is aware, there are only two studies dealing with woodland expansion scenarios in the Park (Armenteras, 1996; Gkaraveli, 1999; Gkaraveli *et al.* 2001). Armenteras (1996) constructed a rule-based model in order to identify potentially suitable areas for broadleaved woodland establishment in the uplands of the National Park which at that time were unwooded. Information on topographic and edaphic factors (elevation, aspect, slope, rock and soil types) was used to identify current bio-physical characteristics that favour broadleaved woodland sites in upland areas of Snowdonia. A model was then built up and interfaced to a GIS in order to simulate the geographical distribution of potential natural forest. The analysis indicated that there was ample land potentially available for woodland expansion which had similar topography, underlying geology and soils to the area at that time forested. In these potential broadleaved establishment areas, the largest area was occupied by upland grass moor, followed secondly by rough pasture and thirdly by improved pasture, upland heath or heath/grass.

Gkaraveli *et al.* (2001), studied the landscape characteristics of the forests and woodlands in Snowdonia using GIS and a spatial pattern analysis programme, FRAGSTATS (McGarigal and Marks, 1994). In order to ameliorate the fragmentation of the broadleaved, mixed forest and scrub habitats, objective GIS simulation techniques were demonstrated in two sites in the National Park of area 10 x 10km. In the first study site, which contained a high proportion of woodlands of different types, the simulation experiment showed that broadleaved woodland on agricultural land and in former coniferous areas would considerably increase the area of core habitat and connectivity between the native woodland fragments. In the second study site, where the woodland habitats were found in a great number of very small and similar-sized patches, especially broadleaves and scrub, simulation results showed that adding a 100m buffer zone around existing woodland would considerably increase native woodland cover and reduce the number of fragments in the landscape.

5.6.2 Approach for this study: Outline

Based on a consideration of the approaches described in the previous section the studies of Purdy and Ferris (1999) and Good *et al.* (2000) appeared to offer the greatest potential for the foundation of a methodology to identify priority areas for the establishment of woodland habitat networks in Snowdonia. These studies consider the requirements for successful woodland expansion from the nature conservation point of view as set out in the *UK BAP* (HMSO, 1994), the *Wales Woodland Initiative-Strategy* (Anon., 1998a) and the more recent *Wales' Woodland Strategy* (National Assembly for Wales, 2001). Both approaches also require existing woodland distribution data, ancient woodland inventory data, conservation status data (*i.e.* SSSIs), and can be implemented within a GIS.

Purdy and Ferris (1999) study, in particular, by developing a set of criteria to measure desirability for new woodland creation at a given location may have the practical advantage that it is seen by landowners as less prescriptive. As Peterken (1996) stated, rather than identifying specific regions, ecological criteria might be used to identify the most appropriate areas for new woodland of native species emphasising the enlargement of existing sites especially in the uplands, the restoration of habitat links in the lowlands between woods, and the creation of woods and other semi-natural habitats along river corridors. In addition the studies by Good *et al.* (2000) and Gkaraveli *et al.* (2001) have shown that for each site within the study area different approaches to woodland expansion (*i.e.* buffer zones, reforestation of agricultural land) may be applied in order to increase woodland area and reduce woodland fragmentation.

Determining which types of land should be prioritised ahead for woodland expansion in Snowdonia from the nature conservation point of view is more straightforward than trying to identify specific regions for woodland establishment, as there may be many factors (*e.g.* suitability of land, availability of land, socio-economic issues) and uncertainties to be considered.

In this study, native woodland expansion is considered in terms of new woodland creation on land that is presently unwooded and restoration of replanted ancient woodlands. Ecological criteria are developed to identify priority areas for the establishment of woodland habitat networks in Snowdonia.

The steps taken to implement this approach are summarised as follows:

- Data on woodland distribution, land cover types, Ancient Woodland Inventory and conservation status were obtained for the study area;
- Criteria that integrate the ideas for a woodland habitat network for Wales were developed for woodland creation and restoration;
- Information on land cover type and conservation status was used to constrain woodland expansion to ensure that woodland management operations are not in conflict with other conservation objectives at the landscape scale and that take account of the need of non-woodland habitats;
- Opportunities for native woodland expansion were identified for both woodland creation and restoration of replanted ancient wood sites; and
- Studies showing how the objective of woodland expansion could be met on a site-by-site basis were presented as examples for woodland expansion in the National Park.

The development and application of this methodology is the subject of the remainder of this Chapter. This approach is different from Purdy and Ferris (1999) study, as that study examined different criteria and GIS methods to suggest broad priorities for woodland creation and the restoration of replanted sites. In this study, with the addition of datasets such as detailed land cover classes, the woodland creation and restoration scenario modelling became more responsive to the regional conditions. In addition, ideas developed in other studies (*e.g.* Good *et al.*, 1997; Good *et al.*, 2000) were integrated by identifying constraints and opportunities for woodland expansion in the landscape of the National Park.

5.7 Data sources and methodological considerations

5.7.1. Datasets used

The range of data available for this study is shown in Table 5.2. The 1980s land cover map of the entire Snowdonia National Park was obtained from an aerial photography/grant survey undertaken for a research project carried out by Silsoe College (Taylor, 1991). The land cover map and the way it was processed are described in section 3.3.1. All climatic variables and how they are produced are described in detail in section 4.2 of this Thesis. Information on conservation status of land in Snowdonia such as SSSIs, NNR and Ramsar sites was kindly provided by CCW. The NNR and Ramsar sites are within the SSSIs in Snowdonia and the latter, therefore, was used as the general designated areas for conservation in the National Park.

Table 5.2. Data sets available for Snowdonia.

Data	Source and format
1980s land cover map	Silsoe College as a SPANS raster file
Ancient Woodland sites	CCW via Forestry Commission as a MapInfo file
SSSI locations NNR locations Ramsar sites	Centre for Ecology and Hydrology via CCW as ARCINFO files
Elevation	School of Agricultural and Forest Sciences via Snowdonia National Park Authority as an IDRISI raster file
Aspect Slope	IDRISI raster files produced from the elevation map
Soil type Geology type	IDRISI raster files produced by Luo (1998) as part of his work
Climatic variables	IDRISI raster files (section 4.2 for full description)

The Ancient Woodland Inventory data were obtained from CCW, but they were originally produced by the Nature Conservancy Council (NCC). NCC started, in 1981, to produce an inventory of ancient woods in Great Britain in order to provide a strong factual basis for woodland nature conservation. The methods adopted had to be relatively simple and quick; detailed historical and field surveys for each site, could not be undertaken, and for many sites little existing information was available. Therefore, the inventories needed to be *inclusive* rather than exclusive (Spencer and Kirby, 1992). An inevitable consequence of this approach was that the inventories could not be completely accurate; for example, some sites would be included that should have been omitted, because the information needed to reach the latter conclusion was not available at the time. Thus, the inventories were (and remain) *provisional* and are subject to periodic revision (Garnett and Richardson, 1989; Spencer and Kirby, 1992). Nevertheless, Ancient Woodland Inventory data have been used in this form in other studies (Purdy and Ferris, 1999; Good *et al.* 2000) and their use could make a major contribution to this project.

The inventories of ancient woodland in England and Wales were produced for each county, following the 1974 boundary revisions, as shown on the OS 1:50000 'Landranger' series of maps (Spencer and Kirby, 1992). Likely areas of ancient woodland in Gwynedd county were identified on the basis of their presence on the OS 1:25000 1st series maps (surveyed 1899-1939), on the earlier 19th century OS 1st Edition maps (published 1835-1840), and on historical records, such as estate maps of small areas between 1760 and 1830, which were used to confirm the presence of sites unclear on the OS 1st Edition (Garnett and Richardson, 1989). All woods greater than 2ha in extent were considered. Field survey information and published material were used in the compilation of each country inventory as a guide to the current state (semi-natural or plantation) and extent of a wood. For each site believed to be of ancient origin from the historical, cartographical and field survey evidence, its extent and location, the area of semi-natural and plantation woodland within each site and the area that had been cleared to other land uses over the last 50 years were recorded (Spencer and Kirby, 1992). The greater part of the data collection for the report on Gwynedd's ancient woodland was carried out in 1983 by Sarah Garnett. The report produced in 1989 (Garnett and Richardson, 1989) was a refinement of that original study.

5.7.2 Data editing

Prior to any analyses being undertaken, a considerable amount of time was spent on examining the datasets shown in Table 5.2, and then converting and editing them as needed to allow analysis in IDRISI v.32 rel.2.0 (Eastman, 2001).

The 1980s land cover map for Snowdonia was obtained from Silsoe College as a SPANS raster map with a 20m pixel resolution (Taylor, 1991). It was initially converted to IDRISI v.2.0 GIS format and then to IDRISI v.32 rel.2.0 for this study, as the new version of IDRISI became available this year. The conversion produced a raster map of a 19.89m pixel resolution. This was a result of conversion of maps from one GIS to another. The resolution of this map (19.89m) was used as the basis for all the raster files produced in this study.

The ancient woodland site data were provided in MapInfo format as a group of polygons for the whole of Wales and therefore needed editing to make them useful in analysis. In MapInfo GIS v.6.0 all polygons of ancient woodland outside Snowdonia were erased using the SNP boundary. The resulting file was exported to CartaLinx v.1.2 software (Hagan and Eastman, 1999), it was then carefully checked, and subsequently exported to IDRISI GIS as a vector file containing polygons. The vector file was then converted to a raster image (POLYRAS function in IDRISI) of 19.89m pixel resolution including the ancient replanted woodland (AWR) and ancient semi-natural woodland (ASNW) categories.

SSSI, NNR and Ramsar site polygons for the whole of Wales were obtained in ARCINFO format and needed further editing. The files were imported into MAPMAKER-PRO software (a demo of the software was obtained from the internet) and then exported as ArcView Shape files which can be read by CartaLinx software. The ArcView shape files were imported into CartaLinx programme and all the polygons were checked, assigned a unique number, and exported to IDRISI as vector polygon files. In IDRISI, the vector files were converted to raster images with POLYRAS module using as parameters those of the 1980s land cover map of Snowdoina. The resulting raster images were then overlayed with a SNP mask (an image where all cells within Snowdonia have a value of 1 and elsewhere 0) to produce raster images of all SSSI, NNR and Ramsar sites within the National Park.

The elevation, aspect, slope, soil and geology type, and climatic maps were in IDRISI format and did not require conversion or further editing.

5.7.3 Woodland Creation Model

At the beginning of this study, summary statistics that describe the study area were produced from the datasets shown in Table 5.2. The 1980s land cover map was overlaid with the maps showing the ancient woodland and SSSI sites using the CROSSTAB routine in IDRISI. This made it possible to identify those woodland areas that are believed to be ancient and have some statutory conservation status such as SSSIs.

5.7.3.1 Criteria

Working with the datasets available, a set of ecological criteria were developed to identify priority areas for the establishment of woodland habitat networks in Snowdonia. These criteria were developed so as to take account of the requirements for successful woodland expansion from the nature conservation point of view and specific policy aims (*e.g.* HMSO, 1994; Anon., 1998a; National Assembly for Wales, 2001):

1. Retain existing woods;
2. Expand existing woods by creating new woodland adjacent to existing ones;
3. Increase the area of native woodlands, targeting extension and connection of existing woods and increase in the core area of native woodland habitats;
4. Create woods that link and protect the irreplaceable remnants of ancient semi-natural woodlands;
5. Create native woods on sites that have been cleared of ancient woodland cover in the recent past;
6. Generate core forest areas that form the 'nodes' within the woodland habitat network;
7. Integrate plantation forests and semi-natural woodland; and
8. Recognise the complementary needs of other habitats.

The criteria developed for this woodland expansion modelling (Table 5.3) give higher priority to ancient semi-natural woodlands, especially those within SSSIs, and to woodland creation close to existing woodland. Thus the high biodiversity value of ancient woodland is emphasised, also the creation of links between the presently fragmented woodlands, while the creation of isolated patches would be avoided. Those woodlands within SSSIs have a high value as they may be seen as core forest areas that form the 'nodes' within the woodland habitat network and as areas with a greater likelihood of longer-term survival. In addition, comparatively recent broadleaved and scrub woods received a high value as some of these woods in Snowdonia are long-established in areas of predominantly intensive agriculture and are likely to have developed rich and varied edge communities.

Table 5.3. Criteria and their weightings of importance for new woodland creation in Snowdonia. Based on the weightings of importance (0-10 scale) given for each criterion, weights for each criterion were derived manually so as they all summed to one (0-1 scale).

Criteria		Weighting of importance	
		0-10 scale	0-1 scale
Woodland type/Conservation status	ASNW BL SSSI	10	0.1274
	ASNW BL	8	0.1019
	ASNW Scrub SSSI	6	0.0764
	ASNW Scrub	5	0.0637
	ASNW Mix SSSI	4	0.0510
	ASNW Mix	3	0.0382
	ASNW Conifer (SSSI or not)	2	0.0255
	ASNW Other (SSSI or not)	2	0.0255
	BL SSSI	6	0.0764
	BL	4	0.0510
	Scrub SSSI	4	0.0510
	Scrub	3	0.0382
	Mix SSSI	3	0.0382
	Mix	2	0.0255
	Conifer (SSSI or not)	1	0.0127
	Other (SSSI or not)	0.5	0.0063
Distance	Distance from ASNW sites recorded as woodlands	5	0.0637
	Distance from BL	4	0.0510
	Distance from Scrub	3	0.0382
	Distance from Mix	2	0.0255
	Distance from Conifer	1	0.0127
Total			1.0000

Other = clear felled/new plantings and all other land cover classes which were mapped as ancient semi-natural woodland (ASNW) or ancient woodland replanted (AWR) in the 1980s land cover map. BL = bloadleaves; Mix = mixed woodland.

The datasets in Table 5.2 were combined to produce raster images for each criterion in Table 5.3. The criteria were then used to produce the *Woodland Creation Model* using the IDRISI macro Modeller, a graphic modelling environment that may assemble and run multi-step analyses[2]. Constructing a model in Macro Modeller involves placing symbols for data files and modules on a special workspace, the graphic page, then linking these model elements with connectors. Figure 5.2 shows a simple sub-model created for the first distance criterion. Sub-models are user-constructed models that are subsequently encapsulated into a single command element. Models are saved to an IDRISI Macro Model file (*.imm* extension). This file preserves all aspects of the model, including the graphic layout. The graphic description of the model may be copied (as a *.bmp* file) to the operating system clipboard then pasted into other word processing and graphics software. All sub-models within the *Woodland Creation Model* are presented in Appendix 3.

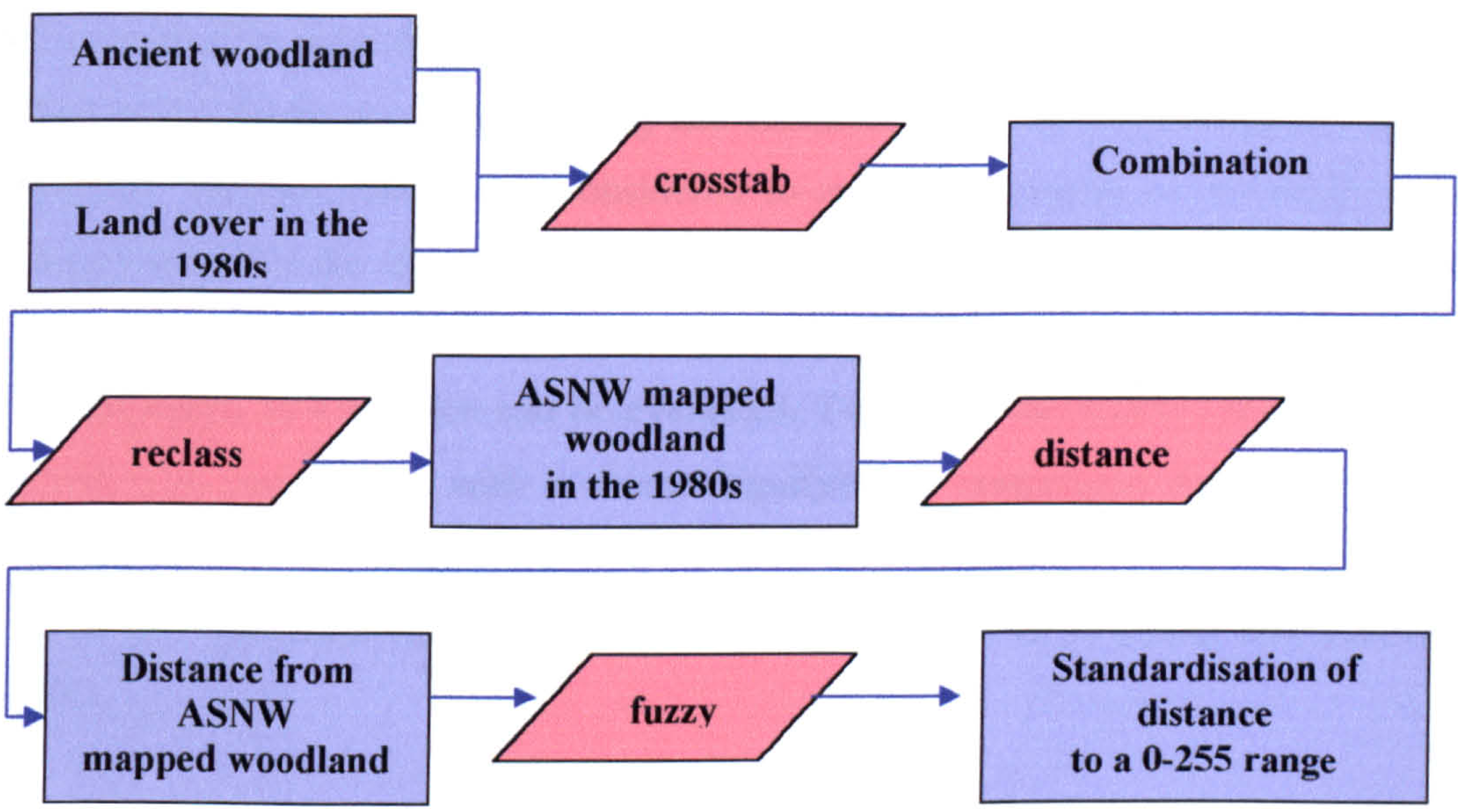


Figure 5.2. Sub-model created for the first distance criterion in the *Woodland Creation Model*. The blue boxes refer to raster images and the red ones to modules in IDRISI GIS.

5.7.3.2 Multi-criteria evaluation

In this study, the IDRISI GIS was used as a decision support system. Multi-criteria evaluation (MCE module) is a method for assessing and aggregating many criteria. MCE computes a multi-criteria evaluation image by means of either a Boolean

[2] This was made available in the most recent release of IDRISI GIS.

analysis, Weighted Linear Combination (WLC) or Ordered Weighted Averaging (OWA) of factor images. WLC was used for this work because it not only allows us to retain all of the variability of our continuous data, but also gives us the ability to have our factors trade off with each other (Eastman, 2001). In Weighted Linear Combination, continuous criteria (factors) are standardised to a common numeric range, and then combined by weighted averaging. The result is a continuous mapping of suitability, that may then be masked by one or more Boolean constraints to accommodate qualitative criteria, and finally thresholded to yield a final decision (Jiang and Eastman, 2000).

Weighted Linear Combination requires fuzzy factors; factors that are standardised to a byte-level range between 0-255. The 'Fuzzy' concept, in Weighted Linear Combination, is used to define those areas that are suitable and to define the boundary between suitable and unsuitable for the factors. Fuzzy set theory has not uncommonly been applied in multi-criteria decision making (Burrough 1989; Wang *et al.* 1990; Smith 1992; Xiang *et al.* 1992; Jiang and Eastman 2000). In most decision making processes, multiple criteria are considered to assess the degree of suitability each location bears to the allocation under consideration. Each criterion chosen by the analyst thus constitutes direct or indirect evidence, based on which fuzzy membership (or suitability) of a location can be evaluated. Two kinds of criteria are recognised, *factors* and *constraints*, with a factor signifying a continuous degree of fuzzy membership (in the range of 0-1 or 0-255), and constraints acting to limit the alternatives altogether (*i.e.* fuzzy membership is either 0 or 1) (Jiang and Eastman 2000).

Firstly, each of the criteria in Table 5.3 was standardised to a continuous scale of suitability from 0 (the least suitable) to 255 (the most suitable). Standardising categorical data, such as the woodland type and conservation status criteria in Table 5.3, amounts to giving a subjective rating (from 0 to 255) to each category based on some knowledge. The images produced for each categorical criterion were reclassified in order to be rescaled into the range 0-255. The rating of 255 was given to all areas representing woodland type/conservation status data. The distance factors were automatically rescaled using the linear monotically decreasing function in the module FUZZY. This function rescaled the measures of relative distance from the woodlands to a range of suitability where the greatest distance has the lowest suitability score (0) and the least distance has the highest suitability score (255).

Weighted Linear Combination procedure, in the module MCE of IDRISI, is accomplished by multiplying each standardised factor by its corresponding weight and then adding each factor together. The ability to give different relative weights to each of the factors in the aggregation process is one of the advantages of the Weighted Linear Combination method. Factor weights, sometimes called tradeoff weights, are assigned to each factor and indicate a factor's importance relative to all other factors, and they control how factors will trade off with each other (Eastman, 1997). Factor weights are given for each factor such that all factor weights, for a set of factors, sum to one. The module WEIGHT in IDRISI, which utilises a pairwise comparison technique, can be used to develop a set of factor weights. However, the current maximum number of variables accepted in this module is 15 (21 factors used in this study), so another way to develop these weights was applied here. Based on the weightings of importance (0-10 scale) given for each criterion in Table 5.3, weights for each factor were derived manually so as they all summed to one (Table 5.3).

5.7.3.3 Constraints

The last step in the WLC analysis, once the factor weights are summed, was to multiply all Boolean constraints[3] on woodland creation to mask out those areas that are not suitable to any degree. The constraints applied to this study were as follows:

1. Existing woodlands;
2. Areas that cannot be planted, such as SSSI designated areas, important non-wooded semi-natural habitats and built-up areas;
3. No woodland creation within a buffer zone of 200m around existing important for conservation non-wooded semi-natural habitats to allow for natural regeneration of the non-wooded habitat.

To identify those non-wooded semi-natural habitats that are important for conservation in the landscape of the National Park, a list of the 1980s land cover types in Snowdonia was given to some of the University's staff with special interest and

[3] Images of 1's and 0's with all areas not suitable for woodland creation having a value of 0 and elsewhere 1.

good knowledge on the subject. After discussions, the land cover types were divided into groups according to whether they were considered to be potentially suitable or unsuitable for conversion to woodland. This division was based primarily on presumed nature conservation constraints. It was realised, however, that other constraints (landscape, agri-economic) may be of considerable significance in determining whether land is made available for woodland expansion in particular cases.

After running the MCE module in IDRISI with all the 21 criteria, their weights and the 3 constraints, the final result was a suitability map in byte binary form with values ranging from 0-255. The raster image was then reclassified into suitability classes namely high, moderate, low and not suitable at any degree (constraints). This was done by arbitrarily thresholding the suitability map into these classes such that, for instance, only areas with the highest suitability were classified into the high suitability class.

5.7.3.4 Opportunities for woodland creation

Taking account of the constraints on woodland creation there could still be opportunities for native woodland expansion in the National Park. These could arise, for example, on sites that have been cleared of ancient woodland cover in the recent past. The location of cleared ancient woodland (AWC) in Snowdonia is shown in the Ancient Woodland Inventory sheets for Gwynedd county (Garnett and Richardson, 1989). These map sheets were reproduced from the OS 1:50000 Landranger Series which were last fully revised between 1965 and 1977. Ancient semi-natural woodland, replanted woodland and sites which have been cleared since the production of the First Series OS 1:25000 maps are all outlined on these maps.

The report for Gwynedd county containing the Ancient Woodland Inventory sheets, originally produced from the Nature Conservancy Council, was given from CCW. From the map sheets, the boundaries of ancient woodland cleared were digitised using the CartaLinx v1.2 software (Hagan and Eastman, 1999). The resulting ancient woodland cleared boundaries were combined with the ancient woodland replanted and ancient semi-natural woodland boundaries given by CCW (5.7.2 section) to check for any inconsistent boundaries. Although these features should match, when combined together some inconsistencies were produced such as duplicate arcs. In addition, when the ancient replanted and ancient semi-natural woodland polygons were checked with those in the map sheets of the report for Gwynedd county, it was noticed that a few ancient woodland sites had not been digitised. This problem is difficult to avoid, as the data sets have originated from different sources, having been digitised by different people, so not only are the boundaries different, but it is not known which boundaries are correct (Purdy and Ferris, 1999). Similar inconsistencies were noticed in other studies such as those of Purdy and Ferris (1999) and Good *et al.* (2000).

Those ancient woodland polygons (ancient replanted and ancient semi-natural woodland) missing from the data set received from CCW were digitised from the report for Gwynedd county (Garnett and Richardson, 1989) and were combined with the other ancient replanted, semi-natural and cleared woodland polygons. The ancient woodland boundaries were further edited to remove any inconsistencies resulting from the combined features. The resulting vector file containing all the polygons of ancient replanted, semi-natural and cleared woodland sites in Snowdonia was converted to a raster image (19.89m pixel resolution) using POLYRAS routine in IDRISI. This was the map used in the woodland expansion and restoration modelling.

Former ancient woodland areas which have been lost in Snowdonia over the past century were examined to determine their current land cover types. It was assumed that it would be considered desirable not only to know where these areas were, but also to return them to native woodland cover where possible. These sites could be considered as the first priority for woodland creation especially if they had a high suitability value in the suitability map for woodland creation.

5.7.4. Woodland Restoration Model

Using the Ancient Woodland Inventory- data, the replanted woodland patches on ancient woodland sites were identified. These could be then prioritised ahead of those patches that are on secondary sites (Purdy and Ferris, 1999). However, priorities should be set among patches on ancient woodland sites. This could be done on the basis of a set of criteria and a combination of site characteristics.

5.7.4.1 Criteria

Working with the data sets available for Snowdonia (Table 5.2), a set of criteria were developed for this woodland restoration modelling (Table 5.4). The criteria give higher priority to those ancient woodland replanted sites which are close to existing ancient semi-natural stands, so that isolated patches would not be prioritised for restoration. Ancient replanted sites within SSSIs have a higher value than those that are not. They were not, however, heavily weighted as it is not always the case that SSSIs occupy land which is most important for conservation; sometimes they were designated on the best available site at the time. In addition, replanted ancient woodland sites consisting of broadleaved and scrub species received a higher value than those of mixed forest (conifers with broadleaves), pure conifers or other habitats as these sites are generally easier to restore.

Raster images were produced for each criterion in Table 5.4. The criteria were subsequently used to create the *Woodland Restoration Model* using the Macro Modeller in IDRISI, as it was described in 5.7.3.1. sub-section. All the sub-models within the *Woodland Restoration Model* are presented in Appendix 3.

The next stage was to identify priority areas within the ancient woodland replanted sites. As the locations of the ancient woodland replanted sites were known and had precise polygons, it was possible to give a value to every site of these polygons (to score each site), rather than creating a general suitability map as with the *Woodland Creation Model.* All raster images representing each criterion were added together (OVERLAY module in IDRISI), so as all weights given to each criterion (Table 5.4) were summed together. In the resulted image, each site within the ancient woodland replanted polygons had a value ranging from 8 (the lowest score a site could have) to 16 (the highest score a site could have) representing the least suitable and most suitable sites for woodland restoration respectively.

5.7.4.2. ASNW site characteristics

The maps showing the topography (altitude, aspect, slope), soil, geology and climate (temperature, rainfall) classes for Snowdonia were overlaid in turn with the map showing the distribution of existing ancient semi-natural stands recorded as woodland in the 1980s land cover map. Data were then obtained showing the amount of ancient

Table 5.4. Criteria and their weights of importance for woodland restoration.

Criteria			**Weights**
Distance from ASNW sites recorded as woodlands		Proportion (%) of AWR within this distance	
	< 300m	40.44	6
	300-900m	34.75	5
	> 900m	24.81	4
Designation			
	SSSI		5
	non-SSSI		3
Woodland type			
	BL		5
	Scrub		4
	Mix		3
	Conifer		2
	Other		1

Other = clear felled/new plantings and all other land cover classes which were mapped as ancient semi-natural woodland (ASNW) or ancient woodland replanted (AWR) in the 1980s land cover map. BL = bloadleaves; Mix = mixed woodland.

semi-natural woodland within each of the classes. Using these data, the environmental variable classes having the most influence on occurrence of existing ancient semi-natural woodland sites were used to create a map of potential areas for woodland expansion having a similar combination of site characteristics. This was overlaid upon the map showing the woodland restoration scores for each site within the ancient woodland replanted polygons to produce a map of potential areas for woodland restoration within the replanted ancient sites having similar site characteristics. These areas could be considered as the opportunity sites for woodland restoration as they share similar site characteristics with those of ancient semi-natural stands. These areas could also be prioritised ahead of those sites that do not have a similar combination of site characteristics with the ancient semi-natural woodland areas.

5.8 Results of analyses

5.8.1 Current woodland status

In Snowdonia, about 5 768ha of land are believed to be ancient woodland; 2 820ha of ASNW and 2 948ha of AWR (Table 5.5). More broadleaved and scrub woodland are in the semi-natural stands (Table 5.6). Coniferous, mixed and clear felled woodland are, as expected, predominantly within the ancient replanted category. Digitising the boundaries of the ancient woodland sites that have been lost and overlaying the map produced with the land cover map, made it possible to identify the present land cover of these sites. 52% of the AWC sites is presently occupied by woodlands, predominantly broadleaves, and the remaining 48% by other habitats (Table 5.6).

With the currently available data, it was possible to identify those woodland areas that have some statutory conservation status such as SSSIs. Only 5% of the SSSIs consists of woodlands. The bulk of the ancient woodland in SSSIs is semi-natural. ASNW represents 7% of the total woodland area in Snowdonia (Table5.5), and ASNW in SSSIs represents 48% of the woodland SSSI area (Table 5.7). This could indicate a reasonable representation of ancient semi-natural woodland relative to non-ASNW. SSSI woodland is, as expected, predominantly broadleaved (73% of the woodland SSSI area), with conifers present at only a low average stand size (10% of the woodland SSSI area) (Table 5.8).

Figures 5.3 maps the ancient woodland sites in Snowdonia.

Table 5.5. Woodland status in Snowdonia.

	Land area (ha)	Total woodland area (ha)	ASNW (ha)	AWR (ha)	AWC (ha)
Snowdonia	214 162	38 831.92	2 819.74	2 948.19	252.90
(%)		100.00	7.26	7.59	0.65

ASNW=ancient semi-natural woodland; AWR=ancient woodland replanted; AWC=ancient woodland cleared.

Table 5.6. Ancient woodland sites in Snowdonia.

Woodland Type	Ancient Woodland					
	ASNW area		AWR area		AWC area	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Broadleaves	1 950.54	69.17	448.07	15.19	83.34	32.95
Conifers	224.93	7.97	1 680.11	56.99	19.82	7.84
Mixed Forest	123.90	4.39	358.09	12.15	12.34	4.88
Scrub	57.22	2.05	17.09	0.58	10.21	4.04
Clear felled/New plantings	30.91	1.09	302.17	10.25	6.57	2.60
Total woodland	2 387.50	84.67	2 805.53	95.16	132.28	52.31
Non-woodland	432.24	15.33	142.66	4.84	120.62	47.69
Total	2 819.74	100.00	2 948.19	100.00	252.90	100.00

ASNW=ancient semi-natural woodland; AWR=ancient woodland replanted; AWC=ancient woodland cleared.

Table 5.7. SSSI sites in Snowdonia.

	No. of SSSIs	SSSI area (ha)	Woodland SSSI area (ha)	ASNW SSSI area (ha)	AWR SSSI area (ha)	AWC SSSI area (ha)
Snowdonia	119	36 395.79	1 755.73	849.33	120.93	36.76
(%)			100.00	48.37	6.89	2.09

SSSI=Sites of Special Scientific Interest; ASNW=ancient semi-natural woodland; AWR=ancient woodland replanted; AWC=ancient woodland cleared.

Table 5.8. SSSIs composition in Snowdonia.

Woodland Type	SSSI area	
	(ha)	(%)
Broadleaves	1 288.19	73.37
Conifers	177.16	10.10
Mixed Forest	79.06	4.50
Scrub	170.72	9.72
Clear felled/New plantings	40.60	2.31
Total woodland area	1 755.73	100.00
Non-woodland	34 640.06	95.18
Total	36 395.79	100.00

SSSI=Sites of Special Scientific Interest.

5.8.2 Woodland Creation Model

Three constraints on woodland creation were applied to this study. These were the areas of existing woodland, sites that cannot be planted (*e.g.* SSSIs and important non-wooded semi-natural habitats) and buffer zones around important for conservation non-wooded semi-natural habitats to allow for natural regeneration. Table 5.9 shows the current areas of land divided into potentially suitable and unsuitable for conversion to woodland land cover types.

Of the total area of the National Park of 214 162ha, 8 2894ha (39%) fall into the 'potentially suitable' category and 131 268ha (61%) into the 'unsuitable' category (Table 5.9). Of the 'potentially suitable' category 34 888ha (42%) and 31 584ha (38%) are improved pasture and rough pasture respectively. The only other land cover types in the potentially suitable category with appreciable areas and proportions are clear felled/new plantings (6 356ha, 8%) and bracken land (5 877ha, 7%).

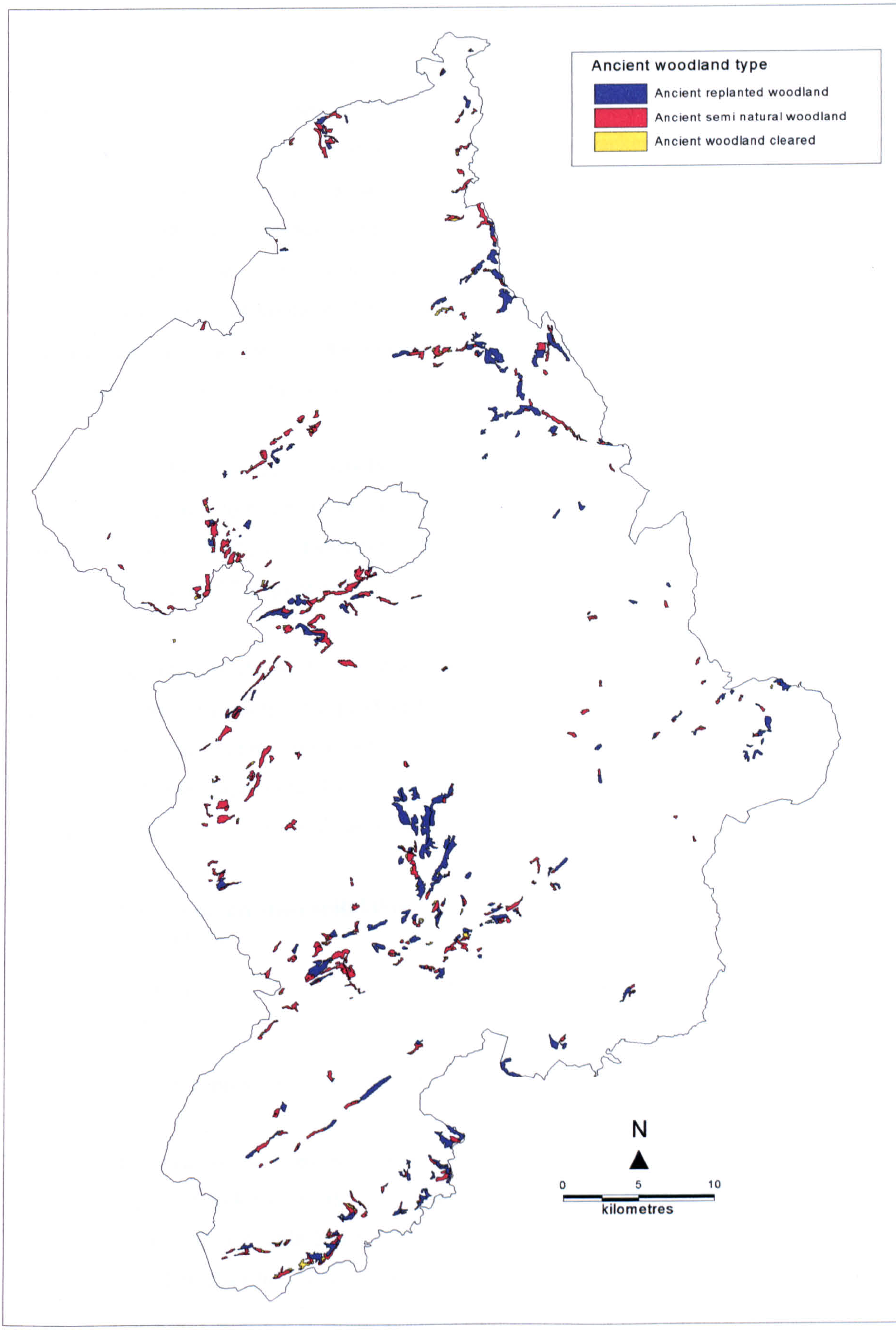


Figure 5.3. Ancient woodland sites in Snowdonia.

All land cover types in Table 5.9 considered potentially suitable for woodland expansion were also sub-divided according to how much of the particular land type might actually be available. For example, some of the bracken, lowland rough grassland, heath/bracken, rough pasture and urban areas land although considered as potentially suitable for woodland expansion, might be unavailable because of its prioritisation for other uses, including in some cases alternative high existing environmental value. Furthermore, there is at least as much opportunity to create open woodland and scrub as forest in the landscape of the National Park, provided grants can be made available for this (Good, 2000).

Running of the MCE module in IDRISI with all the 21 criteria and the 3 constraints produced a map in byte binary form with values within the range 0 to 255. All values within the types of land considered potentially suitable for woodland expansion were in the range from 41-57 (Figure 5.4).

To check the output of the MCE procedure, the module was run with the same factors but without any constraints. This produced higher values ranging from 1-140. Visual inspection revealed that the higher values were those at the ASNW sites which were excluded with the constraints. The raster map was then reclassified into suitability classes by arbitrarily thresholding the values in the map as follows:

Woodland creation suitability	Values
Not suitable	0-41
Low	41-47
Moderate	47-50
High	50-57

The resulted map is presented in Figure 5.5.

Of the total area of the National Park (214 162ha), 3 914ha fall into the 'low suitability' class, 4 3347ha into the 'moderate suitability' class and 1 1247ha into the 'high suitability' class (Table 5.10). Of the 'low suitability' class 1 828ha (47%) is rough pasture, 1 022ha (26%) improved pasture and 851ha (22%) clear felled and new

Table 5.9. Snowdonia National Park-current areas of land in each land cover type divided into types a) considered potentially suitable for woodland expansion, b) considered unsuitable for woodland expansion.

Description of land cover types	Area (ha)	(%)
Land cover types considered **potentially suitable** for woodland expansion		
Clear Felled/New Plantings	6 356.43	7.67
*Bracken	5 877.25	7.09
*Lowland Rough Grassland	465.89	0.56
*Heath/Bracken	1 299.95	1.57
**Mineral Soil (eroded)	31.70	0.04
***Cultivated Land	104.55	0.13
Improved Pasture	34 888.21	42.09
*Rough Pasture	31 584.20	38.10
*Urban Boundary	1 660.50	2.00
***Quarries \ Mineral Workings	39.57	0.05
Derelict Land	316.74	0.38
Unclassified	268.99	0.32
Total	**82 893.98**	**100.00**
Land cover types considered **unsuitable** for woodland expansion		
Broadleaved High Forest	8 272.84	6.30
Coniferous High Forest	21 608.72	16.46
Mixed High Forest	1 221.40	0.93
Scrub	1 372.53	1.05
Upland Heath	14 360.61	10.94
Upland Grassmoor	56 531.72	43.07
Blanket Peat Grassmoor	1 450.68	1.11
Lowland Heath	1.23	0.00
Heath/Grass	13 605.41	10.36
Heath/Blanket Peat	2 454.20	1.87
Peat (eroded)	205.18	0.16
Open Water (coastal\estuarine)	325.88	0.25
Open Water (inland)	2 591.47	1.97
Peat Bog	3.32	0.00
Fresh Water Marsh	45.59	0.03
Salt Marsh	567.27	0.43
Inland Bare Rock	4 407.92	3.35
Sea Cliffs \ Bare Rock	22.95	0.02
Dunes	404.90	0.31
Sandy Beach	1 235.61	0.94
Shingle Beach	26.32	0.02
Mudflats	88.25	0.07
Transport Routes	8.15	0.01
Farmsteads	366.91	0.28
Public Houses \ Garages...etc	88.96	0.07
Total	**131 268.02**	**100.00**
Grand total	**214 162**	

* Some, much will either be prioritised for other uses or will have a high existing environmental value.

** Most, provided it will grow trees satisfactorily.

*** Should be a preference for woodland or scrub, not necessarily forest.

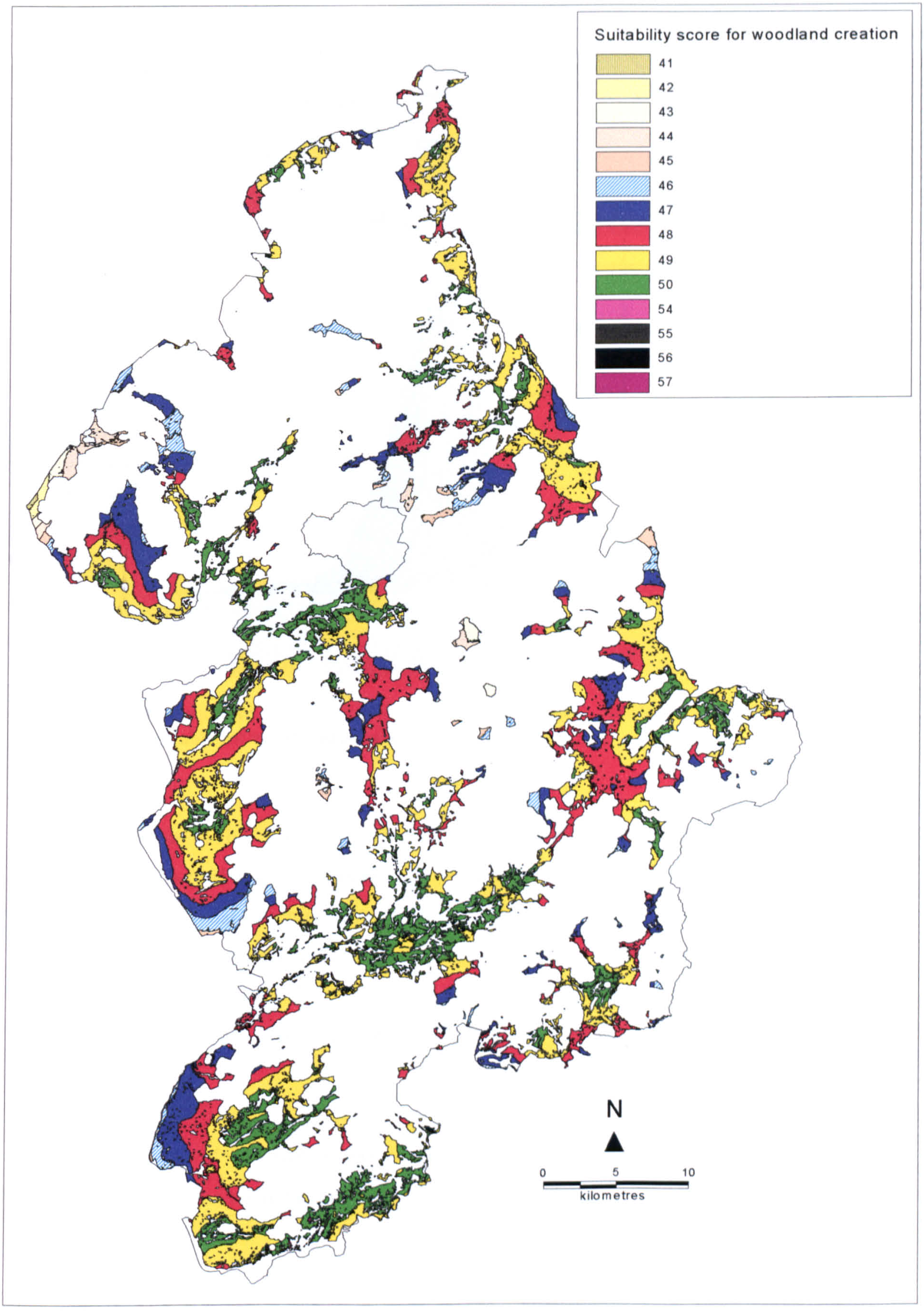


Figure 5.4. Suitability scores a) for sites potentially suited to woodland expansion.

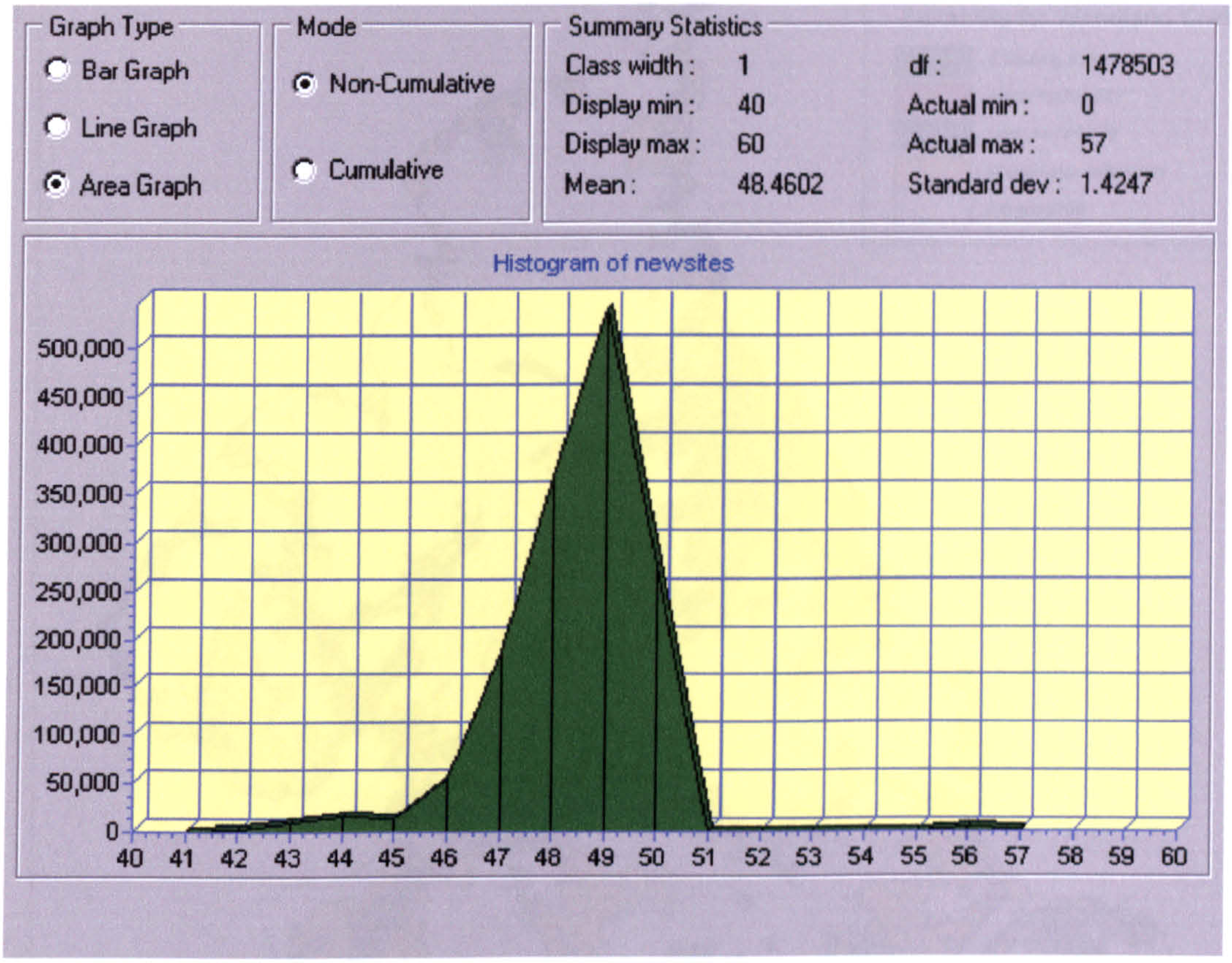


Figure 5.4. Continued. b) of sites (histogram-output from IDRISI GIS) in Snowdonia considered suitable for woodland expansion.

planting areas (Table 5.11). Of the 'moderate suitability' category 2 1981ha (51%) and 15 600ha (36%) are improved and rough pasture respectively. Improved pasture (7 003ha, 62%) and rough pasture (2 718ha, 24%) were also the dominant land cover types in the 'high suitability' class. All suitable areas for woodland creation fall into 0-650m elevation (Table 5.12). This altitudinal limit seems reasonable given the fact that the natural tree line is close to 600m (Hale *et al.*, 1998).

Table 5.10. Area of woodland creation suitability classes.

Woodland creation suitability class	Area (ha)	Proportion (%)
Unsuitable land	155 654.12	72.68
Low	3 913.98	1.83
Moderate	43 347.28	20.24
High	11 246.62	5.25
Total	214 162	100.00

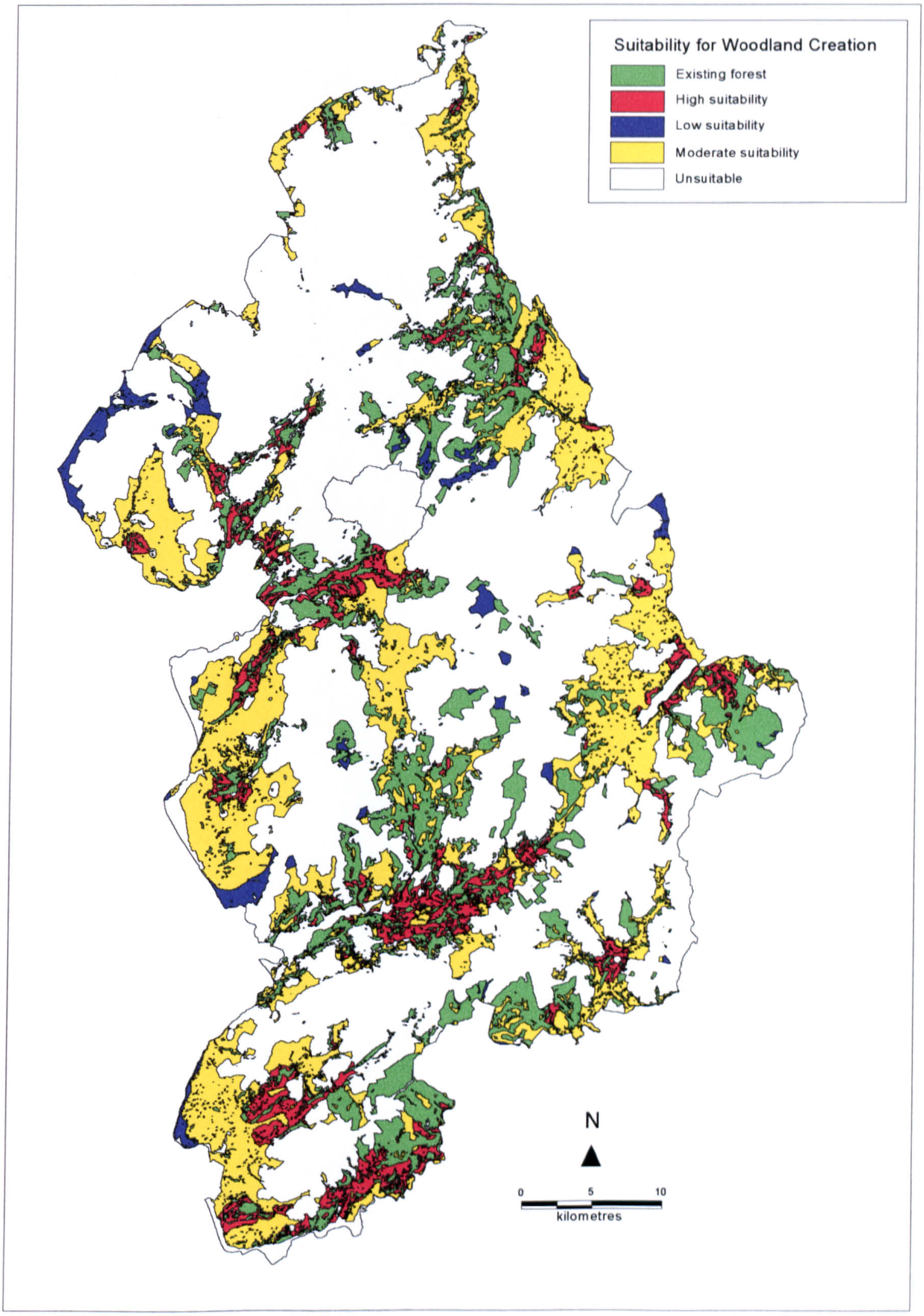


Figure 5.5. Suitability class of each site in Snowdonia for new woodland creation.

Table 5.11. Area of land cover types within each of the woodland creation suitability class.

	Suitability class					
	Low		Moderate		High	
Land cover type	(ha)	(%)	(ha)	(%)	(ha)	(%)
Clear Felled / New Plantings	851.28	21.75	2 873.15	6.63	332.92	2.96
Bracken	62.64	1.60	1 338.93	3.09	737.23	6.55
Lowland Rough Grassland	48.39	1.24	59.79	0.14	0.00	0.00
Heath/Bracken	0.36	0.01	212.79	0.49	88.72	0.79
Mineral Soil (eroded)	0.00	0.00	0.00	0.00	0.00	0.00
Cultivated Land	2.89	0.07	84.29	0.19	13.02	0.12
Improved Pasture	1 022.04	26.11	21 981.26	50.71	7 003.08	62.27
Rough Pasture	1 827.65	46.69	15 600.33	35.99	2 717.55	24.16
Urban Boundary	75.78	1.94	1 086.30	2.51	304.39	2.71
Quarries \ Mineral Workings	8.43	0.22	12.82	0.03	1.15	0.01
Derelict Land	14.40	0.37	61.65	0.14	10.53	0.09
Unclassified	0.12	0.00	35.97	0.08	38.03	0.34
Total	3 913.98	100.00	43 347.28	100.00	11 246.62	100.00

Table 5.12. Area analysis of elevation classes for each woodland creation suitability class.

	Suitability class area (ha)		
Elevation class (m)	Low	Moderate	High
0-50	337.48	5 627.55	2 724.52
50-100	87.10	2 706.55	1 786.02
100-150	321.25	3 961.03	2 273.83
150-200	491.49	6 931.34	1 940.07
200-250	594.54	9 368.79	1 453.53
250-300	616.66	7 908.30	651.00
300-350	529.00	4 259.57	311.36
350-400	340.96	1 601.57	77.28
400-450	325.97	694.22	27.27
450-500	198.69	226.31	1.74
500-550	64.66	58.41	0.00
550-600	4.08	3.56	0.00
600-650	2.10	0.08	0.00
650-1100	0.00	0.00	0.00
Total	3 913.98	43 347.28	11 246.62

Ancient woodland sites that have been cleared since the production of the First Series OS 1:25000 maps might be considered to provide some of the most appropriate opportunities for native woodland expansion in Snowdonia. 52% of the area of these sites is presently occupied by woodland, predominately broadleaves (Table 5.6). Of the remaining 121ha (48%), 35ha (14%) is bracken, 31ha (12%) is improved pasture and 29ha (11%) is rough pasture (Table 5.13). 23% (57ha) of the ancient woodland cleared sites received a high suitability value for woodland creation, whereas 68% (173ha) was classified as not suitable land (Table 5.14). This is due to the fact, however, that the majority of these sites lies within existing woodland area or SSSI sites and important for conservation non-wooded semi-natural habitats (Table 5.15).

Table 5.13. Area analysis of ancient woodland sites cleared since the production of the First Series OS 1:25000.

Land cover type	AWC area (ha)	AWC area (%)
Woodland	132.28	52.31
Upland Heath	2.06	0.81
Upland Grassmoor	6.77	2.68
Bracken	34.63	13.69
Heath/Grass	4.47	1.77
Heath/Bracken	2.89	1.14
Improved Pasture	30.67	12.13
Rough Pasture	28.69	11.34
Open Water (inland)	0.36	0.14
Urban Boundary	7.04	2.78
Derelict land	0.47	0.19
Farmsteads	0.12	0.05
Outside S.N.P.	2.45	0.97
Total	120.62	47.69
Grand total	252.90	100.00

AWC=ancient woodland cleared.

Table 5.14. Suitability area of ancient woodland cleared sites.

	Suitability class area (ha)					
	Outside S.N.P.	Unsuitable	Low	Moderate	High	Total
AWC	2.45	172.97	0.00	20.02	57.46	252.90
(%)	0.97	68.39	0.00	7.92	22.72	100.00

AWC=ancient woodland cleared.

Table 5.15. Status of the ancient woodland cleared sites.

Status	AWC area (ha)	AWC area (%)
Unsuitable land for woodland expansion*	141.95	56.13
SSSIs	36.76	14.54
Within 200m from non-wooded semi-natural habitats	75.54	29.87
Outside S.N.P.	2.45	0.97
Total	252.90	

* As indicated in Table 5.9.

5.8.3 Woodland Restoration Model

The majority of AWR sites (40%) lies at <300m distance from ASNW mapped as woodland in the 1980s land cover map of Snowdonia (Figure 5.7). However, an appreciable proportion of AWR sites (25%) are at a distance greater than 900m from the nearest ASNW area. There are replanted ancient woodland sites even at a distance of 5 000-5 100m from the nearest ASNW (Figure 5.6).

After adding together, in IDRISI, all the maps representing the criteria in the *Woodland Restoration Model*, a raster image was produced showing the restoration score for each site within the AWR patches. The scores ranged from 8 (least suitable sites) to 16 (most suitable sites) (Figure 5.7).

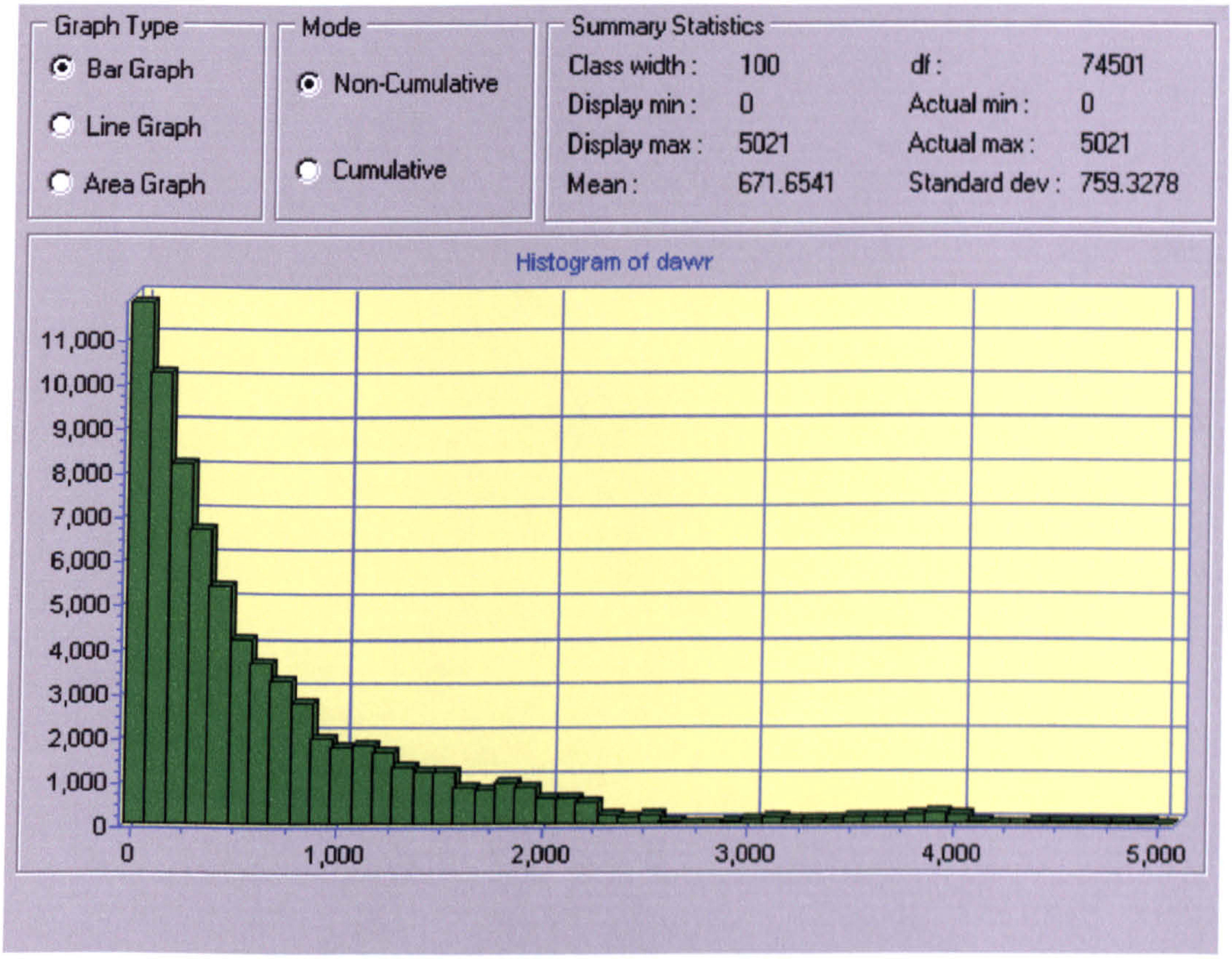


Figure 5.6. Histogram of the distance of ancient woodland replanted areas from ancient semi-natural woodland sites, mapped as woodlands in the 1980s land cover map of Snowdonia, showing the number of replanted cells occupying each of the 100m width classes (output from IDRISI).

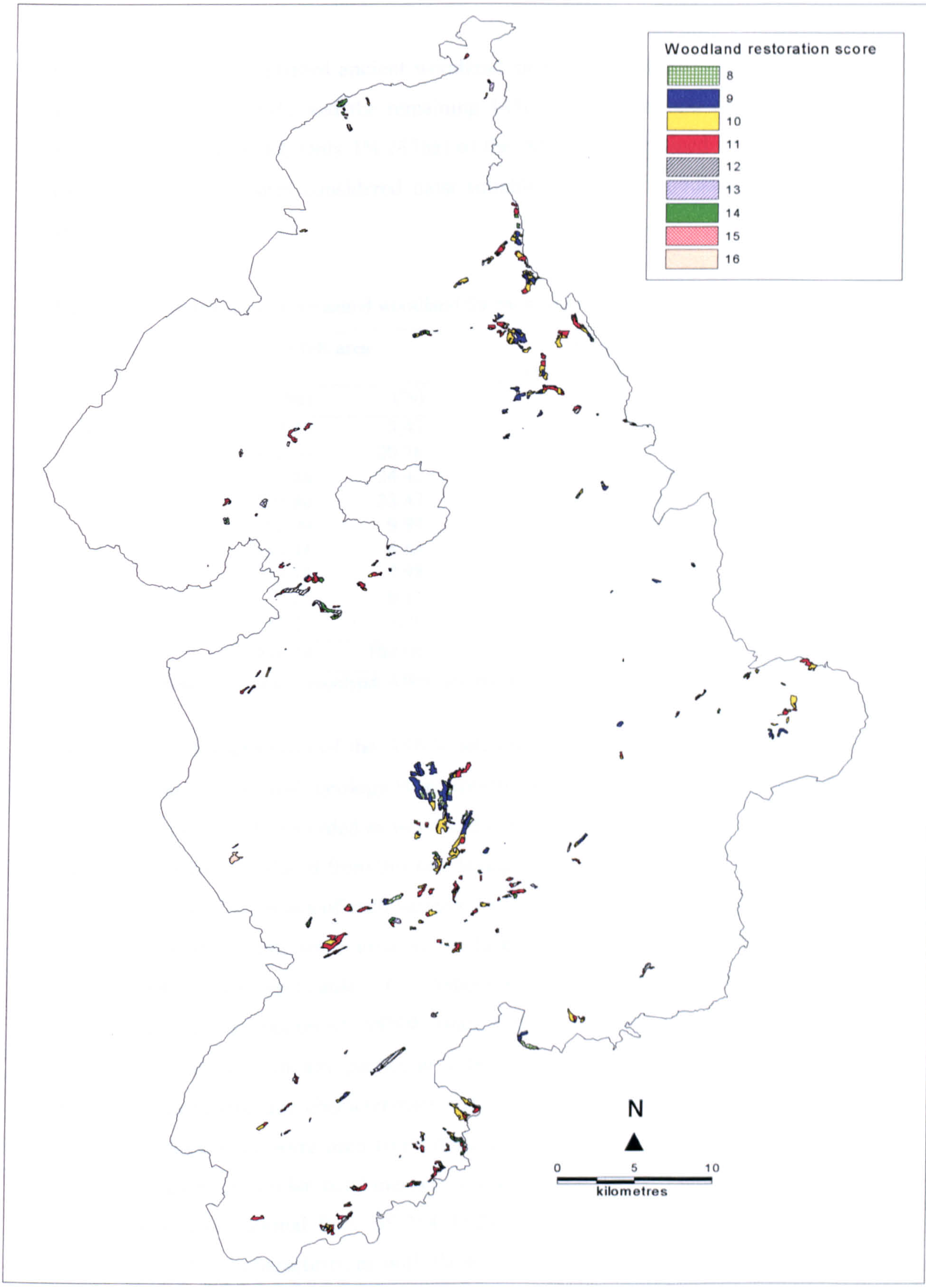


Figure 5.7. Restoration score for each replanted ancient woodland site in Snowdonia.

Of the total area of replanted ancient woodland sites (2 948ha), 86% (2 536ha) had values ranging from 8-12 and the remaining 14% (412ha) obtained values ranging from 13-16 (Table 5.16). Only 1% (37ha) of the AWR sites obtained a value of 16, the score that those sites considered most suitable for native woodland restoration should have.

Table 5.16. Area of ancient replanted woodland for each woodland restoration score.

Woodland restoration score	AWR area		AWR area with similar site characteristics to those of ASNW	
	(ha)	(%)	(ha)	(%)
8	160.15	5.43	157.85	5.35
9	612.10	20.76	599.72	20.34
10	720.06	24.42	702.49	23.83
11	750.80	25.47	719.90	24.42
12	292.99	9.94	292.99	9.94
13	136.44	4.63	136.44	4.63
14	235.14	7.98	231.73	7.86
15	3.24	0.11	3.24	0.11
16	37.27	1.26	37.27	1.26
Total	2 948.19	100.00	2 881.63	98.00

ASNW=ancient semi-natural woodland; AWR=ancient woodland replanted.

The physical characteristics of the ASNW sites were defined by overlaying maps of altitude, aspect, slope, soil, geology type, annual mean temperature and precipitation with the map of ASNW recorded as woodland in the 1980s land cover survey (Taylor, 1991). All the data produced from this overlaying procedure are given in Appendix 3. Using these data, the classes of each variable having the most influence on occurrence of existing ASNW sites were used to produce a matrix indicating the ASNW x environment relationship (Table 5.17). Aspect was not considered of importance in determining the distribution of ASNW since ASNW sites did not seem to have a specific association with any particular aspect class (Appendix 3). The series of decision rules linking site characteristics and climate to the requirements of ASNW existing in Snowdonia were used to produce a map of potential areas for woodland expansion having a similar combination of site characteristics (Figure 5.8). Of the total area of the National Park of 214 162ha, 150 100ha (70%) have a similar combination of site characteristics with those of the ASNW sites. It was mainly the highest elevation areas and some coastal areas that were excluded.

After overlaying the map in Figure 5.8 with that showing the restoration score of each replanted ancient woodland site (Figure 5.7), it was made possible to map the replanted ancient woodland sites having similar site characteristics to those of the semi-natural stands and their score for woodland restoration (Figure 5.9). Of the total area of AWR sites (2 948ha), only 67ha (2%) showed a different combination of site characteristics to those of ancient semi-natural woodland sites. The new areas of AWR sites for each woodland restoration score are given in Table 5.16. No significant differences were indicated.

Table 5.17. Matrix of environmental variable classes having the most influence on occurrence of existing ancient semi-natural woodland sites in Snowdonia.

Variable	Category
Altitude (m)	0-500
Slope (degrees)	0-45
Geology type*	2-12, 14, 16
Soil type*	1, 3-11, 15
Mean annual temperature (^{0}C)	7-10
Mean annual rainfall (mm)	600-3400

*Description of each geology and soil type is given in Appendix 3.

5.9 Discussion of results

5.9.1 Methodology

Before deciding to devise a method for prioritising sites in Snowdonia for the establishment of woodland habitat networks, the requirements set out in the report for the *Wales Woodland Initiative-Strategy* (Anon., 1998a), in CCW's suggestions for a woodland management framework (Latham, 2000), and in the more recent *Wales' Woodland Strategy* (National Assembly for Wales, 2001) were carefully considered. These requirements are summarised in section 5.2 of this study.

Possible approaches were then examined to creating forest habitat networks. It was considered that, rather than identifying specific regions in Snowdonia, ecological criteria could be used to identify the most appropriate areas for new native woodland creation emphasising the requirements for any new woodland as set out in the reports mentioned above. In addition, determining which areas should be prioritised ahead for woodland expansion in the Park using objective ecological criteria was considered more straightforward than trying to identify specific regions for woodland establishment, as this could not provide a generic methodology and there could be many factors to consider such as suitability and availability of land.

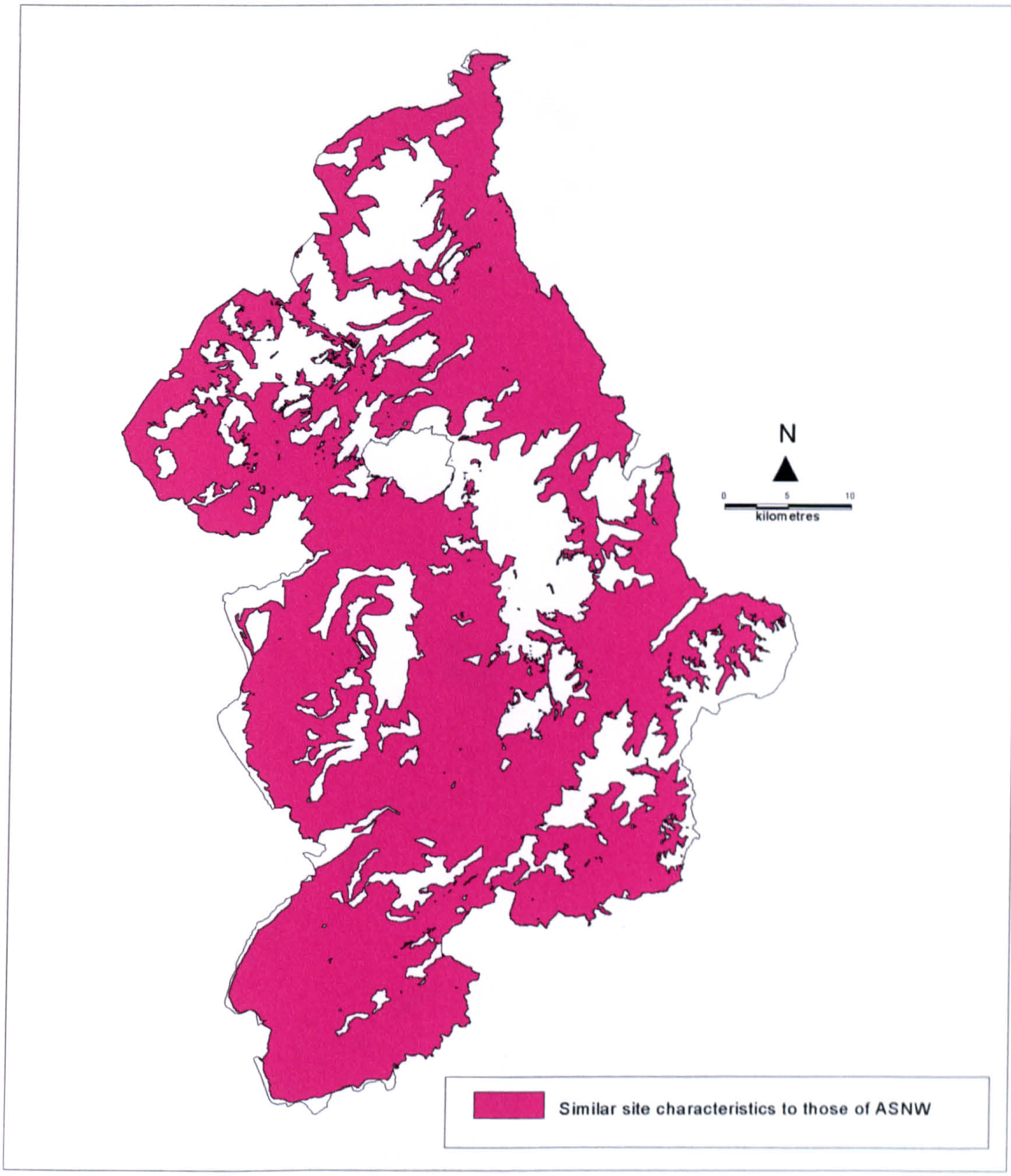


Figure 5.8. Sites in Snowdonia with similar physical and climate characteristics to those of existing ancient semi-natural woodland.

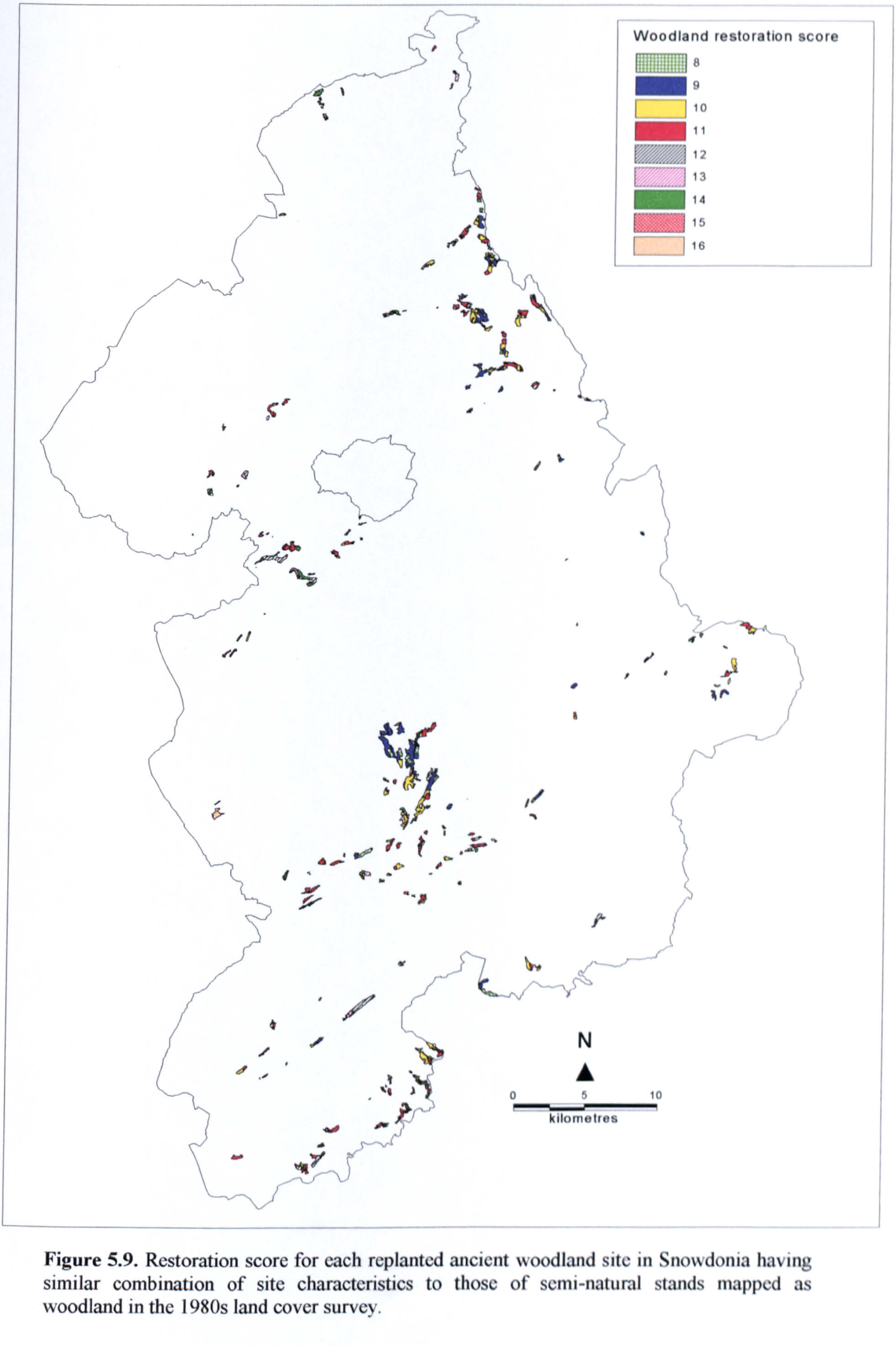


Figure 5.9. Restoration score for each replanted ancient woodland site in Snowdonia having similar combination of site characteristics to those of semi-natural stands mapped as woodland in the 1980s land cover survey.

Ecological criteria were subsequently developed to identify priority areas for native woodland expansion. Constraints on woodland creation were also applied to this study. The land cover map of Snowdonia in the 1980s (Taylor, 1991) was divided into two groups according to whether a land cover type was considered to be potentially suitable or unsuitable for conversion to woodland.

The 'unsuitable' category (Table 5.9) comprises land already wooded, rock, open water, built-up areas and semi-natural habitats that would not normally be considered for conversion to woodland from the nature conservation standpoint because of their existing conservation values. These constraints, however, should not be regarded as prescriptive since there are likely to be situations where the net conservation benefit would be best served by converting semi-natural habitats to woodland (Good *et al.*, 2000). One example might be where conversion would result in the linking of isolated woods to create a substantially enlarged core forest area. Another could be where the current area of native woodland in a district is low whereas the area of habitat which would be replaced is insignificant as a proportion of the total of that habitat in the district. A third example might be where the opportunity arose to expand a woodland of a type which is rare locally or nationally and for which few other opportunities for expansion are likely to occur.

The land cover types included in the 'potentially suitable' for woodland creation category (Table 5.9) are considered generally to have fewer or less severe nature conservation constraints. Although there are no landscape or nature conservation constraints upon conversion of improved pasture land to woodland, there may well be agri-economic constraints. Bracken infested land is more likely to be made available for woodland expansion and as much of it would have carried woodland prior to its clearance in historical times there is likely to be a net ecological gain from its restoration to woodland. There are cases, however, where bracken land has quite high nature conservation value in which case the presumption might be against its conversion to woodland (Good *et al.*, 2000). It seems that in the end local decision will be required to decide which sites should be considered unsuitable or suitable for woodland creation.

A more general constraint to woodland expansion would be the need to avoid damaging sites of cultural or historic significance (*e.g.* archaeological features, former agricultural or woodland boundary features). Woodland expansion should not take place on these sites, but an exception could be made where there was an opportunity to re-establish or expand ancient semi-natural woodland, if this could be achieved without compromising the integrity of the site (Good *et al.*, 2000).

Having prioritised the sites in Snowdonia for native woodland expansion, opportunity areas for both woodland creation and restoration were identified. These could be ancient woodland sites that have been cleared over the past and the replanted ancient woodland areas having physical characteristics matching those of the ancient semi-natural stands. Although the majority of cleared ancient woodland sites are within the constraints area (*e.g.* SSSIs and important semi-natural habitats), there would be a net ecological gain from their conversion to woodland. Furthermore, a site might have a low suitability for woodland creation value or a low restoration score but its known history may suggest that should have a higher value. An example could be an isolated woodland site in the agricultural matrix which has developed rich and varied edge communities. In this case compromises should be made and the suitability or restoration scores should not be taken as prescriptive.

5.9.2. Woodland creation

Of the total area of the National Park about 2% (3914ha) was given a low suitability score, 20% (43347ha) a moderate suitability value and 5% (11247ha) a high suitability score for woodland creation (section 5.8.2.). In total, approximately a quarter of the land in Snowdonia was given a suitability value for woodland expansion by the *Woodland Creation Model.* The dominant land cover types in all suitability classes were improved and rough pasture. In many cases the agricultural value of this land, especially the improved pasture, may be considerable. Thus, any proposal for woodland expansion which involves substantial loss of this type of land is likely to meet farmer and landowner resistance given current farm economics which generally favour livestock production over forestry. Unless there are substantial changes in the EU Common Agricultural Policy which lead to a more equitable return from forestry as compared with agriculture, careful negotiation will be needed on a site-by-site basis if woodland expansion is to be implemented.

In the first two years of the Farm Woodland Scheme, as it is mentioned in Chapter 3, 87% of planting in Wales was with broadleaves, while the mean size of scheme approved was 5.2 ha (Price and Willis, 1994). Species richness tends to increase with woodland area and some studies suggest that there is a threshold area of about 5 ha above which it is more likely that woodland specialist plants may occur (Usher *et al.* 1992). The total area of woodland, however, rather than the individual patch size, may be more important for overall species richness (Kirby *et al.*, 1999). There are circumstances where 10ha spread as five 2ha patches could eventually contain more species than a single 10 ha wood, because the small woods between them span a wider range of soils, slopes and aspects (Peterken and Game, 1984).

The ecological criteria applied to this study give highest priority to ancient woodlands, especially those within SSSIs, and to native woodland expansion close to existing woodland. Ancient woods are indeed richer in species than recent woods (Peterken and Game, 1984). One of the reasons the authors suggested for recent woods remaining poorer is because they are isolated in time from original natural woods and some species of ancient woodlands cannot bridge the isolation in space from refuges that are mostly in ancient woods. The age of forest and thus, its continuity in space and time has been shown to be of prime importance for species richness. This is equally so in the U.K (Peterken and Game, 1984) and Denmark (Lawesson et al. 1998) which have long since lost their original forest cover, in comparison to North America, Eastern Europe and Asia, where old-growth stands can still be found (Peterken, 1996).

The species richness and floristic composition of recent woods developing on former fields, meadows or pastures, are dependent on their proximity to other woods, particularly ancient woodlands, which are the main source of diaspores of typical woodland species (Peterken and Game, 1984; Dzwonko, 1993). Colonization success increases with proximity to ancient woodland, and secondary woodlands contiguous to ancient woodlands may be colonized by many herbaceous species (Peterken and Game, 1984; Grashof-Bokdam and Geertsena, 1998). Recent studies show that migration rates across ancient-recent woodland border-lines usually vary from 0 to 2.5 m/yr for Northeast American and European woodland species (Matlack, 1994;

Honnay *et al.*, 1999b). Distance from the ancient-recent woodland boundary was the single most important factor controlling the number and percentage cover of woodland species in recent woods in Sweden (Brunet and von Oheimb, 1998; Brunet *et al.* 2000). However, the importance of distance to species distributions decreased with increasing stand age as most woodland species gradually colonized the recent woodlands. After 70 years, about 50% of the woodland species present at a site showed complete colonization within 50 m from the ancient woodland border (Brunet *et al.* 2000).

Although recent farm woods are less rich in woodland species than ancient woods, this is not an argument against creating new woodland, unless such creation increases the likelihood of clearance of ancient woodland or diverts resources away from ancient woodland management (Kirby *et al.*, 1999). New woodland can gradually gain woodland specialist species (Webster and Kirby, 1988) and guidance is now available on how to speed up this process (Rodwell and Patterson, 1994; Ferris-Kaan, 1995). Even without special treatment the woodland species content of new woodland is likely to be greater than that of the farmland it has replaced (Kirby *et al.*, 1999).

New woods on farmland in the U.K have mostly been established by planting, but there is now more interest amongst woodland managers in the potential for use of natural colonization, allowing woodland to develop by secondary succession on uncultivated land. Natural succession is thought to have a number of environmental and conservation benefits, which include matching tree species to site, maintaining local genotypes, and the creation of woodlands with more natural appearance (Rodwell and Patterson, 1994). The process of natural colonization to create new farm woodlands is supported by grant aid under the U.K. Forestry Commission's Woodland Grant Scheme (Anon., 1998b). The findings, however, of a study in Hertfordshire (U.K.) suggested that natural regeneration of woodland on farmland can take at least 20-30 years to achieve a complete canopy cover, and that many locally characteristic woodland plants may fail to establish populations even after a century or more (Harmer *et al.*, 2001). They also confirmed the fact that, in small woods where no open spaces persist, the flora of the established woodland is poorer than the flora of precursor vegetation. The study concluded that if native nature conservation is one of the objectives of schemes to establish new farm woodlands, then there is a strong case for ensuring that such woods are large enough to ensure that some open spaces remain permanently. This is likely to require woods of at least 3ha (Peterken and Francis, 1999).

5.9.3. Woodland Restoration

Since the 1930s about 38% of ancient broadleaved woodland has been converted to plantations, predominantly of coniferous species (Radford, 1998). After changes in policy, following the recognition of the importance of ancient woodland, coniferisation has now largely ceased. There is now considerable interest in restoration of replanted sites to their former semi-natural state. Added impetus has come from the Habitat Action Plans that are being developed under the *Biodiversity Action Plan* process, particularly with the introduction of target areas for restoration.

It is necessary to establish priority areas for restoration. This could be done by classifying existing woodland areas on the basis of a number of factors such as species, site type, size proximity to other woodland patches and conservation status (Purdy and Ferris, 1999). In this study, a set of ecological criteria were developed in order to create the *Woodland Restoration Model.* The criteria give higher priority to those replanted ancient woodland sites that consist of broadleaves and scrub species, are within SSSIs, and are close to existing ancient semi-natural woodland so that isolated patches would not be prioritised for restoration.

Of the total area of replanted ancient woodland sites (2 948ha), 2 536ha (86%) were scored from 8-12 (8-16 scale) and the remaining 412ha (14%) from 13-16. The higher the score of a replanted site, the higher its priority for restoration. It is worth noting that 98% (2 881 ha) of the total area of replanted sites showed a similar combination of physical characteristics to those of the semi-natural stands.

In practical terms, we know relatively little about timescales for restoration. Some preliminary research has been undertaken on the rates of recovery of vegetation in restored woods (Radford, 1998), and recommendations have been provided on appropriate restoration techniques (Forestry Commission, 1998). Key factors are likely to be their species complement, proximity to existing ancient woods, and the hostility of the intervening matrix (Purdy and Ferris, 1999).

Radford (1998) examined a small number of selected sites in England and provided preliminary data on ground flora recovery and woody species regeneration after removal of conifers. The results suggested that at least some of the sites where the species characteristic of the semi-natural community, including ancient woodland indicators, persist, and there are low levels of competition from non-woodland species, restoration of semi-natural ground flora could be successful after felling of the conifers. The findings also recommended that some intervention may be required at some sites to remove undesirable species, if the restored sites are to regain a semi-natural tree cover.

5.9.4 Woodland expansion on a site-by-site basis

The results of the *Woodland Creation Model* and the *Woodland Restoration Model* indicated priority areas for new native woodland in Snowdonia. The woodlands of the National Park have been fragmented for centuries. Expanding the woodland resource could help to address this problem in the medium to long term. New woodland can increase the size of woods, provide a buffer between existing woodland and its surroundings to reduce edge effects. It can also reduce the distance from wood to wood, thus increasing the likelihood of spread between woods and the potential for species to migrate through the countryside (Kirby *et al.*, 1999). The extent to which new woodland, however, addresses these issues depends on the size and location of new woods in relation to the existing landscape pattern (Kirby *et al.*, 1999).

The studies of Good *et al.* (2000) and Gkaraveli *et al.* (2001) showed that for each site within the study area different approaches to woodland expansion may be applied in order to increase woodland area and decrease woodland fragmentation. These two studies are presented here as examples showing how the objective of woodland expansion in Snowdonia could be met on a site-by-site basis.

In the Ystwyth Valley in mid-Wales, Good *et al.* (2000) divided the valley into three zones, the lower, the middle and the upper. In the first two zones, buffer zones around existing woodlands were created. These increased substantially the overall area of woodland, increased connectivity between woodlands, and seemed to have little overall impact on the appearance of the landscape. However, as the authors pointed out buffer zones cannot be used to increase woodland cover substantially in areas where existing cover is small, alternative approaches are needed. In the upper part of the Ystwyth Valley, because of the little existing broadleaved woodland cover, a different approach was applied. Appropriate and inappropriate areas for woodland expansion from the landscape standpoint were identified and these sites subsequently formed the basis for the planning of woodland expansion.

In Snowdonia, Gkaraveli (1999) and Gkaraveli *et al.* (2001) demonstrated objective GIS simulation techniques for ameliorating the fragmentation of broadleaves, mixed forest and scrub using two sites in the National Park. In the first study site (Figure 5.10), the expansion of the overall woodland habitat was considered to be the best strategy, because the site contained a high proportion of different types of woodland. It seemed that it was not necessary to minimise the impacts from surrounding land use. In addition, linkage between the three woodland classes was not considered critical, as direct corridors may act as barriers to species of another habitat such as grassland or heathland (Kirby, 1995). The simulation experiment showed that conversion of conifers (including clear-felled areas) to broadleaves (Figure 5.10c) would dramatically increase the broadleaved area and the interior habitat. In contrast, the expansion of broadleaves on agricultural land (Figure 5.10b) would increase habitat area, decrease the number of fragments, suggesting a more continuous habitat and better connectivity between fragments, but with less core area. This results from broadleaved patches being scattered in agricultural land in the lowlands, whereas the majority of conifers exist in larger blocks in the uplands. Gkaraveli *et al.* (2001) suggested that a combination of approaches, increasing broadleaved woodland on agricultural land and in former coniferous areas, would be the most appropriate solution for this site. It is worth noting the priority areas identified for this site by the *Woodland Creation* and *Restoration Models* (Figure 5.11). A visit to the site was made to gain a better impression of the woodlands in the actual landscape. The approaches described by Gkaraveli *et al.*, (2001) could be used to increase native woodland on agricultural land (Plate 5.1) and restore broadleaved cover in coniferous areas after felling (Plate 5.2).

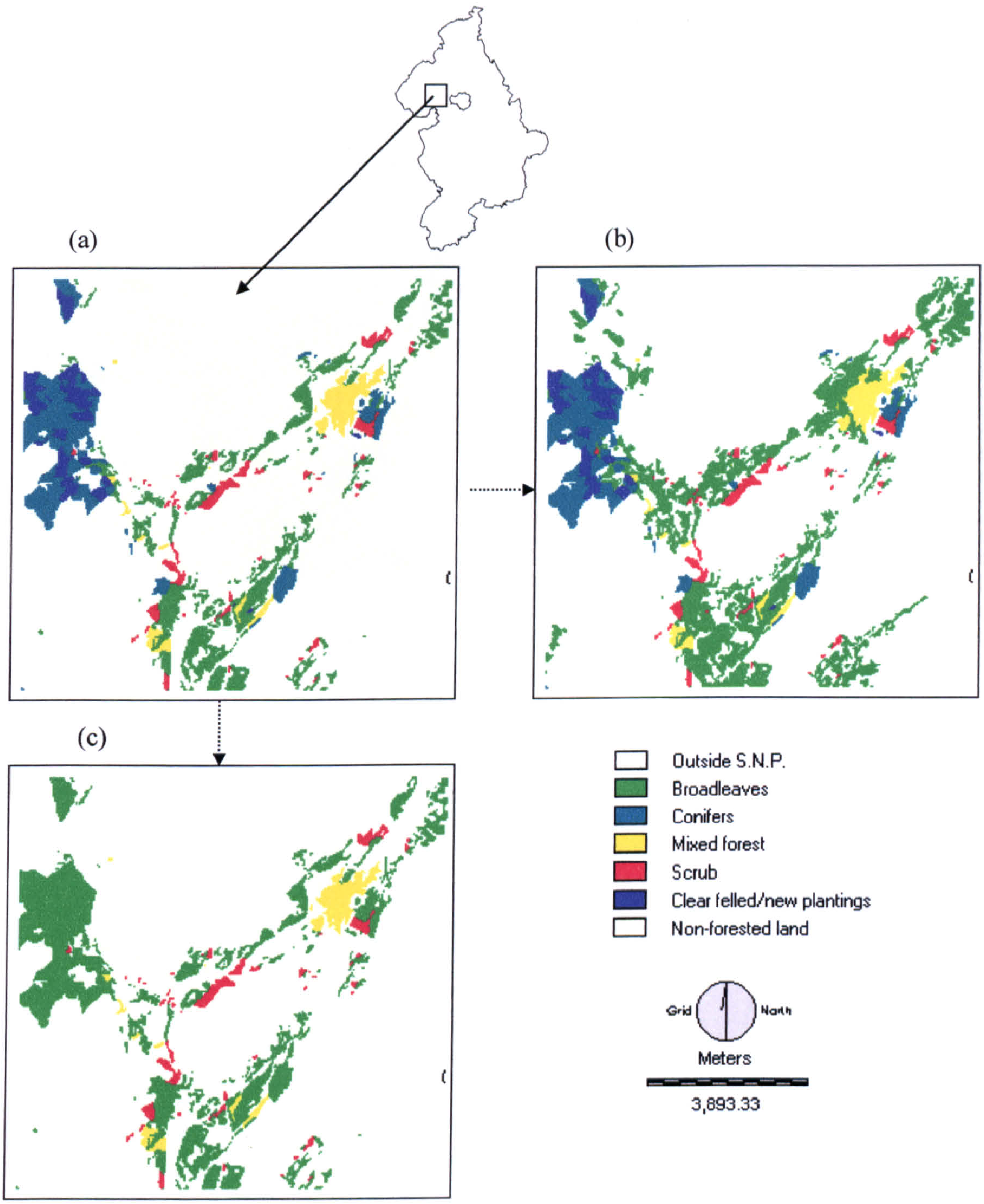


Figure 5.10. Forested areas in the first study site used within the National Park in the simulation experiment. The study site of 10 x 10 km size (a) as it is at present; (b) after expansion of broadleaves on agricultural land; and (c) after conversion of conifers to broadleaves (adapted from Gkaraveli *et al*., 2001).

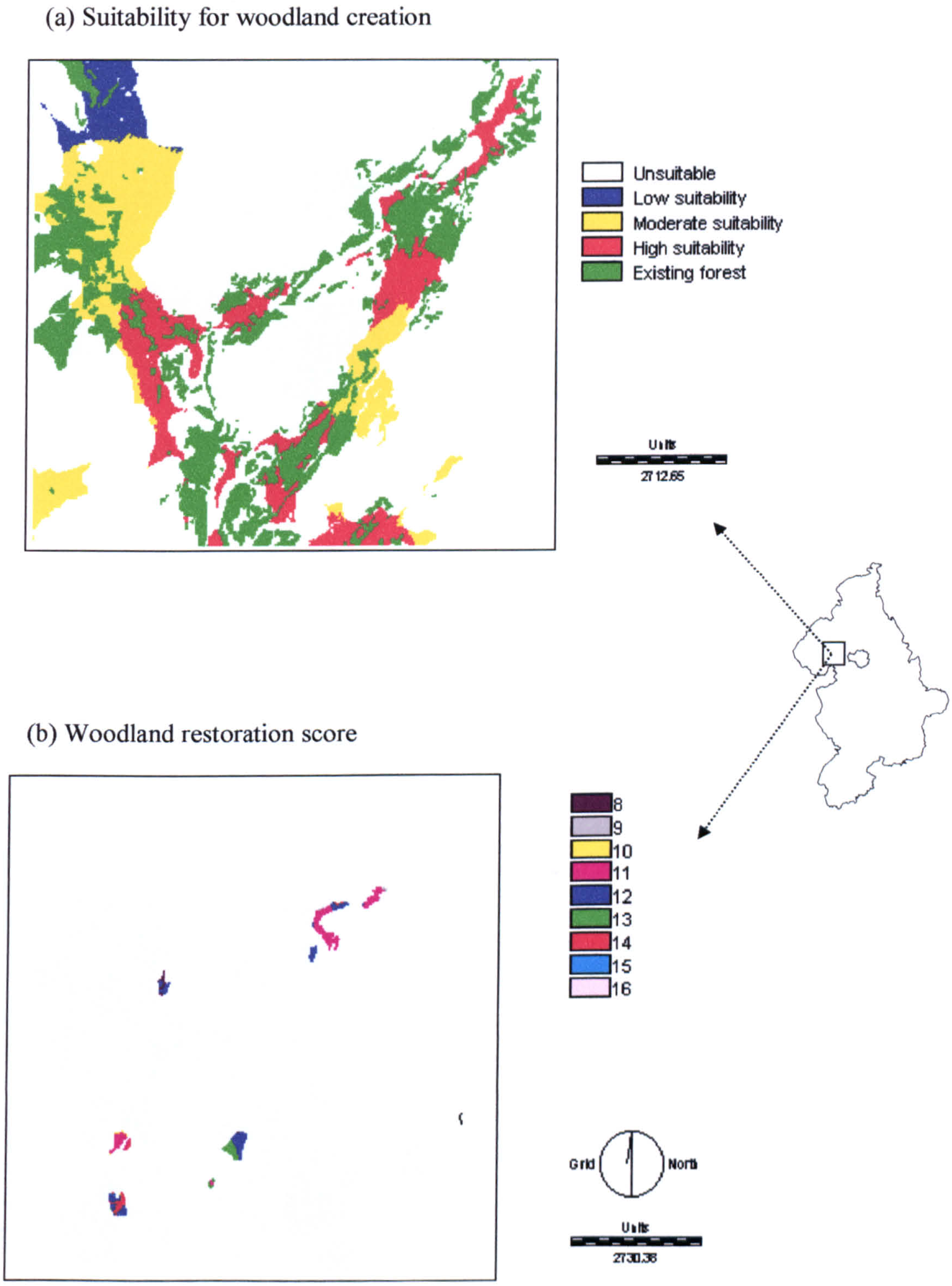


Figure 5.11. Priority areas for woodland expansion identified for this site in Snowdonia by a) the *Woodland Creation Model* and b) the *Woodland Restoration Model*.

Plate 5.1. Beddgelert – looking NW across improved pasture fields with small woods in the background (SH 580 480) (taken in August 2001).

Plate 5.2. Beddgelert – looking NW across improved pasture fields with broadleaved woodland and conifer plantations in the background (SH 580 480) (taken in August 2001).

In the second study site (Figure 5.12), the woodland habitats were found in a great number of very small and similar-sized patches, especially broadleaves and scrub (Gkaraveli, 1999; Gkaraveli *et al.*, 2001). The proportion of semi-natural habitats was low and it was assumed that the matrix would be hostile for some species. The approach recommended was buffer zones around existing woodlands. The simulation results showed that adding a 100m buffer zone of a similar habitat around broadleaved, mixed and scrub woodlands, would considerably increase woodland area. Habitats would be less subdivided into patches with less complexity in shape and with larger core areas. The priority areas for woodland expansion identified for this site by both methods created for this study are presented in Figure 5.13. Buffer zones created around existing woodlands (Plate 5.3) are likely to reduce external influences (Bennett, 1999) and make the enlarged patches easier to manage (Kirby, 1995). Furthermore, restoration of replanted ancient woodland sites (Plate 5.4) would additionally increase the native woodland area in the landscape.

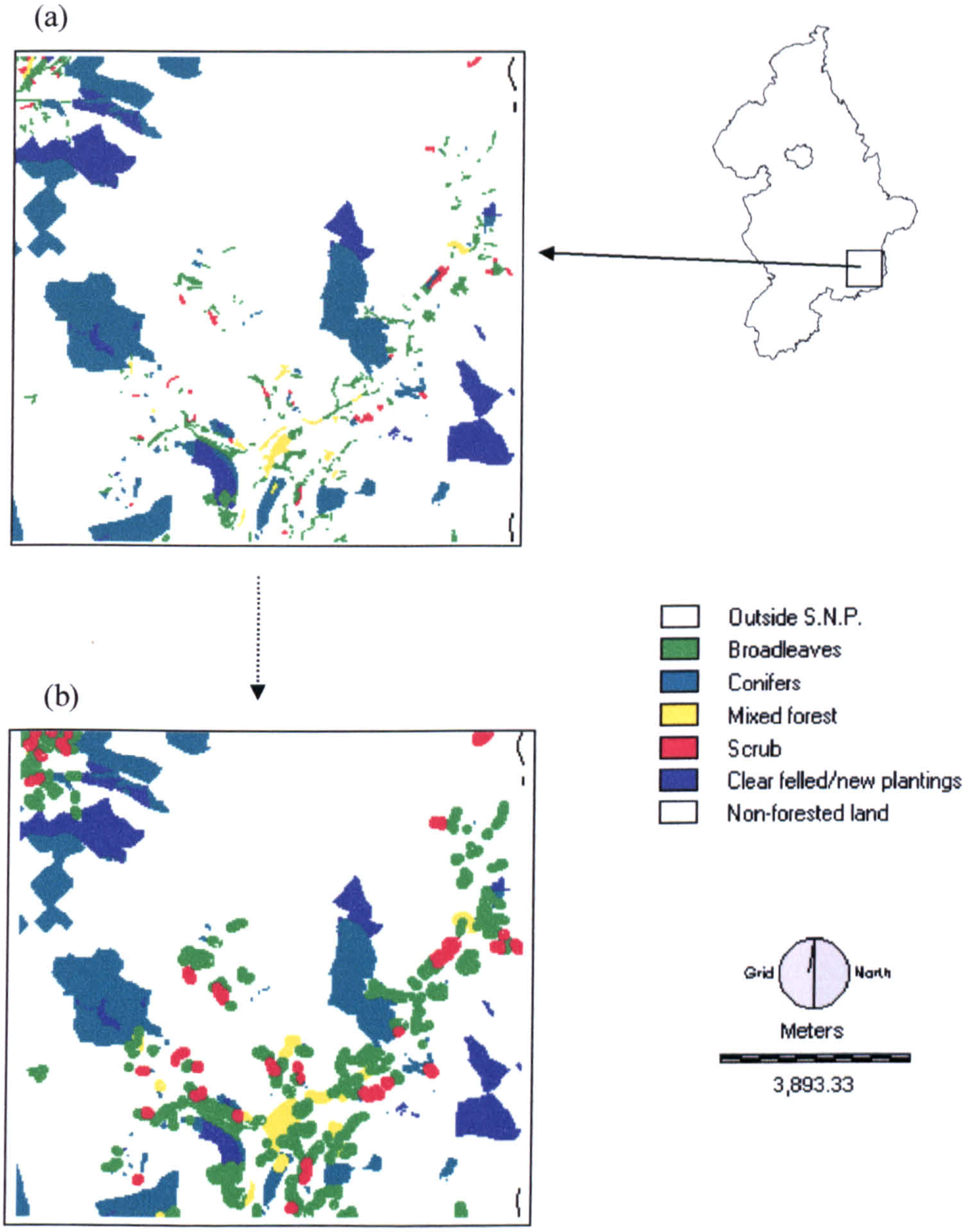


Figure 5.12. Forested areas in the second study site within the Park in the simulation experiment. The study site of 10 x 10 km (a) as it is at present; and (b) after adding a buffer zone of 100m around woodlands (adapted from Gkaraveli *et al.*, 2001).

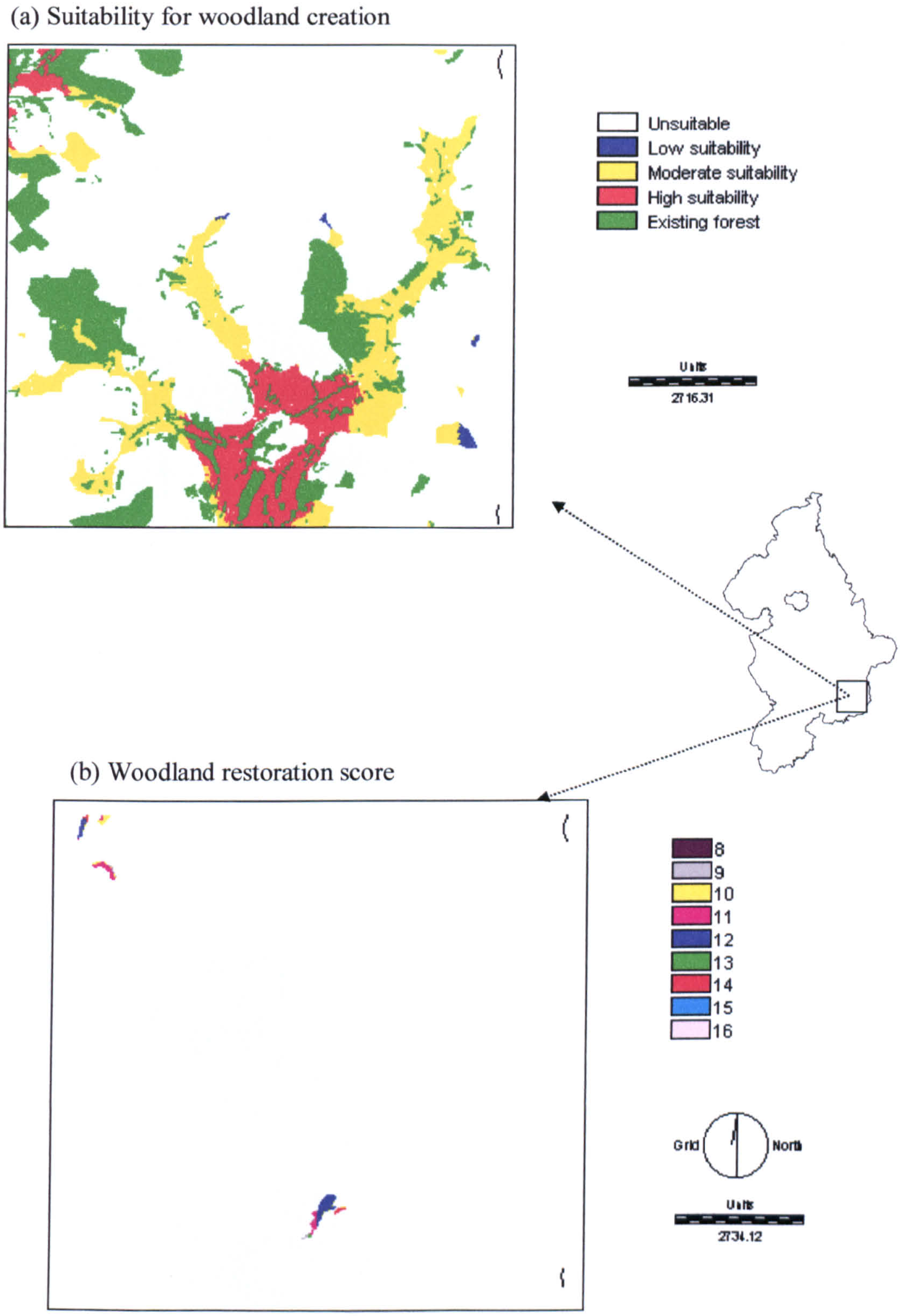


Figure 5.13. Priority areas for woodland expansion identified for this site in Snowdonia by a) the *Woodland Creation Model* and b) the *Woodland Restoration Model*.

Plate 5.3. Dinas Mawddwy – looking ES towards small scattered broadleaved woods (SH 855 150) (taken in August 2001).

Plate 5.4. Dinas Mawddwy – looking ES across improved pasture fields with conifer plantations and small broadleaved woodlands in the background (SH 850 150) (taken in August 2001).

5.9.5. Targeting BAP and NVC woodland types

In any approach to native woodland creation and restoration of replanted sites it is normally appropriate to have target woodland types in mind, although this may not be needed in cases where natural regeneration is an option. Target types may be NVC communities. The approaches that may be followed in deciding what they should be and how they may be achieved are described in Rodwell (1991a) and Rodwell and Patterson (1994). Bringing in mind the NVC woodland communities occurring within the Park, woodland of NVC oak woodland types W11 or W17, upland mixed ash woodland of NVC types W8 and W9, alder-ash woodland (NVC type W7) or birch woodland (NVC type W4).

To help guide native woodland expansion in Snowdonia, the Ecological Site Classification (ESC) decision support system (Ray, 2000) developed by the Forestry Commission could be used. ESC classifies a site in terms of its climate and soil quality. It assesses the suitability of alternate tree species and woodland community choices (NVC woodland types), based on the match between key site factors and the ecological requirements of different species and woodland communities. Alternatively, having identified the priority areas for native woodland expansion, a model could be created based on a series of decision rules which link site characteristics (topography, soil and geology type, vegetation cover) and climate to the requirements of existing NVC woodland communities present in the National Park under current environmental conditions. This approach is taken forward to the subsequent chapter.

As an alternative to targeting NVC woodland types it might be appropriate to consider broader HAP woodland types (*e.g.* as it is proposed in SNPA, (1999) and Latham, (2000)). In this case the NVC types W11 and W17 could be considered as a single target community 'upland oakwood', the NVC types W8 and W9 as 'upland mixed ashwood' and NVC types W4 and W7 as 'wet woodland'. This approach may be better appreciated by practitioners who would be unlikely to work within the narrow constraints imposed by rigid adherence to NVC guidelines (Good *et al.* 2000).

5.10. Conclusions and further research

In this study, criteria that integrate the ideas for a woodland habitat network for Wales (Anon., 1998a; National Assembly for Wales, 2001) were developed for woodland expansion scenario modelling in Snowdonia. Woodland expansion was considered in terms of new woodland creation on land that is presently unwooded and restoration of replanted ancient woodland sites. The criteria give higher weighting in ancient woodlands, especially those within SSSIs, and in native woodland expansion close to existing woodland, so that the high biodiversity value of ancient woodland is emphasised and isolated woodland sites would not be created or restored.

The criteria developed were used to produce two models in the IDRISI GIS (Eastman, 2001), the *Woodland Creation Model* and the *Woodland Restoration Model*, showing priority areas in Snowdonia for woodland creation and restoration of replanted sites respectively. For the *Woodland Creation Model*, the GIS was used as a decision support system. The multi-criteria evaluation method was used to assess and aggregate all the criteria. In the *Woodland Restoration Model*, priority areas within the ancient woodland replanted sites were identified by making an extensive use of the OVERLAY technique in the GIS in order to add together all the criteria.

Of the total area of the National Park (214 162ha), 3 914ha (2%) were given a 'low suitability' value for woodland creation, 43 347ha (20%), a 'moderate suitability' value and 11 247ha (5%) a 'high suitability' value. Improved and rough pasture land were the dominant land cover types in all the suitability classes.

Of the total area of replanted ancient woodland sites in Snowdonia (2 948ha), 2 536ha (86%) were scored from 8-12 (8-16 scale) and the remaining 412ha (14%) from 13-16. The higher the score of an ancient replanted site, the higher its priority for restoration.

Constraints on woodland creation were also applied to this study. These were areas of existing woodland, sites than cannot be planted such as SSSIs, built-up areas and areas important for conservation of non-wooded semi-natural habitats, and buffer zones of 200m around important non-wooded semi-natural habitats to allow for natural regeneration. This made the woodland expansion scenario modelling more responsive to the regional conditions. Other constraints, however, could also be considered for further research. These could be buffer zones around existing open habitat SSSIs (to allow natural expansion of these habitats to occur) and landscape, cultural and agri-economic constraints that can be of considerable significance in determining whether land is made available for woodland expansion in particular cases.

Opportunities for native woodland expansion were identified for both woodland creation and restoration of replanted ancient wood sites. These could be the ancient woodland sites that have been cleared in the past and the replanted ancient wood sites that match the characteristics of the semi-natural stands. The results indicated that there are 121ha of ancient woodland cleared in the recent past in Snowdonia which are not presently occupied by woodlands. In addition, almost all ancient woodland replanted sites (98%) have a similar combination of site and climate characteristics to those of the ancient semi-natural woodlands.

Information on the location of WGS woods, Forest Enterprise land, or ownership by major NGOs such as the Woodland Trust in Snowdonia, could be used to suggest who may be approached to help create the new woodlands produced from this analysis. These new wooded landscapes, however, need analysing (Purdy and Ferris, 1999). The landscape indices calculated in studies such as those of Gkaraveli (1999), Gkaraveli *et al.* (2001), and in Chapter 3 in combination with species location data and habitat requirement data for key species could be used to assess the landscapes in a more meaningful way, by looking at the impact that the potential changes would have on these species. This is an area requiring more research.

It is normally appropriate to have target woodland types in mind in any approach to native woodland creation and restoration of replanted sites. Target types may be NVC woodland communities or broader HAP woodland types. To help native woodland expansion in Snowdonia, having identified the priority areas, a model could be created to predict the occurrence of NVC woodland types in the National Park for current environmental conditions. The results could indicate the appropriate woodland communities for the priority areas identified in this study. This approach is taken forward to the next chapter.

5.11. Summary

This chapter reviewed a number of issues, which relate to the ideas for woodland habitat networks for Wales. In addition, it described how two models were created, using ecological criteria and GIS methods, in order to prioritise areas in the Snowdonia National Park for native woodland expansion. Constraints and opportunities on woodland expansion were also identified. Furthermore, studies indicating how woodland expansion could be done on a site-by-site basis in the National Park were presented as examples.

The next chapter examines the distribution of the NVC woodland communities in Snowdonia in relation to environmental parameters.

CHAPTER 6

'Understanding the patterns of variation among existing kinds of broadleaved woodland is essential for the sensitive creation of new woods intended to have a more natural character'.

Rodwell and Patterson (1995).

6.0 MODELLING NATIVE WOODLAND POTENTIAL: DISTRIBUTION AND ENVIRONMENTAL RELATIONSHIPS OF NVC WOODLAND

In Chapter 5, criteria that integrate the ideas for a woodland habitat network for Wales (Anon., 1998; National Assembly for Wales, 2001) were developed for woodland expansion scenario modelling in Snowdonia. Having identified priority areas for native woodland expansion in the National Park, particular woodland types could be targeted.

Unfortunately very little is known about the potential distribution and extent of different woodland types to guide native woodland expansion at regional and local levels. Comparisons with historical reconstructions from palaeobotanical studies (Bennett, 1996) are likely to be of limited relevance since site conditions have been modified by climate change, environmental pollution, the removal of the original forest cover and the cultivation of soils for agricultural use (Macmillan *et al.*, 1997).

In this case the 'present-natural' *i.e.* the native species inherited from primeval conditions, taking into account site and climatic changes to the present day (Peterken, 1993), is the most suitable template for developing such forest habitat networks (Ratcliffe *et al.*, 1998, cited in Towers *et al.*, 2000a). It expresses the inherent pattern of site conditions on which any woodland expansion might be based.

There has been no comprehensive study of the distribution and relationship of NVC communities with environmental factors in Snowdonia, although modelling techniques are becoming available to predict the distribution of NVC communities at site or regional scales (Pyatt and Suárez, 1997; Macmillan *et al.*, 1997; Pyatt *et al.*, 2001). Such methods have yet to be widely used in Wales.

To help guide native woodland expansion plans in the Snowdonia National Park, this study has three main purposes:

1. to use all the available spatially referenced data for Snowdonia to examine the distribution of existing NVC woodland sub-communities in relation to environmental parameters;

2. to develop a site suitability model that predicts and maps the distribution of NVC woodland sub-communities and communities for current environmental conditions;
3. to indicate the appropriate NVC woodland communities and Biodiversity Action Plan Priority Habitat types for those priority areas for woodland expansion identified in Chapter 5.

6.1 National Vegetation Classification

Since its development in the 1980s, the NVC has become the standard classification used for describing vegetation in Britain. Whereas many other classifications are restricted to particular types of vegetation (*e.g.* the Stand Type classification which describes only woodland (Peterken, 1993)), the NVC aims to describe the whole range of British vegetation as a series of plant communities (Rodwell, 1991a, 1991b, 1992, 1995). This means that it is possible to analyse, and map, a complex site, composed of several habitat types (*e.g.* woodland, scrub, heathland and bog) using the same classification system. Successional or treatment related changes in the vegetation, for example between open glades, shaded rides and the vegetation of clear-fells can be more easily described than is possible with other classifications (Hall *et al.*, 2001).

The NVC is a 'phytosociological' classification, classifying vegetation solely on the basis of the plant species of which it is composed. The resulting communities can usually be correlated to other factors, especially geology and soils, age and management; but the plant species alone are used to assign the vegetation to a community (Hall *et al.*, 2001).

The woodland section of the NVC comprises 25 communities (Rodwell, 1991a); 18 main woodland types (seven types of wet woodland and eleven dry-land high forest communities) and 7 scrubs or underscrubs, most of which were divided further to give a total of 73 sub-communities. Each community can be recognised by distinctive mixtures of trees and shrubs, and has a characteristic associated flora of flowering plants and often, too, some ferns, mosses, liverworts and lichens. Each is related to particular climatic and edaphic conditions and represents the kind of climax vegetation that could develop wherever such conditions were fulfilled, if succession everywhere was allowed to take its full course (Rodwell and Patterson, 1994). Although such successions have often been modified by man and the resulting stands greatly influenced by management, interference and neglect, these woodlands still provide important clues as to the kinds of vegetation we might aim for in planning broadleaved woodlands where the intention is to encourage a natural character. More particularly, classifications of these woodlands enable us to predict appropriate mixtures of trees and shrubs suitable for existing climatic and soil conditions in sites which are at present unwooded (Rodwell and Patterson, 1995).

The NVC is currently the main classification system used by the statutory and voluntary conservation organisations to describe British woodland. It is the basis for selection of SSSIs (NCC, 1989), and has been adopted as a fundamental tool for planning and creating new native woodlands (Rodwell and Patterson, 1994; Pyatt *et al.*, 2001). Its uses are reviewed in Kirby *et al.* (1991) and Cooke and Kirby (1994), and distributions maps can be found in Rodwell (1991a), Hall (1997), Hall *et al.* (2001) and Latham (2001b) for an updated knowledge of the woodland NVC in Wales.

6.2 Modelling the potential distribution of native woodland

Sanderson *et al.* (1995) developed a modelling system to predict the distribution of grassland, heath, moor and mire NVC plant communities in the area of the catchment of the River Tyne in north-east England using spatially referenced environmental and land management data. Twenty one variables were used to describe each plant community: four environmental variables such as altitude, slope, soil type and rainfall, and seventeen management variables including grazing and cutting regimes and fertilizer applications. The model was validated by comparing the predicted plant communities and species with those observed at two sites of contrasting scales: one at a farm scale and the other at a landscape scale. The results suggested a failure of the model to predict accurately some of the plant communities because of inaccuracies in the source data and/or attempting to use the model at too fine a resolution.

At the Macaulay Land Use Research Institute, in Scotland, a habitat restoration model was developed to predict the distribution of NVC woodland communities in the Cairngorms Partnership Area (Macmillan *et al.*, 1997). The model linked expert knowledge on woodland and scrub habitat requirements with digital biophysical data to predict the occurrence and distribution of a range of woodland communities. Two digital data sources were incorporated in the model: the 1:250 000 National Soils Map and the 1:25 000 scale Land Cover of Scotland dataset. The two data sets were overlayed within a GIS, forming a new integrated data set which held a number of soil/land cover combinations. These combinations, which were essentially a description of the present site conditions, formed the basis of the model predictions.

In the same work (Macmillan *et al.*, 1997) the patterns of potential woodland cover predicted conformed well with previous qualitative assessments such as generalised maps, surviving estate records from the 17th and 18th centuries and palaeoecological evidence from the area. The model outputs were also compared with a 1:10 000 NVC dataset for a portion of the study area. The results indicated difficulties of using data sources at different scales. Furthermore, the authors suggested that a more detailed soils data at 1:50 000 scale and other variables including elevation, temperature and rainfall, aspect and topex could be incorporated into the model and influence its accuracy.

The Native Woodland Model of Macmillan *et al.* (1997) and Towers *et al.* (2000b) was further developed with Scottish Natural Heritage to predict the woodland Habitat Action Plan types across much of Scotland (Gray and Stone, in press). The model outputs for the Highlands included pinewood, oakwood and ashwood types. These were compared with actual NVC surveys and the correlations were computed. How the model outputs could be combined with land cover and Ancient Woodland Inventory data to permit an estimate of the woodland type of the current semi-natural woodland resource, along with the extent and patterns of potential expansion was also discussed.

The development of the Ecological Site Classification (ESC) (Pyatt and Suárez, 1997; Pyatt *et al.*, 2001) introduced a methodology and a decision support system (ESC-DSS) (Ray, 2000) applicable throughout Great Britain. ESC classifies a site in terms of its climate, soil moisture regime and soil nutrient regime. Four climatic factors are currently used in ESC: warmth, wetness, continentality and windiness. ESC assesses the suitability of alternate tree species and woodland community choices, based on the match between key site factors and the ecological requirements of different species and woodland communities. The minimum site information required by ESC-DSS is the grid reference, the elevation and the soil type. Outputs of the system include a report of the site information and the tree species suitability diagrams, ESC yield predictions and native woodland suitability predictions.

6.3 Modelling approach for this study

The NVC communities represent the kind of woodland habitats that are likely to be established on particular sites based on observations of similar areas. Where woodland has been replaced by other communities such as heather moor or rough grassland, the appropriate NVC woodland can be predicted from climatic zone, soil type, terrain, topographic position and the existing flora (Rodwell and Patterson, 1994).

This study incorporates these associations between site characteristics and woodland characteristics in Snowdonia to predict and map the distribution of NVC woodland sub-communities and communities within a GIS. In addition, it identifies the most suitable sites for the re-establishment of a number of native woodland types.

The steps taken to implement this modelling approach are summarised as:

- Spatially referenced data on land cover, topography, soil and geology type, and climate were obtained for the study area;
- All the survey sites in the National Park with mapped distributions of NVC woodland sub-communities were digitised;
- A site suitability model, based on a series of decision rules that link the site characteristics within a GIS to the existing NVC woodland resource, was developed;
- The most appropriate native woodland types for different areas in Snowdonia for current environmental conditions were indicated;
- To evaluate the performance of the model and the quality of the results qualitative and quantitative comparisons were made;
- The results of the *Woodland Creation Model* and the *Woodland Restoration Model* developed in Chapter 5 were incorporated into the present NVC model to identify the most suitable NVC woodland types for the priority areas for woodland expansion in Snowdonia.

A flow-chart summarising the whole modelling procedure is given in Figure 6.1.

The development and application of this methodology is the subject of this Chapter. This modelling approach is different from the studies of Sanderson *et al.* (1995), Macmillan *et al.*, (1997), Pyatt and Suárez, (1997), Towers *et al.* (2000b) and Pyatt *et al.* (2001) as it examines the relationships of NVC woodland types currently present in the National Park with environmental factors and is not based on expert knowledge and published data. In addition to the distribution of NVC woodland communities which generally have wide, national-scale, geographical distributions within Britain (Rodwell, 1991a) it examines the distribution of NVC woodland sub-communities which often have a restricted, regional distribution.

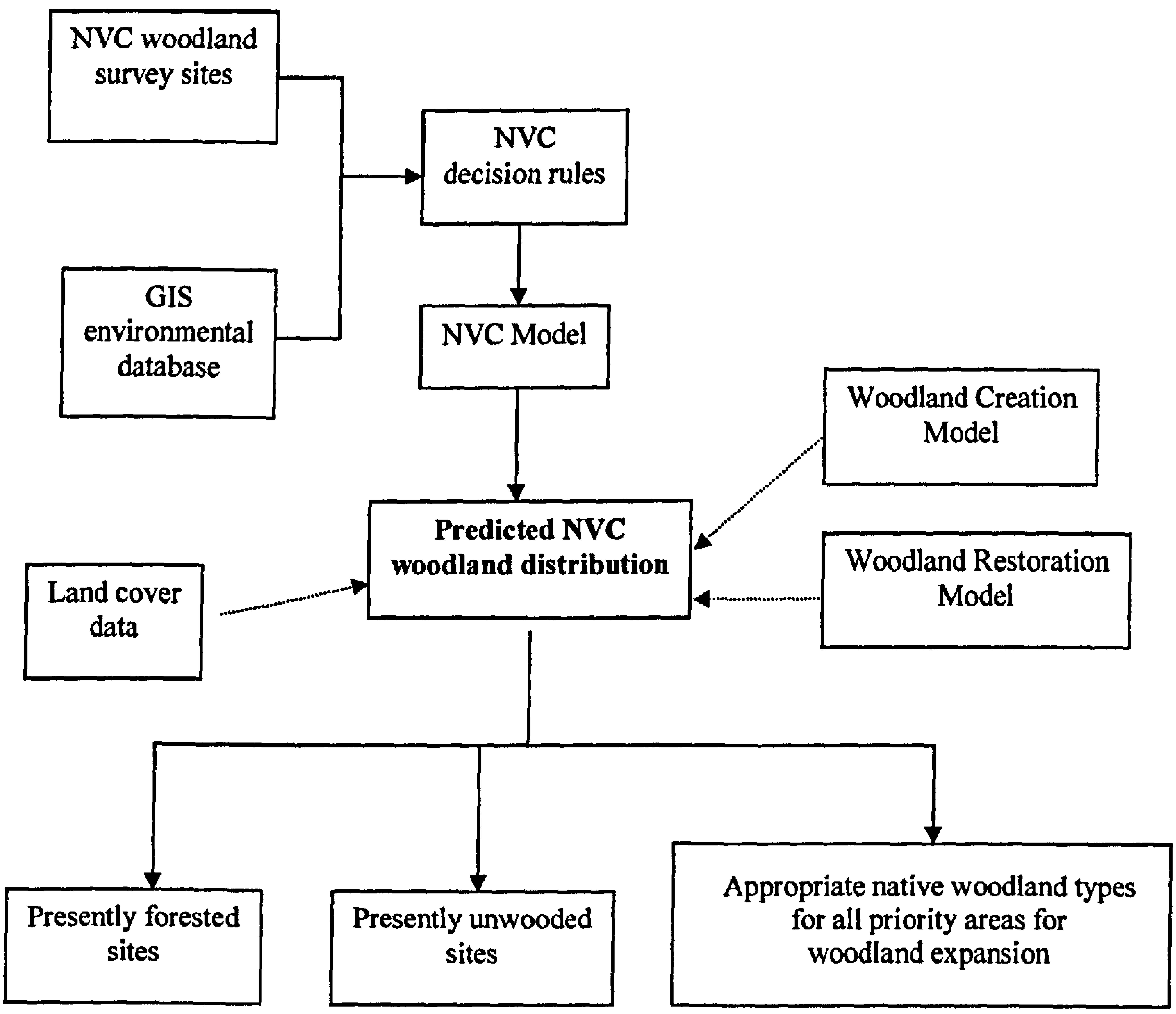


Figure 6.1. Flow-chart of modelling approach.

6.4 Data sources and methods

6.4.1 Data used

The data available for Snowdonia to implement this study comprise the 1980s land cover map of the entire National Park, a set of environmental factors related to climate, topography, soil and geology conditions, and NVC data from survey sites within Snowdonia kindly provided by CCW (Table 6.1).

The land cover map and the way it was processed are described in section 3.3.1. All climatic variables and how they were produced are described in detail in section 4.2. The soil map was digitised by X. Luo at the School of Agricultural and Forest Sciences from the 1:250 000 scale map of the Soil Survey of England and Wales during his Ph.D. research for Snowdonia (Luo, 1998). The 1:250 000 scale national map provides a classification of soil associations, each of which may comprise a mosaic of disparate soil series. The geology map was also produced by Luo from the 1:250 000 scale OS Geological Map of Wales. More detailed soil and geology maps (at 1:50 000 and 1:25 000 scale), which exist for some parts of Wales, were not available at the time of this study. More information on the surveys of NVC woodland in Wales and how the NVC survey sites data were processed is given in the next sections.

Table 6.1. Data for Snowdonia used in the analysis.

Maps	Comment
NVC woodland boundaries	Data from survey sites with maps of 1:10 000 and 1:5 000 scale
NVC survey sites data	Spreadsheet with information on survey sites, dates, and area estimates of NVC woodland sub-communities for sites without mapped information
1980s land cover map	The aerial photographs were all taken in 1990
Altitude	m
Aspect	degrees
Slope	degrees
Soil type	1:250 000 scale
Geology type	
Mean annual temperature Mean annual rainfall	Both climatic variables cover the 1961-1990 period

6.4.2 NVC woodland survey in Wales

Since the introduction of the National Vegetation Classification in the 1980s and publication in Rodwell (1991a), many surveys have been carried out in Wales (Latham, 2001b; Latham, in press.a). These have ranged from one-off surveys by individuals to large scale and systematic surveys carried out under contract for CCW (*e.g.* Castle and Mileto, 1998). Much of this information has been collated by CCW to aid several high profile programmes, including Biodiversity Action Plan implementation, selection of Special Areas of Conservation (SACs, as required by EU Directive 92/43) and Tir Gofal. The NVC dataset contains many more records than used for the original distribution maps (Rodwell, 1991a), and should give a more complete understanding of woodland plant communities in Wales.

NVC information has been collated from 802 woodland sites in Wales with a total area of around 11 500ha, and is described in (Latham, 2001b). The majority of the surveyed area (54%) has been within SSSIs. Full NVC maps, for the majority of the survey sites, were produced and areas of communities measured from these by the surveyors. For others, mapping was only partial and areas of communities have had to be estimated.

All woodland communities except W18 and all sub-communities except W6c and W15d have been recorded in Wales (Appendix 4 provides a description of each NVC woodland community) (Latham, in press.a). Most communities showed a wider geographic distribution than shown in Rodwell (1991a), and W3, W13, W14 and W16 were previously unrecorded. Oak wood types accounted for most of the area, with W10, W11 and W17 representing oak woods across a cline of progressively more acidic and upland conditions. Ash woodland communities (W8 and W9) were also well represented, making up a quarter of the total area surveyed. Beech wood communities accounted for a small percentage of the total area surveyed. Wet woodlands too accounted for a relatively small percentage. The updated distribution maps of NVC woodland communities in Wales can be found in Latham (2001b).

6.4.3 NVC survey data processing

The CCW provided NVC data for 53 survey sites within the Snowdonia National Park. Records for each site were held in CCW in a computer database with fields for areas of NVC community and sub-community, along with information on site location, name, surveyor, reliability, date of survey and protected status. These records were provided and linked to a GIS (IDRISI v.32 rel.2.0), allowing spatial and geographic analyses to be carried out.

Only 29 of the survey sites had full NVC maps of 1:10 000 and 1:5 000 scale. From these maps, provided by CCW, the polygons of each NVC sub-community within each survey site were digitised on a Calcomp 9 500 tablet and processed using the CartaLinx v.1.2 software. The resulting boundaries were drawn together to form a map showing the distribution of NVC woodland sub-communities within the survey sites in Snowdonia. This map was exported to IDRISI GIS and was further analysed.

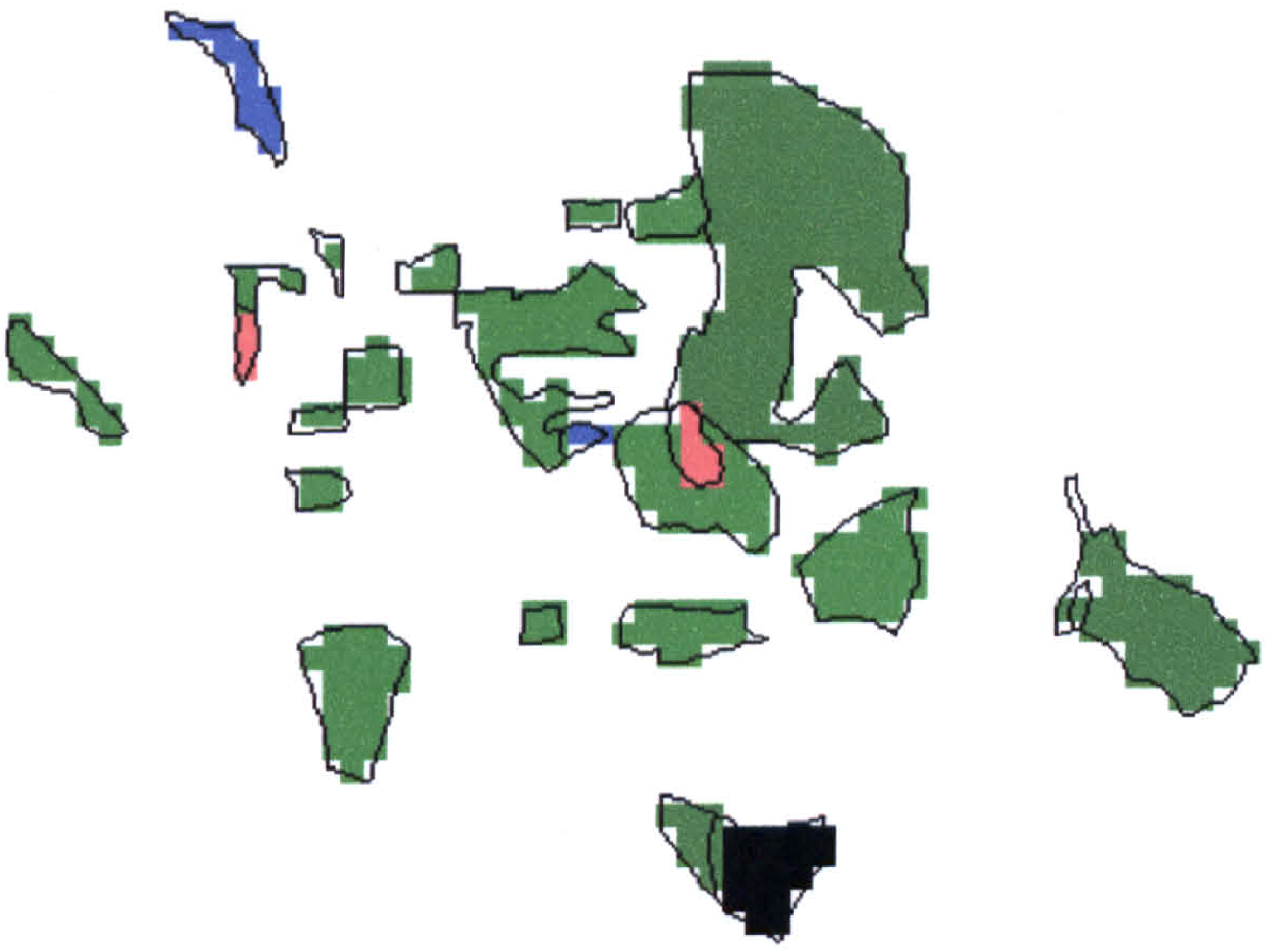
For those survey sites without NVC mapped information, the grid reference of each site was used to create a file in IDRISI (EDIT function), allowing a distribution map of the survey sites to be produced. This map in combination with information on NVC woodland sub-communities present in each survey site was used to qualitatively assess the results of the *NVC Model* developed.

6.4.4 NVC Model

The vector file, exported from CartaLinx software to IDRISI, containing the NVC woodland polygons was converted in the GIS to a raster image (POLYRAS module) using the parameters of the 1980s land cover map of Snowdonia (19.89m resolution). Experimenting with different resolutions revealed that a finer pixel resolution such as 10m would better represent the NVC woodland polygons, as some of the surveyed sites were small (Figure 6.2). That would mean, however, that all the environmental factors used for the development of the *NVC Model*, including the land cover map, would have to be resampled into the new resolution, and the development of the model would have to be computationally intensive and time consuming.

Prior to the development of the *NVC Model*, the land cover map in the 1980s was overlayed with the map showing the distribution of the NVC woodland sub-communities using the CROSSTAB module in IDRISI. This made possible to identify the relationship between them.

a) 19.89m pixel resolution (used in the analysis)



b) 10.00m pixel resolution

Figure 6.2. Representation of NVC woodland sub-community boundaries with two different pixel resolutions. Some of the smallest survey sites is Snowdonia have been selected.

6.4.4.1 Model implementation

The objective of this study was to develop a model to help identify the most suitable sites in Snowdonia for the re-establishment of a number of native woodland types according to the National Vegetation Classification.

To achieve this, the *NVC Model* which links the NVC woodland sub-communities currently present in Snowdonia with current environmental conditions, was produced using the IDRISI Macro Language (IML files). All Macro files created are given in Appendix 4.

To develop the *NVC Model*, the map showing the distribution of NVC woodland sub-communities in the National Park was reclassified so as to produce separate maps for each NVC sub-community. Each NVC sub-community map was, then, overlayed (CROSSTAB routine) with each of the seven environmental variables given in Table 6.1. The cross-tabulation results were used to create matrices for each NVC woodland sub-community indicating the woodland sub-community x environment relationship (Table 6.2).

The matrices for each NVC sub-community were used to develop a series of decision rules linking site characteristics and climate to the existing NVC woodland resource in Snowdonia. This required reclassifying each environmental factor according to the requirements of each NVC sub-community as indicated in the matrices. The multi-criteria evaluation method in the GIS (MCE module) was then applied to aggregate all the reclassified environmental factors and map the suitable sites for each NVC woodland sub-community in Snowdonia.

All maps showing the predicted distribution of NVC sub-communities were overlayed in turn to form a single image. This made it possible to detect any overlap between the sub-communities. This image was subsequently reclassified to create images showing the distribution of NVC communities and Biodiversity Action Plan (BAP) Priority Habitat Types as defined by Hall and Kirby (1998) and Hall *et al.* (2001). The latter map was overlayed with the final maps in the *Woodland Creation* and *Restoration Models*, created in the previous Chapter, in order to detect the appropriate native

Table 6.2. Matrices produced for each NVC woodland sub-community present in Snowdonia. Total areas of each NVC sub-community surveyed are shown in parentheses.

Environment	Category		
	W1 (2.37ha)	W4b (10.41ha)	W4c (2.61ha)
Altitude (m)	0-50, 100-150	0-50, 100-300	0-100
Aspect (degrees)	0-90, 315-360	At all classes	0-90, 135-360
Slope (degrees)	0-25	0-25	0-10
Geology type	5, 8	5, 7-9	8
Soil type	5, 11	5, 11	3
Mean annual temperature (^{0}C)	9-10	8-10	9-10
Mean annual rainfall (mm)	1400-2200	1400-3000	1400-2200

Environment	Category		
	W7a (12.58ha)	W7b (12.11ha)	W7c (20.58ha)
Altitude (m)	50-200	50-300	0-300
Aspect (degrees)	0-135, 225-360	At all classes	At all classes
Slope (degrees)	0-25	0-35	0-40
Geology type	5-7, 9	7, 9, 11	7-9, 11, 16
Soil type	5	3, 5, 9, 11	3, 5, 9, 11
Mean annual temperature (^{0}C)	8-10	8-10	8-10
Mean annual rainfall (mm)	1000-2600	1400-3400	1000-2200, 2600-3800

Environment	Category		
	W8e (18.04ha)	W9a (45.15ha)	W9b (9.42ha)
Altitude (m)	0-200	0-400	0-200
Aspect (degrees)	0-45, 270-360	At all classes	At all classes
Slope (degrees)	0-45	0-50	0-35
Geology type	8, 12	3-9, 11	3, 7, 16
Soil type	5, 11	1, 3, 5, 9, 11	5, 9
Mean annual temperature (^{0}C)	9-10	7-10	9-10
Mean annual rainfall (mm)	1400-3000	600-3800	1000-3000

Environment	Category		
	W10a (4.00ha)	W10e (93.31ha)	W11a (113.10ha)
Altitude (m)	0-150	0-300	0-350
Aspect (degrees)	At all classes	At all classes	At all classes
Slope (degrees)	0-35	0-50	0-45
Geology type	5, 9	2-5, 7-9, 11-12	3-9, 11, 16
Soil type	5	3, 5, 9, 11	1, 3, 5, 8-9, 11, 14
Mean annual temperature (^{0}C)	9	8-10	7-10
Mean annual rainfall (mm)	1400-2600	600-3400	1000-3000

Environment	Category		
	W11b (24.69ha)	W14 (7.08ha)	W15c (3.01ha)
Altitude (m)	50-300	50-150	0-100
Aspect (degrees)	0-45, 90-360	0-90, 180-360	0-90, 225-360
Slope (degrees)	0-50	0-40	0-25, 30-35
Geology type	3, 7, 9, 11	5, 8-9	7-8
Soil type	5, 11	3, 5, 9	3-5
Mean annual temperature (^{0}C)	8-9	8-10	9-10

Table 6.2. Continued.

Mean annual rainfall (mm)	1000-3800	1400-3000	1400-3000

Environment	Category		
	W17a (167.47ha)	W17b (283.22ha)	W17c (150.30ha)
Altitude (m)	0-350	0-300	0-350
Aspect (degrees)	At all classes	At all classes	At all classes
Slope (degrees)	0-50	0-50	0-50
Geology type	5, 7-12, 14, 16	5-10, 12, 16	5-12, 15-16
Soil type	1, 3-5, 9, 11	1, 3, 5, 7, 9, 11	1, 5, 8-11, 14
Mean annual temperature (^{0}C)	8-10	8-10	8-10
Mean annual rainfall (mm)	1400-3800	1000-3400	1000-3000

Environment	Category		
	W17a+W17b (3.36ha)	W17a+W17c (3.64ha)	W17b+W17c (10.01ha)
Altitude (m)	0-200	100-200	0-50
Aspect (degrees)	0-45, 180-360	0-135, 180-360	At all classes
Slope (degrees)	0-35	0-20	0-20
Geology type	7, 12	7, 12, 16	5
Soil type	5	5, 14	5, 11
Mean annual temperature (^{0}C)	9-10	9	10
Mean annual rainfall (mm)	1800-3000	1800-2600	1800-2600

Environment	Category		
	W17c+W4b (0.99ha)	W7b+W7c (0.95ha)	W10a+W10e (0.59ha)
Altitude (m)	0-50	100-250	200-250
Aspect (degrees)	0-45, 180-270	90-225	135-180
Slope (degrees)	0-5, 10-15, 315-360	0-25	15-30
Geology type	5	9	9
Soil type	5	5	5
Mean annual temperature (^{0}C)	10	8-9	8
Mean annual rainfall (mm)	1800-2600	1800-2600	2200-3000

woodland types for the priority areas for woodland expansion in Snowdonia. Furthermore, overlaying the NVC simulated map with the land cover map indicated those areas that are currently forested (*e.g.* broadleaves) and the suitable NVC woodland types for those that are not.

6.4.4.2 Testing and validating the model

To evaluate the performance of the *NVC Model* and the quality of the simulated NVC woodland maps, qualitative and quantitative comparisons were made. The qualitative assessment involved the comparison of predicted NVC woodland types with those observed at survey sites in the National Park. From the 53 survey sites, as explained in section 6.4.3, 24 sites did not have full NVC maps but only estimates of each NVC woodland sub-community present. The empirical map created showing the survey sites as points was overlayed with the simulated NVC woodland maps and the reliability of the model was assessed.

To validate the predicted NVC distributions quantitatively and more objectively, the maps showing the simulated distributions of each NVC woodland sub-community were compared with the map of their present distribution in the surveyed sites. This revealed how well the model predicted the present distributions of NVC sub-communities.

6.5 Results

6.5.1 Present NVC woodland

The NVC woodland sub-communities occurring within the National Park are shown in Table 6.3. These are not the only NVC sub-communities present in Snowdonia but those with mapped distributions in the survey sites (Figure 6.3). Mosaics of sub-communities are also present and have been mapped as separate categories. W10, W11 and W17 oak wood types account for most of the surveyed area (82%) (Table 6.4). W17 oak community represents 59% of the total area surveyed, with W17b sub-community accounting for most of the area (about 28%). The only other woodland sub-communities with appreciable areas and percentages are W9a (4.5%), W8e (1.8%) and W7c (2%). Only 1.3% of the woodland area was unclassifiable with the NVC.

Table 6.3. NVC woodland sub-communities occurring in Snowdonia.

NVC code		Community description
W1		*Salix cinerea-Galium palustre* woodland
W4		*Betula pubescens-Molinia caerulea* woodland
	W4b	*Juncus effuses* sub-community
	W4c	*Sphagnum* sub-community
W7		*Alnus glutinosa-Fraxinus excelsior-Lysimachia nemorum* woodland
	W7a	*Urtica dioica* sub-community
	W7b	*Carex remota-Cirsium palustre* sub-community
	W7c	*Deschampsia cespitosa* sub-community
W8		*Fraxinus excelsior-Acer campestre-Mercurialis perennis* woodland

Table 6.3. Continued.

	W8e	*Geranium robertianum* sub-community
W9		*Fraxinus excelsior-Sorbus aucuparia-Mercurialis perennis* woodland
	W9a	Typical sub-community
	W9b	*Crepis paludosa* sub-community
W10		*Quercus robur-Pteridium aquilinum-Rubus fruticosus* woodland
	W10a	Typical sub-community
	W10e	*Acer pseudoplatanus-Oxalis acetosella* sub-community
W11		*Quercus petraea-Betula pubescens-Oxalis acetosella* woodland
	W11a	*Dryopteris dilatata* sub-community
	W11b	*Blechnum spicant* sub-community
W14		*Fagus sylvatica-Rubus fruticosus* woodland
W15		*Fagus sylvatica-Deschampsia flexuosa* woodland
	W15c	*Vaccinium myrtillus* sub-community
W17		*Quercus petraea-Betula pubescens-Dicranum majus* woodland
	W17a	*Isothecium myosuroides-Diplophyllum albicans* sub-community
	W17b	Typical sub-community
	W17c	*Anthoxanthum odoratum-Agrostis capillaris* sub-community
W17a+W17b		W17a and W17b sub-communities mosaic
W17a+W17c		W17a and W17c sub-communities mosaic
W17b+W17c		W17b and W17c sub-communities mosaic
W17c+W4b		W17c and W4b sub-communities mosaic
W10a+W10e		W10a and W10e sub-communities mosaic
W7b+W7c		W7b and W7c sub-communities mosaic

Table 6.4. Area analysis of NVC sub-communities within the survey sites of Snowdonia.

NVC code	Area (ha)	Percentage (%)
W1	2.37	0.23
W4b	10.41	1.03
W4c	2.61	0.26
W7a	12.58	1.24
W7b	12.11	1.19
W7c	20.58	2.03
W8e	18.04	1.78
W9a	45.15	4.45
W9b	9.42	0.93
W10a	4.00	0.39
W10e	93.31	9.20
W11a	113.10	11.15
W11b	24.69	2.43
W14	7.08	0.70
W15c	3.01	0.30
W17a	167.47	16.51
W17b	283.22	27.92
W17c	150.30	14.82
W17a+W17b	3.36	0.33
W17a+W17c	3.64	0.36
W17b+W17c	10.01	0.98
W17c+W4b	0.99	0.10
W10a+W10e	0.95	0.09
W7b+W7c	0.59	0.06
Unclassified land	13.22	1.30
Total	1014.43	100.00

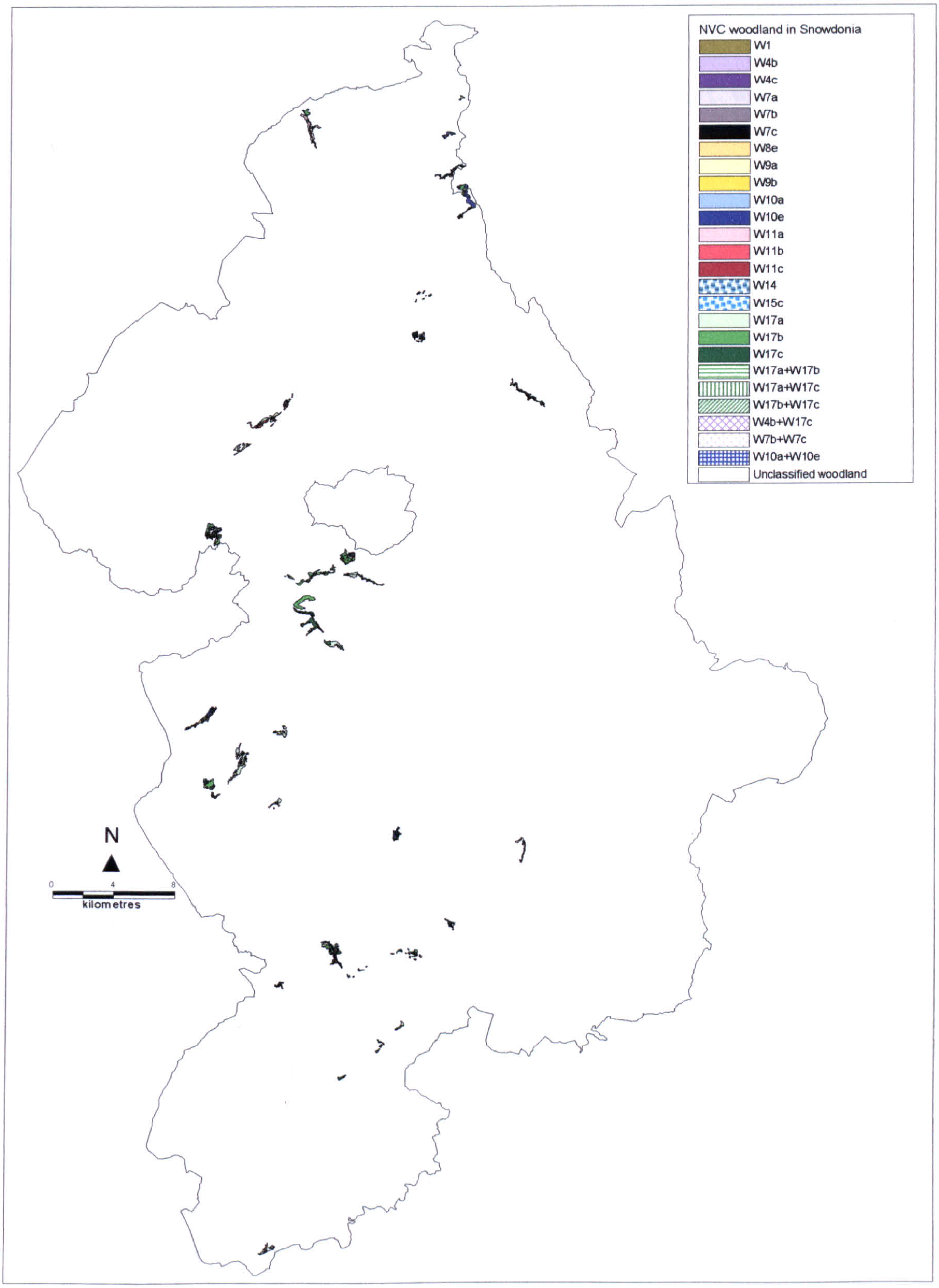


Figure 6.3. Survey sites of NVC woodland sub-communities in Snowdonia. W11c sub-community was found outside of the National Park's boundary.

Comparisons of the NVC woodland map (Figure 6.3) with the land cover map of Snowdonia, revealed a very good agreement between the two land classifications. About 87% of NVC woodland had been classified as woodland in the 1980s land cover map (Table 6.5), with broadleaves accounting for 81% of the NVC woodland in the survey sites. The small disagreement could be attributed to the date of woodland mapping (1990 for the land cover map and 1996-onwards for the majority of the NVC survey sites), the finer resolution used in the NVC woodland mapping, and the process of surveying and recording woodland cover.

Table 6.5. Agreement of NVC woodland survey with the land cover map of Snowdonia.

Woodland type	NVC woodland area (ha)	Percentage (%)
Broadleaves	811.83	81.08
Conifers	18.01	1.80
Mixed forest	15.24	1.52
Scrub	22.40	2.24
Clear felled/New plantings	1.19	0.12
Non woodland	132.55	13.24
Total	1 001.22	100.00

6.5.2 Predicted woodland distribution

The predicted areas of NVC woodland sub-communities and mosaics in Snowdonia are shown in Table 6.6. The predicted woodland patterns are demonstrated in Figures 6.4-6.12.

W11a the least heavily grazed W11 sub-community, typically forming closed-canopy high forests where sessile oak is abundant and often co-dominant with downy birch (Rodwell, 1991a), has the greatest potential in the study area. Approximately 41% of the area has the potential to sustain this sub-community (Figure 6.8) which is one of the commonest and most typical woodland communities in Wales.

W9a (typical sub-community of W9 community) with ash and hazel as the most abundant woody species has also a great potential in Snowdonia. About 38% of the area appears as suitable for the sub-community. W9 community is the upland counterpart of W8 and the distribution of suitable sites in the National Park reflects this relationship, with W9a potential sites found up to 400m elevation (Figure 6.6).

Table 6.6. Predicted area of NVC woodland sub-communities and mosaics in Snowdonia. Total percentage area is greater than 100% because of overlaps between the NVC types.

NVC type	Suitable area (ha)	Percentage (%)
W1	1108.18	0.52
W4b	17 733.88	8.28
W4c	1 205.69	0.56
W7a	8 186.02	3.82
W7b	14 251.67	6.65
W7c	18 371.47	8.56
W8e	1 501.10	0.70
W9a	81 331.99	37.98
W9b	10 115.25	4.72
W10a	3 453.16	1.61
W10e	58 668.19	27.39
W11a	87 448.41	40.83
W11b	16 172.87	7.55
W14	4 957.27	2.31
W15c	2 734.96	1.28
W17a	56 306.16	26.29
W17b	54 953.22	25.66
W17c	76 492.65	35.72
W17a+W17b	3 744.14	1.75
W17a+W17c	2 823.65	1.32
W17b+W17c	619.58	0.29
W17c+W4b	119.23	0.06
W7b+W7c	539.69	0.25
W10a+W10e	46.02	0.02
Total area of Snowdonia	214 162	

W17 (Upland oak-birch woodland with bilberry) seems to be the most extensive single woodland type with W17c sub-community accounting for most of the area (36%). W17a, a sub-community thriving in the high rainfall and humidity characteristic of the Atlantic region, is concentrated on sites with mean annual rainfall exceeding 1 400mm (Figure 6.10).

Suitable sites for W10e, the most abundant W10 sub-community in Wales (Latham, 2001), represent 27% of the area of the National Park. W10e is the most northwestern and upland W10 sub-community and it can be transitional to upland woodland types (Figure 6.7).

Among the wet woodlands, W4b, W7b and W7c sub-communities appear to have the greatest potential in the study area (about 8%, 7% and 9% respectively). These woodlands are generally concentrated on wet ground (annual rainfall in most instances exceeds 1 400mm), particularly in valleys but also in some cases as patches on wet level ground at higher elevations (Figures 6.4 and 6.5). W4c sub-community occurs on bogs and is the only habitat in Wales equivalent to the Natura 2000 type 'bog woodland' (Jackson and McLeod, 2000). It seems to be limited by the rarity of conditions suitable for its development and has a very local distribution (Figure 6.4); only 1 206ha (0.56%) in the lowland parts of Snowdonia were found suitable for its development. The other single NVC sub-community types are of minor extent.

W17a+W17b is the most extensive of the predicted mosaic categories (about 2% of the study area) and comprises a mixture of sites with low altitude (up to 200m) and high rainfall (over 1 800mm) (Figure 6.11).

Overlaying the predicted distributions of oak, ash, beech and wet woodland types revealed where there was some overlap between the preferred habitats for NVC woodland types. Examples are given for oak and ash wood types in Tables 6.7 and 6.8 and Figures 6.13 and 6.14 accordingly, and for the rest in Appendix 4.

The analysis of oakwood types showed a great overlap between sub-communities. 4.3% and 4% of the total area of Snowdonia is suitable for W17c and W11a sub-communities respectively whereas 5.8% of the study area appears as equally suitable for both (Table 6.7). It is worth noting that W17 community and W11a and W10e sub-communities are predicted equally likely to be present in 9.3% of the study area.

The analysis of ashwood types indicated that 33% of the land in Snowdonia is likely to sustain W9a as an individual sub-community whereas all sites suitable for W9b sub-community are also likely to sustain W9a (Table 6.8). Only 0.4% of Snowdonia has the potential of W8e sub-community and 0.3% is predicted equally suitable for W9a.

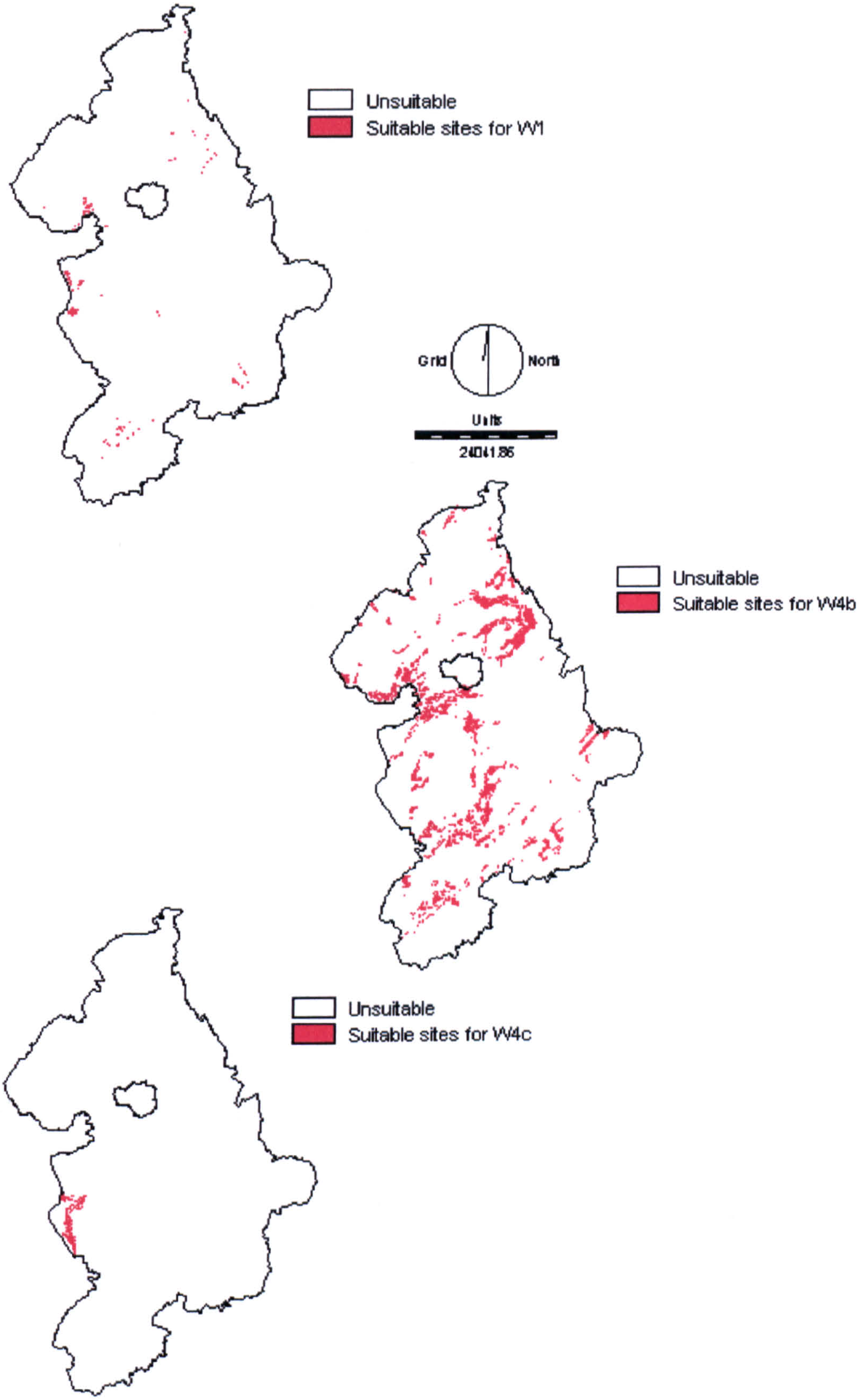


Figure 6.4. Predicted suitable areas for W1 community and W4b and W4c sub-communities.

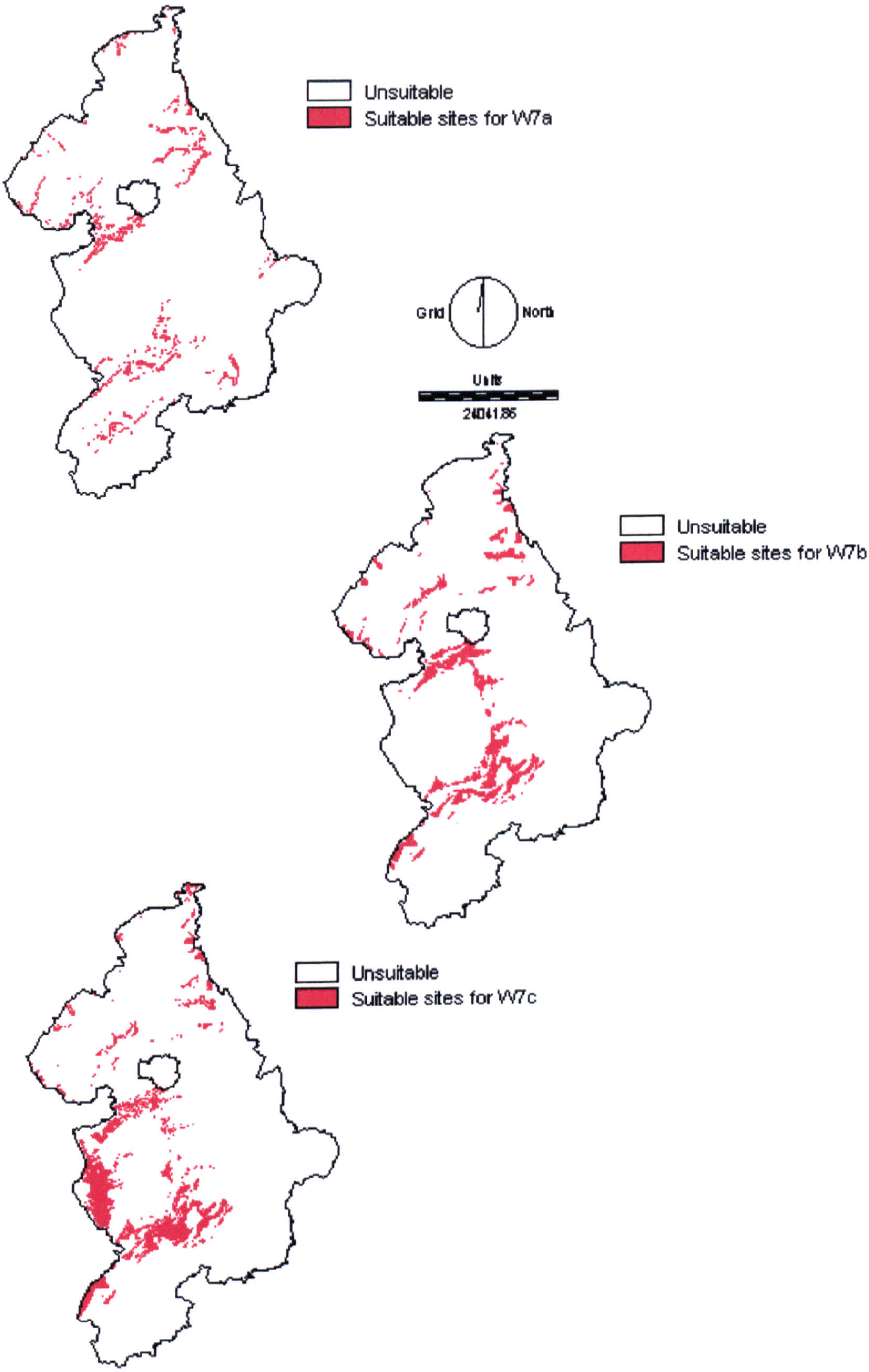


Figure 6.5. Predicted suitable areas for W7 sub-communities.

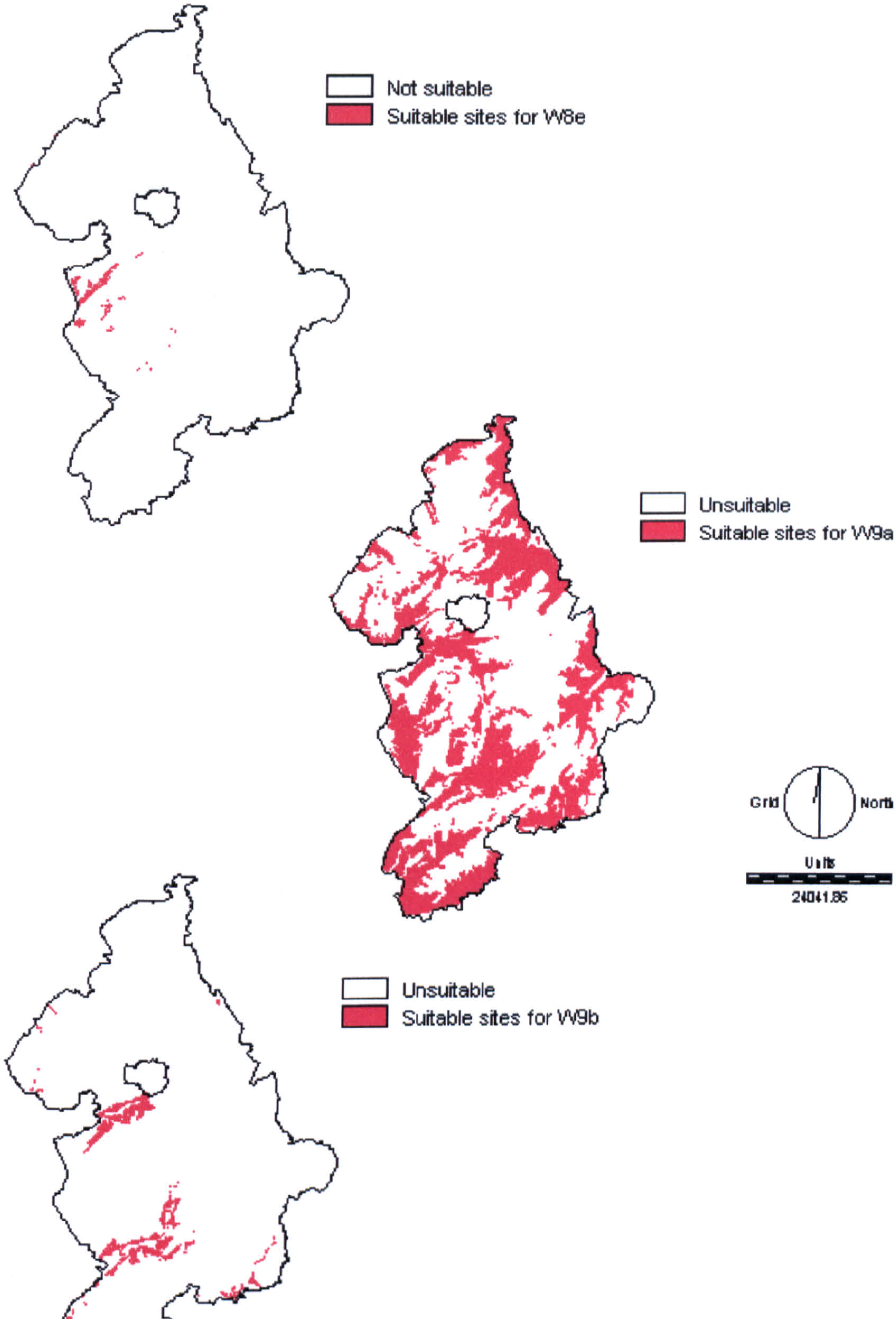


Figure 6.6. Predicted suitable areas for W8e sub-community and W9a and W9b sub-communities.

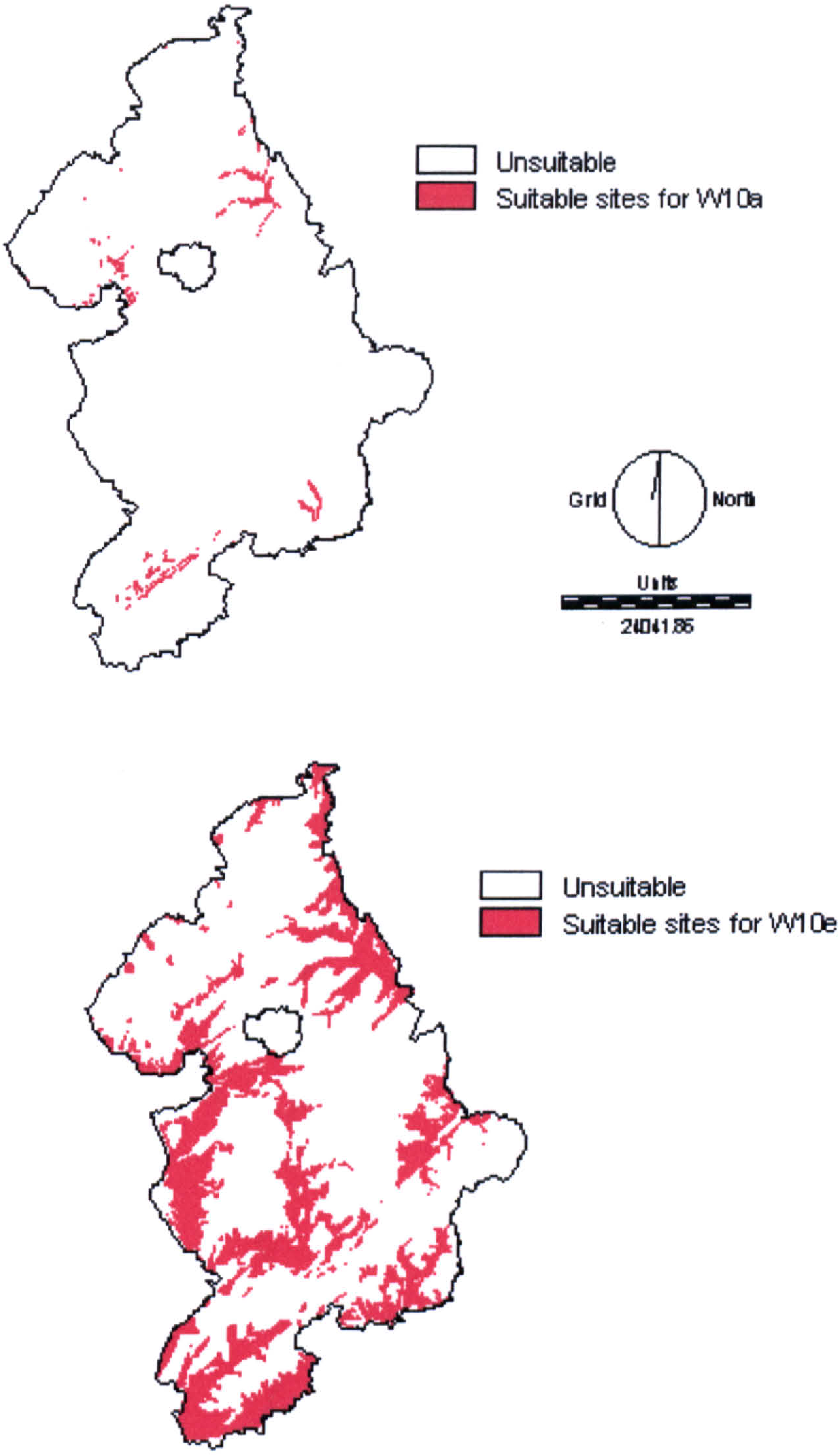


Figure 6.7. Predicted suitable areas for W10a and W10e sub-communities.

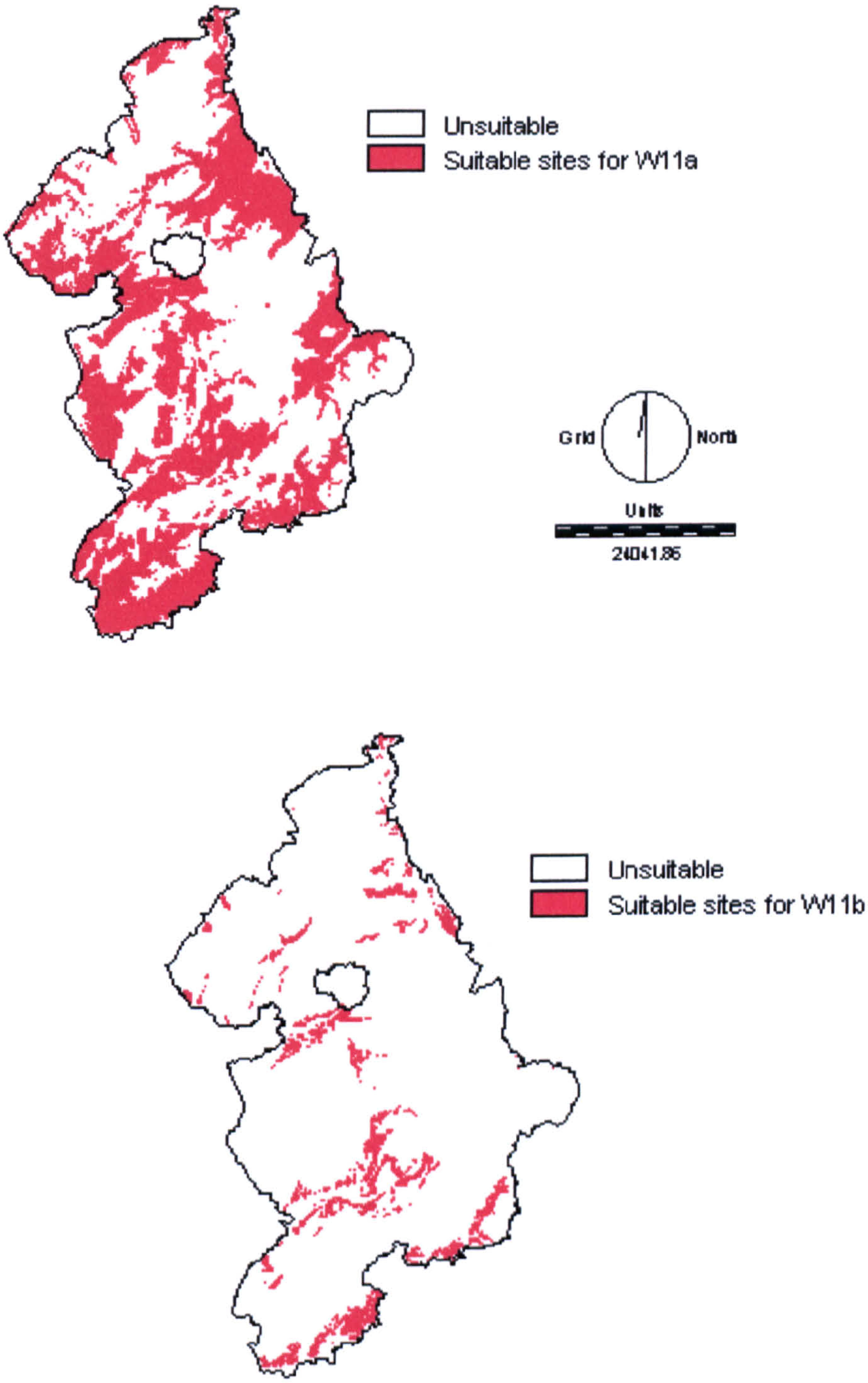


Figure 6.8. Predicted suitable sites for W11a and W11b sub-communities.

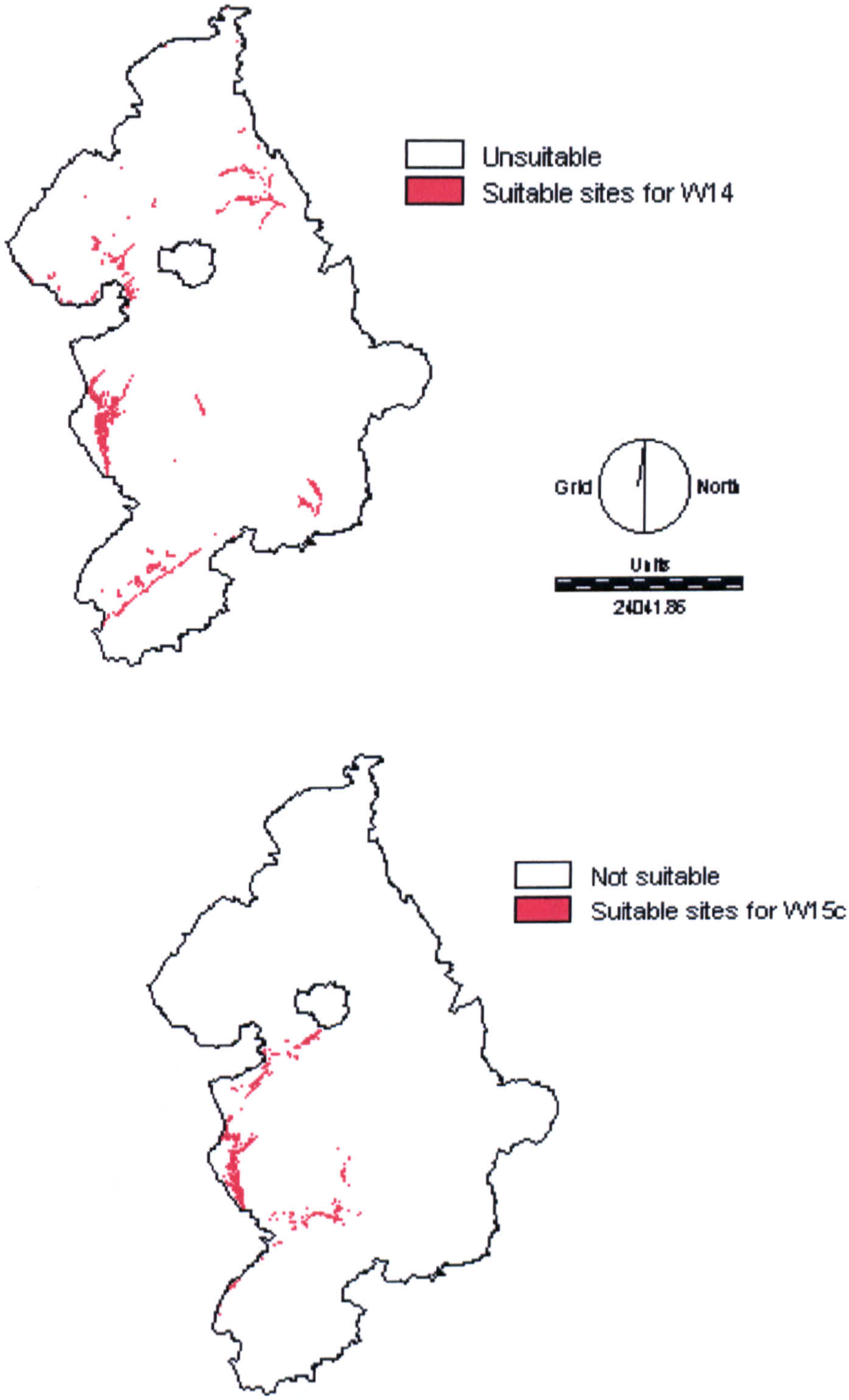


Figure 6.9. Predicted suitable areas for W14 community and W15c sub-community.

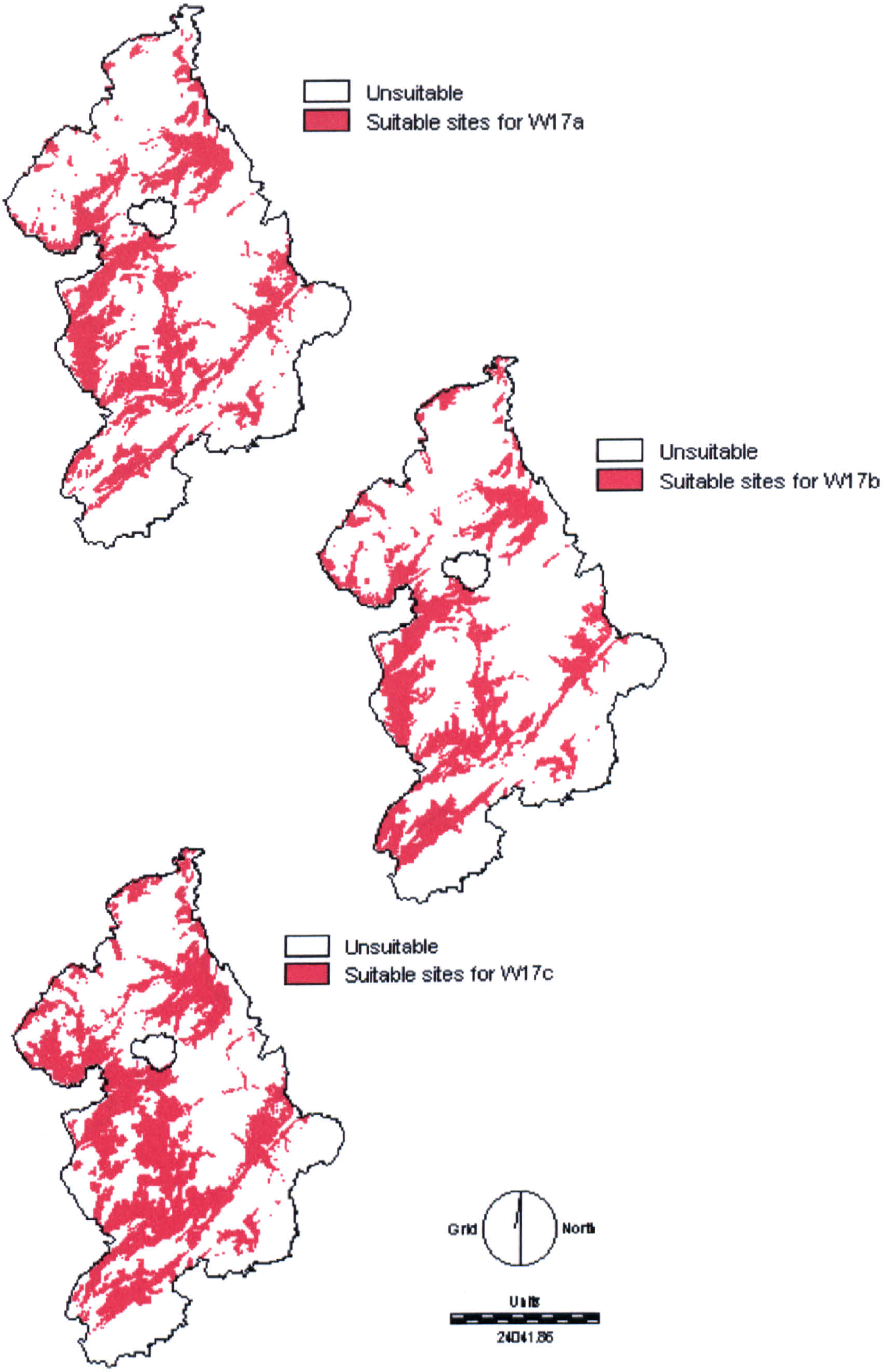


Figure 6.10. Predicted suitable areas for W17 sub-communities.

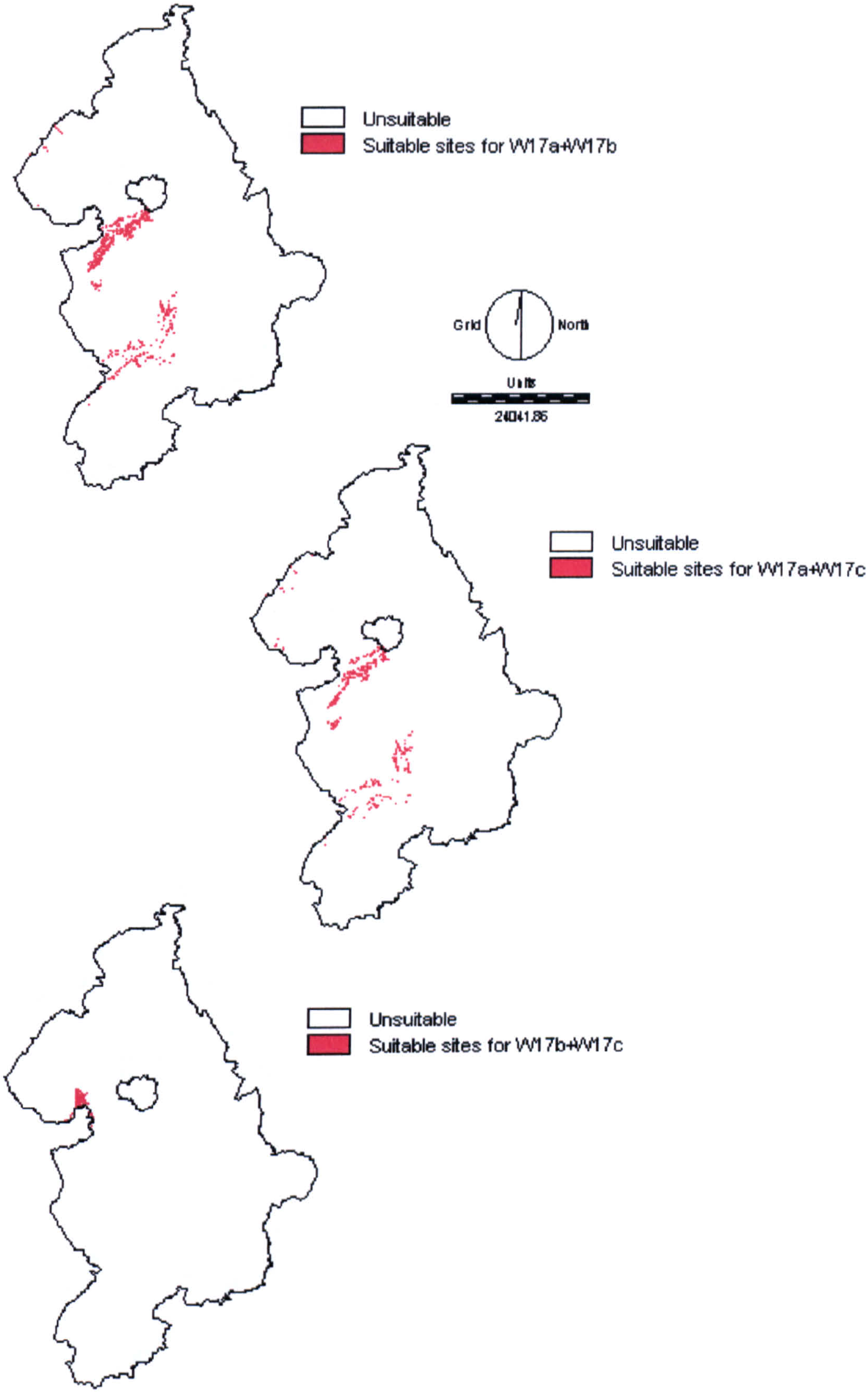


Figure 6.11. Predicted suitable areas for oak woodland mosaics.

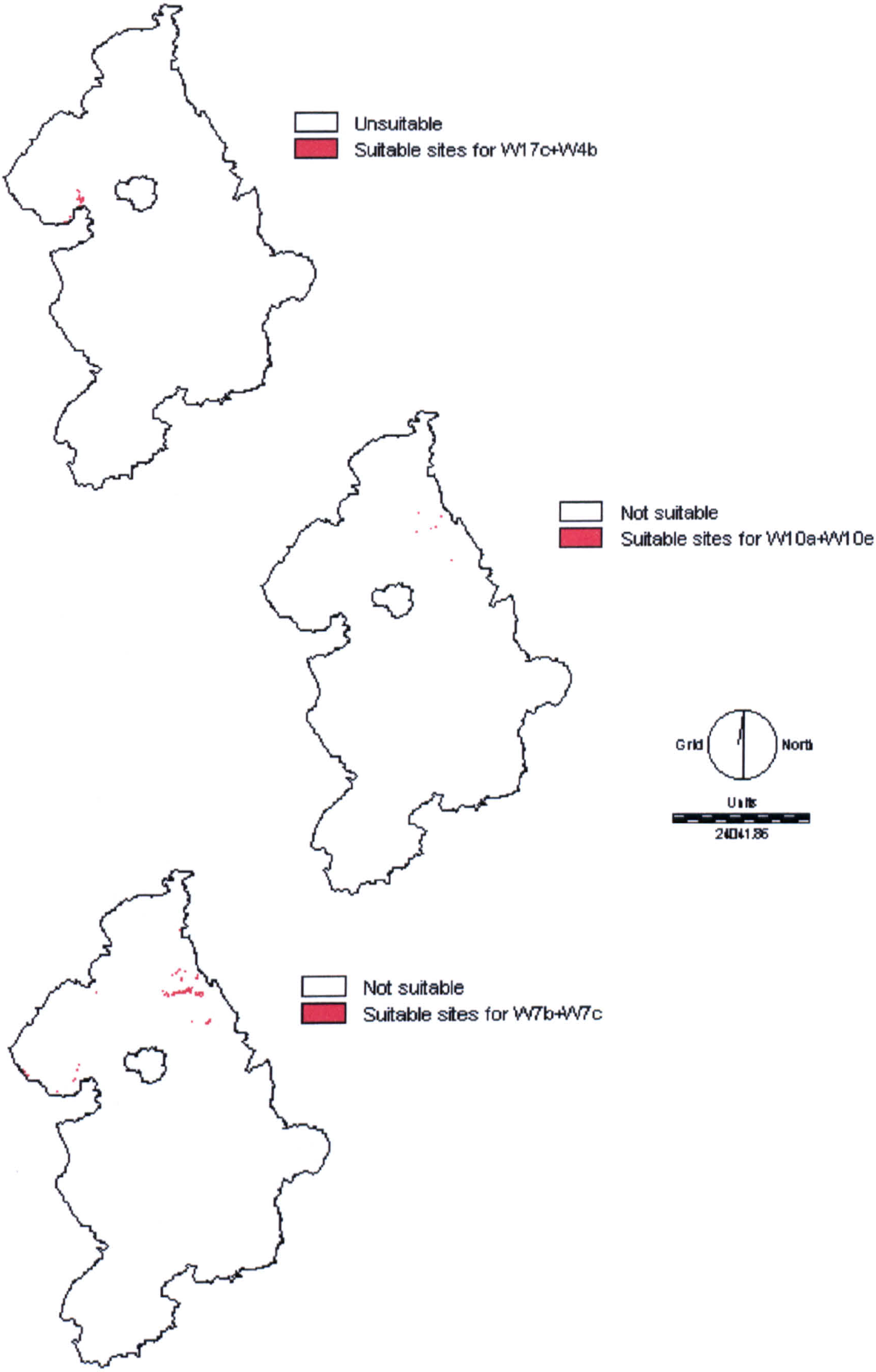


Figure 6.12. Predicted suitable areas for oak and wet woodland mosaics.

Table 6.7. Area analysis of suitable sites for oak woodland types (W10, W11 and W17).

NVC type	Suitable area (ha)	Percentage (%)
W10e	1 533.90	0.72
W11a	8 453.25	3.95
W17a	1 706.40	0.80
W17b	1 217.68	0.57
W17c	9 228.08	4.31
W17a/W17b	237.28	0.11
W17a/W17c	1 137.19	0.53
W17b/W17c	146.34	0.07
W17a/W11a	90.42	0.04
W17b/W11a	743.17	0.35
W17c/W11a	12 441.47	5.81
W17a/W11b	30.55	0.01
W17a/W10e	12.62	0.01
W11a/W10e	6 840.99	3.19
W11b/W10e	0.36	0.00
W17a/W17b/W17c	1 951.31	0.91
W17a/W17c/W11a	4 677.14	2.18
W17b/W17c/W11a	4 052.29	1.89
W17a/W17b/W10e	346.65	0.16
W17a/W11a/W10e	84.01	0.04
W17b/W11a/W10e	1 045.03	0.49
W17c/W11a/W10e	67.08	0.03
W17a/W11b/W10e	99.80	0.05
W11a/W11b/W10e	5 292.76	2.47
W17a/W17b/W17c/W11a	3 985.89	1.86
W17a/W17b/W17c/W10e	3 585.49	1.67
W17a/W17b/W11a/W10e	4 458.26	2.08
W17a/W17c/W11a/W10e	487.10	0.23
W17b/W17c/W11a/W10e	1 175.14	0.55
W17a/W17b/W11b/W10e	80.85	0.04
W17c/W11a/W11b/W10e	27.23	0.01
W17a/W17b/W17c/W11a/W10e	19 958.67	9.32
W17a/W17b/W17c/W11b/W10e	3.72	0.00
W17a/W17c/W11a/W11b/W10e	1 603.08	0.75
W17b/W17c/W11a/W11b/W10e	195.72	0.09
W17a/W17b/W17c/W11a/W11b/W10e	8 316.57	3.88
W17a/W17b/W17c/W11a/W10a/W10e	2 930.93	1.37
W17a/W17b/W17c/W11a/W11b/W10a/W10e	522.24	0.24
Total	108 766.66	50.78
Total area of Snowdonia	214 162	100.00

Figure 6.15 shows the predicted distribution of NVC woodland communities in Snowdonia for current environmental conditions and was produced after reclassifying all NVC sub-communities to form communities. Beech wood communities were not included in this map because they have been perceived as 'un-natural' as beech is only considered native in the southeast of Wales (Rackham, 1997), and seemed to overlap with all the other communities. Mosaics were also not included, as they appeared to overlap with some of the NVC communities and form transitions.

W17 community is predicted to be the most extensive single woodland type (7% of the study area) (Table 6.9) forming in cool, damp, upland conditions on acidic soils and areas of highest rainfall. W17 suitable sites appear to overlap with the other oak, ash and wet woodland types in lower altitudes. 5.7% of the total area of Snowdonia has the potential to sustain both W17 and W11 oakwood types whereas about 5.8% of the area has also potential for W9 ashwood type. It is worth noting that all oak wood types (W17, W11 and W10), W9 ashwood community, and W7 and W4 wet woodland types are all predicted equally likely to be present in 5.8% of the study area. W11 has the potential as an individual community (1.6% of the total area) or it overlaps mainly with W17 and W9 communities (5.8%) or with W10 and W9 communities (5.7%).

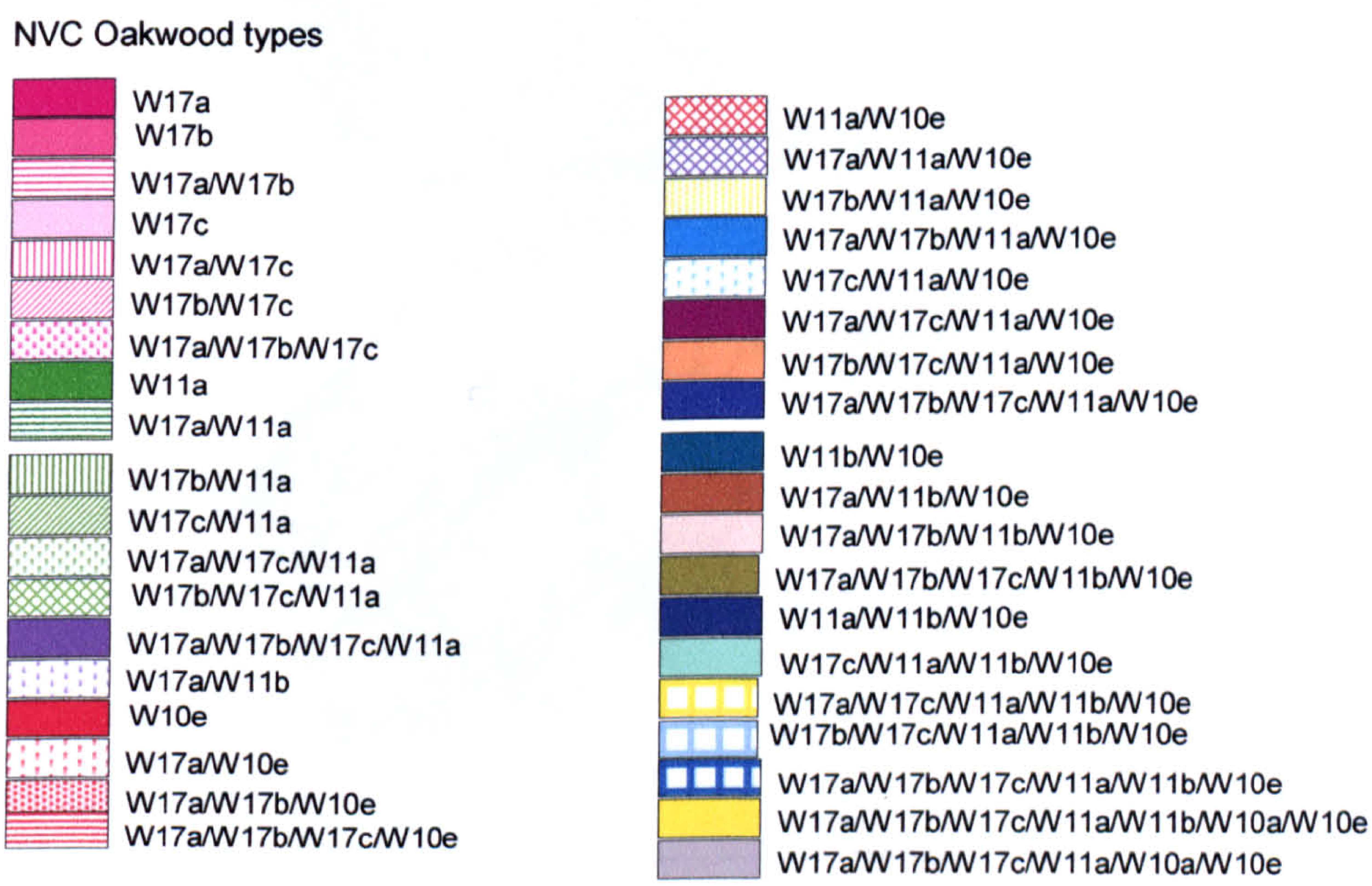


Figure 6.13. Key categories. Predicted suitable sites for NVC oak woodland sub-communities.

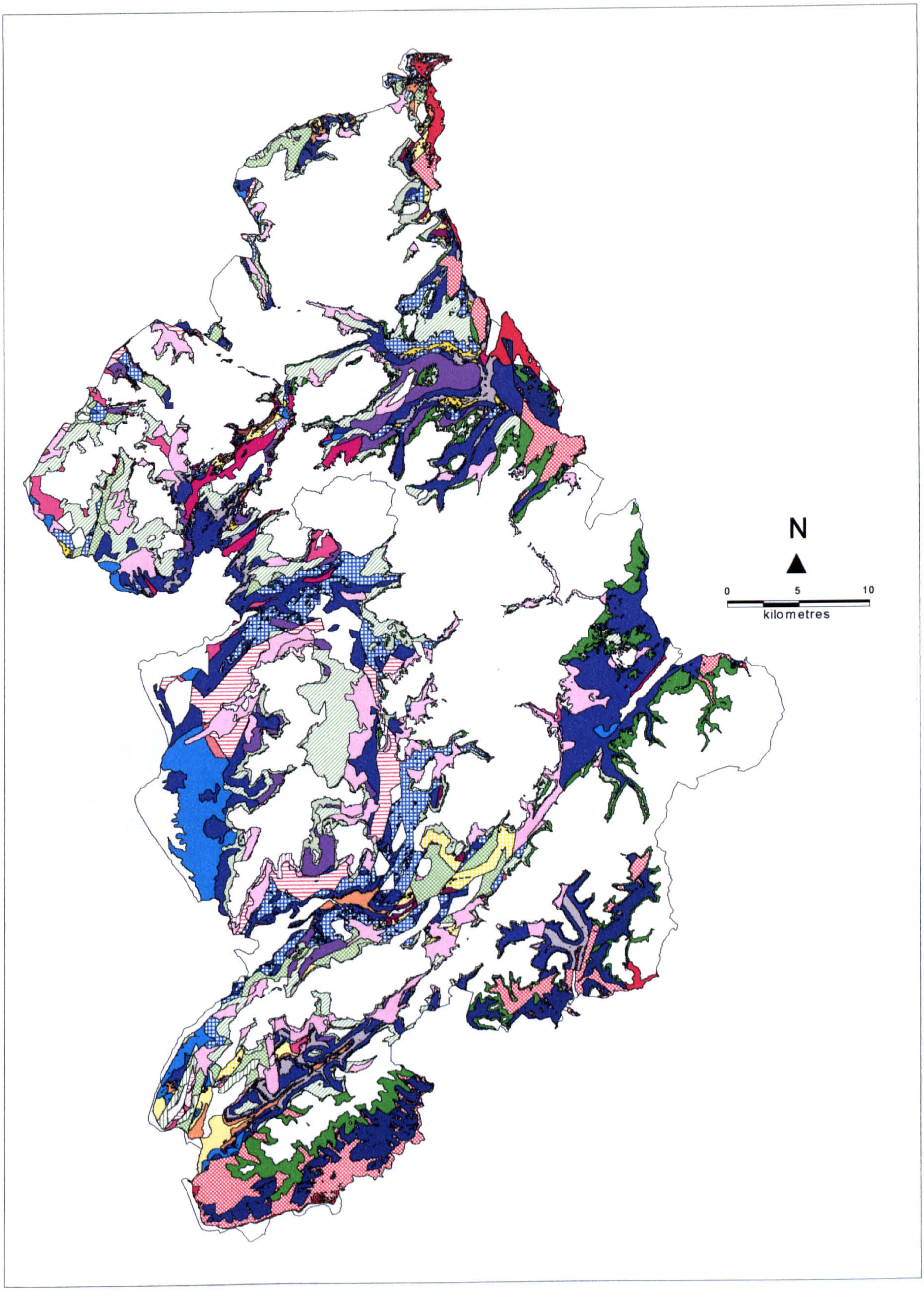


Figure 6.13. Continued. Predicted suitable sites for NVC oak woodland sub-communities.

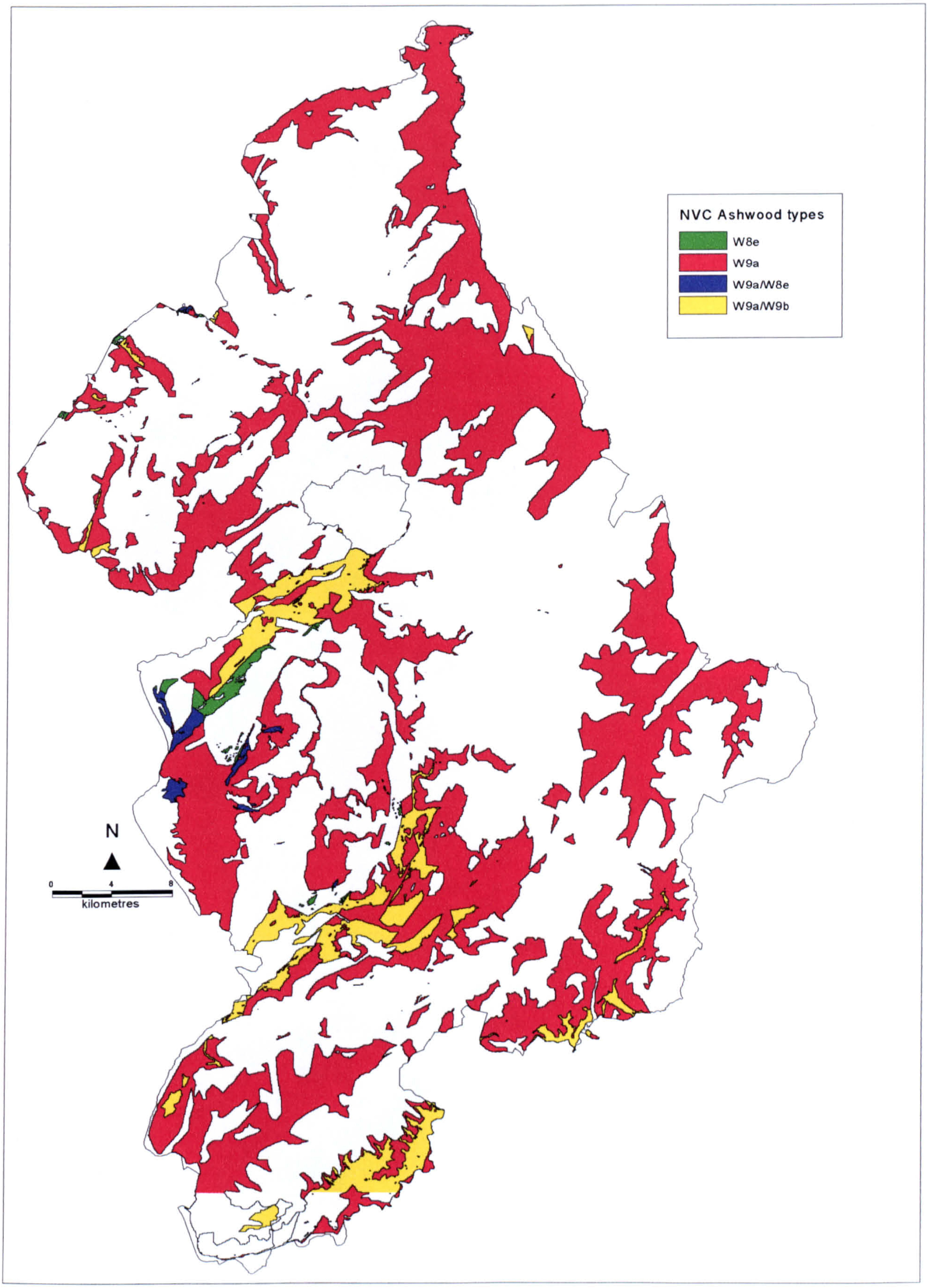


Figure 6.14. Predicted suitable sites for NVC ash woodland sub-communities.

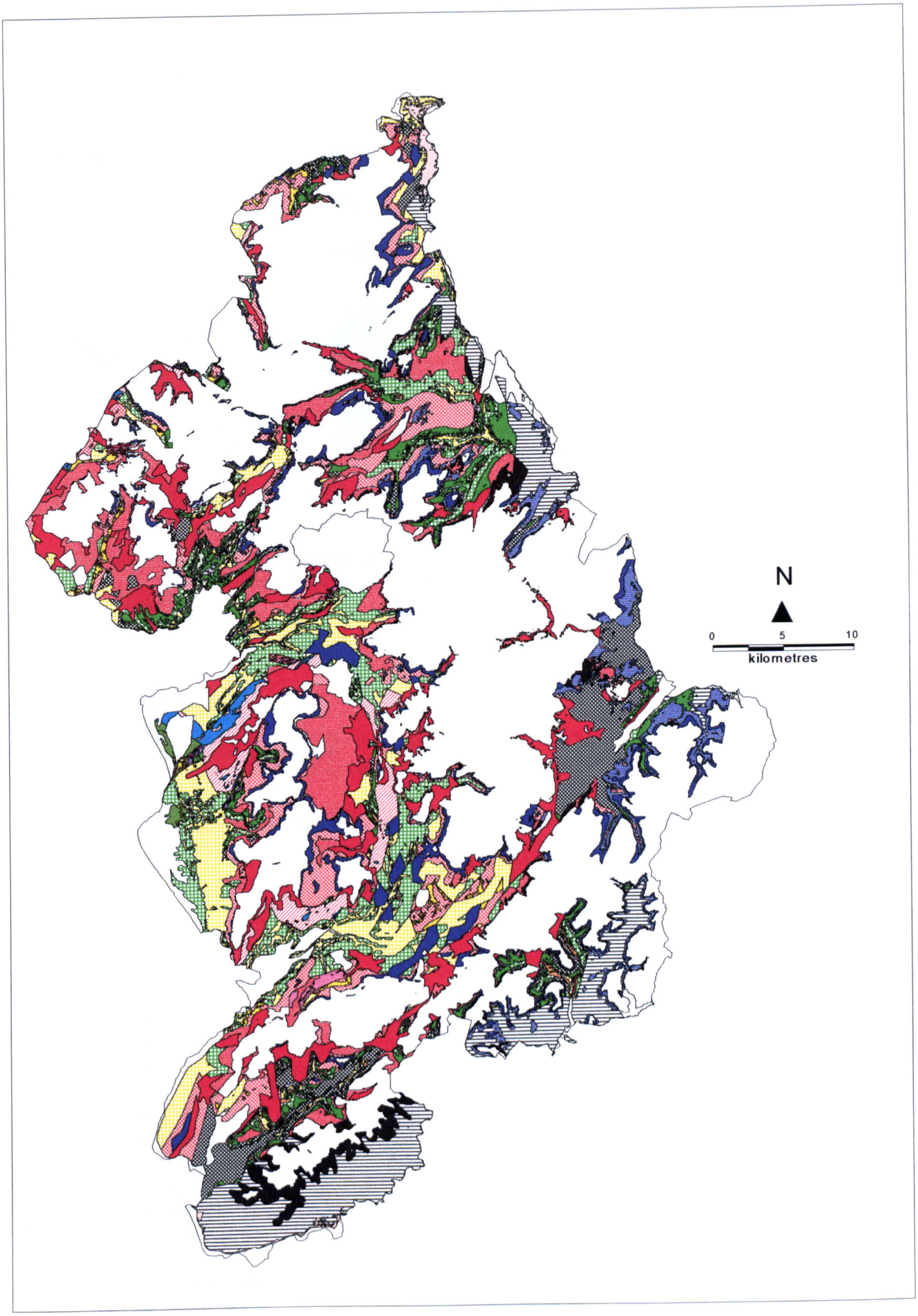


Figure 6.15. Predicted distribution of NVC woodland communities in Snowdonia.

Figure 6.15. Continued. Key categories.

Table 6.8. Area analysis of suitable sites for ash woodland types (W8 and W9).

NVC type	Suitable area (ha)	Percentage (%)
W9a	70 487.90	32.91
W9a/W9b	10 115.25	4.72
W8e	772.25	0.36
W9a/W8e	728.84	0.34
Total	82 104.24	38.33
Total area of Snowdonia	214 162	100.00

Table 6.9. Area analysis of suitable sites for NVC woodland communities.

NVC type	Suitable area (ha)	Percentage (%)
W9	8 462.71	3.95
W10	848.87	0.40
W11	3 454.31	1.61
W17	15 112.48	7.06
W17/W11	12 303.04	5.74
W17/W10	2 985.77	1.39
W17/W9	491.92	0.23
W11/W9	4 998.94	2.33
W10/W9	685.04	0.32
W17/W7	13.42	0.01
W17/W11/W9	12 334.35	5.76
W17/W10/W9	124.61	0.06
W11/W10/W9	12 103.48	5.65
W17/W10/W8	772.25	0.36
W17/W11/W7	407.20	0.19
W17/W9/W7	6.45	0.00
W17/W11/W10/W9	9 424.39	4.40
W17/W11/W9/W7	976.32	0.46
W17/W10/W9/W7	62.13	0.03

Table 6.9. Continued.

W11/W10/W9/W7	30.63	0.01
W17/W11/W10/W9/W8	40.48	0.02
W17/W11/W10/W9/W1	115.63	0.05
W17/W11/W10/W9/W4	5 677.45	2.65
W17/W11/W10/W9/W7	12 131.06	5.66
W17/W11/W10/W9/W8/W4	101.94	0.05
W17/W11/W10/W9/W4/W1	221.33	0.10
W17/W11/W10/W9/W8/W7	72.85	0.03
W17/W11/W10/W9/W7/W4	12 362.96	5.77
W17/W11/W10/W9/W7/W1	4.19	0.00
W17/W11/W10/W9/W8/W7/W4	136.09	0.06
W17/W11/W10/W9/W8/W7/W1	327.22	0.15
W17/W11/W10/W9/W7/W4/W1	389.55	0.18
W17/W11/W10/W9/W8/W7/W4/W1	50.26	0.02
Total	117 229.28	54.74
Total area of Snowdonia	214 162	100.00

6.5.3 BAP Priority Habitat Types

The UK Biodiversity Action Plan (HMSO, 1995) identified six woodland Priority Habitats (then called key habitats) for which HAPs should be produced. These were Lowland beech and yew woodland, Upland mixed ashwood, Upland oakwood, Native pine woodlands, Wet woodland, and Lowland wood-pastures and parkland. Two additional types, Lowland mixed deciduous woodland and Upland birchwoods, have been proposed as new Priority Habitat types (Hall *et al.*, 2001) and are now accepted. The relationship between the BAP Priority Habitats and the NVC woodland types is discussed in Hall and Kirby (1998).

Figure 6.16, showing the predicted distribution of BAP Priority Habitat Types in Snowdonia, was produced after reclassifying the maps of NVC sub-communities according to Hall and Kirby (1998) and Hall *et al.* (2001). Upland mixed ashwood, Upland oakwood and Wet woodland were those Priority Habitats identified. Lowland beech and yew woodland was not included as beech is only considered native in the southeast of Wales (Rackham, 1997), and beech stands are few and local in Snowdonia, probably derived from plantations (usually into existing semi-natural woodland) (Latham, 2001a). Lowland wood-pasture and parkland was also not considered because it is not a vegetation type but a management system and, theoretically at least, the system can arise from any NVC type (Hall *et al.*, 2001). In addition, beech communities although often associated with wood pasture in lowland England have little to do with wood pasture in Snowdonia. Upland birchwoods type was not included as northern birchwoods occur in Scotland. Furthermore, the predicted W10a sites which can form the Lowland mixed deciduous woodland type were included in the Upland oakwood type as it seems that these sites occur locally in Snowdonia in a mosaic with W10e, W11 and W17 types.

Of the total area of the National Park, about 16% has the potential to sustain the Upland oakwood habitat and 4% the Upland mixed ashwood type (Table 6.10). For the majority of the land predicted suitable for a Priority Habitat (approximately 19%) both habitats appear to be equally suitable. The local BAP for Snowdonia emphasised the need to expand these two woodland types and encourages the restoration of their habitats (SNPA, 1999). Wet woodland overlaps with both Upland oakwood and ashwood habitats.

Table 6.10. Predicted suitable sites for BAP Priority Habitat Types.

BAP Priority Habitat	Suitable area (ha)	Percentage (%)
Upland oakwood	34 704.48	16.20
Upland mixed ashwood	8 462.71	3.95
Upland oakwood/Upland mixed ashwood	40 975.47	19.13
Upland oakwood/Wet woodland	420.61	0.20
Upland oakwood/Upland mixed ashwood/Wet woodland	32 666.07	15.25
Total	117 229.34	54.73
Total area of Snowdonia	214 162	100.00

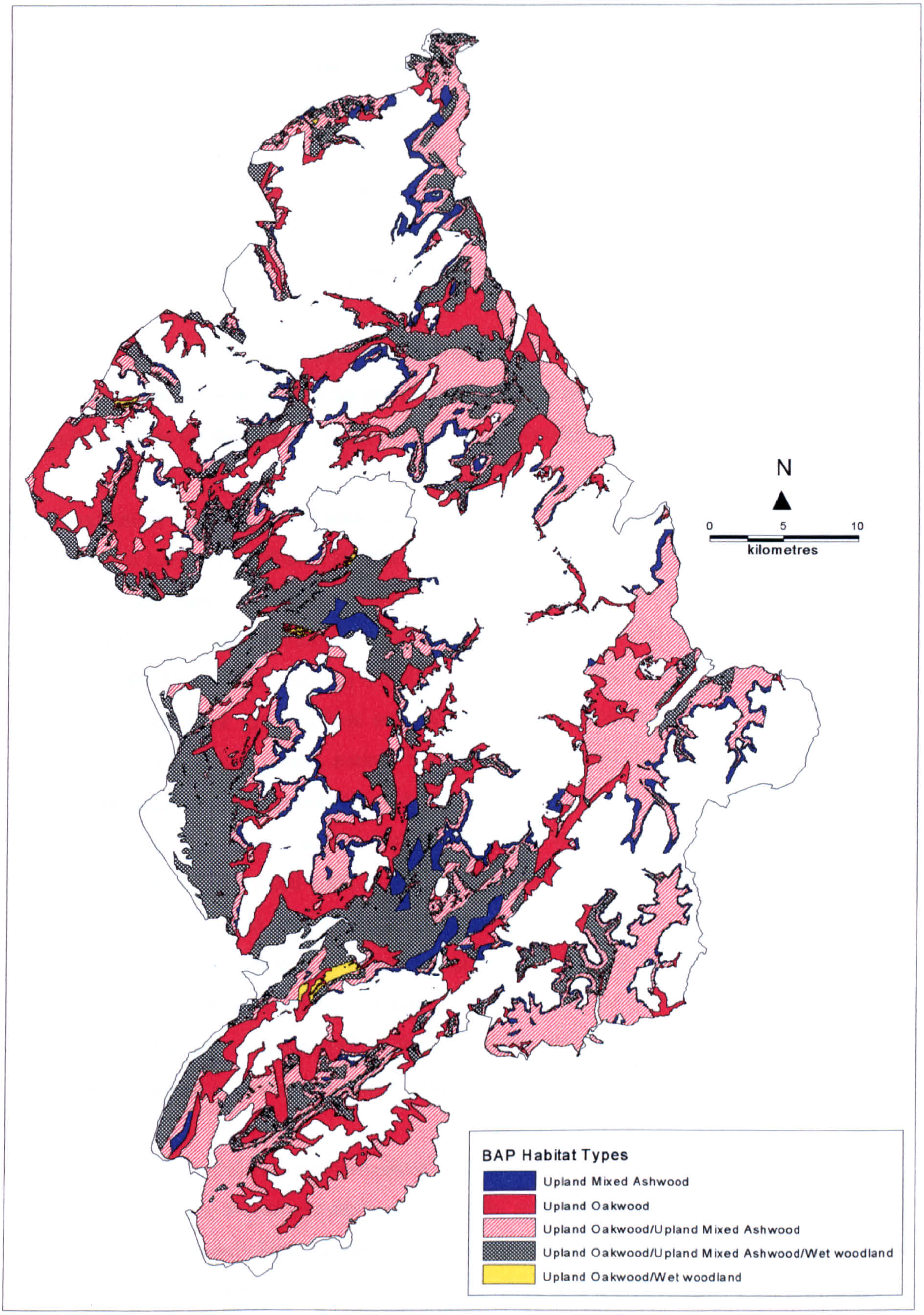


Figure 6.16. Biodiversity Action Plan Priority Habitat Types for Snowdonia as predicted by the *NVC Model*.

6.5.4 NVC woodland for priority areas for woodland expansion

Of the total area of the National Park, 18% is wooded (including clear felled areas and new plantings) and consists of broadleaves, conifers, mixed forest and scrub. Approximately 42% of the unwooded area has the potential to sustain a BAP Priority Habitat type (Table 6.11). Upland oakwood and Upland mixed ashwood Priority Habitats are predicted to have the greatest potential in the study area.

Linking the *NVC Model* with the *Woodland Creation Model* and *Woodland Restoration Model*, produced in the previous Chapter, predicted the appropriate native woodland types for the priority areas for woodland expansion in Snowdonia.

Approximately 5% of the total area of Snowdonia is of high suitability for woodland creation and has the potential to sustain one of the BAP Priority Habitats (Table 6.12). This could be mainly Upland oakwood, Upland mixed ashwood or wet woodland. About 18% of the land with moderate suitability value is suitable for the BAP Priority types, chiefly Upland ash and oak woodland types (about 7%). In addition, only 1% of the National Park given a low suitability value for woodland creation has the potential for a Priority Habitat, mainly Upland oak woodland (0.52%). Furthermore, 31% of the study area projected for a BAP Priority Type has been characterised as not suitable by the *Woodland Creation Model*. This could be sites of existing woodland, those that cannot be planted such as SSSI designated areas, important non-wooded semi-natural habitats and built-up areas, or sites within a buffer zone of 200m around important for conservation non-wooded semi-natural habitats to allow for natural regeneration. Finally, it is noteworthy that 97% (10 853ha) and 87% (37 845ha) of the high (11 247ha) and moderate (43 347ha) suitability land respectively for woodland creation was found as suitable for a BAP Priority Habitat.

Almost all (97%) of the ancient woodland replanted sites receiving a high restoration score (14-16) in the *Woodland Restoration Model* were predicted suitable for a BAP Priority Habitat, mainly Upland oakwood, Upland ashwood and wet woodland (Table 6.13). In addition, 708ha (0.33% of the study area) of the total area of replanted ancient woodland sites with a restoration score 11 (751ha, the majority of the sites) have the potential to sustain a Priority Habitat, chiefly Upland oakwood and ashwood or wet woodland (0.12% of Snowdonia).

Table 6.11. Predicted BAP Priority Habitat Types in Snowdonia in relation to existing wooded areas.

BAP Priority Habitat	Presently wooded land		Non-wooded land	
	(ha)	(%)	(ha)	(%)
Upland oakwood	7 419.62	3.47	27 284.86	12.74
Upland mixed ashwood	1 478.15	0.69	6 984.56	3.26
Upland oakwood/Upland mixed ashwood	9 925.42	4.63	31 050.05	14.50
Upland oakwood/Wet woodland	63.32	0.03	357.30	0.17
Upland oakwood/Upland mixed ashwood/Wet woodland	9 445.68	4.41	23 220.38	10.84
Total	28 332.19	13.23	88 897.15	41.51
Total wooded and non-wooded land	38 831.92	18.13	175 330.08	81.87
Total area of Snowdonia	214 162	100.00		

Table 6.12. Results from linking the *NVC Model* with the *Woodland Creation Model.*

BAP Priority Habitat*	Suitability classes for woodland creation							
	Unsuitable		Low suitability		Moderate suitability		High suitability	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
1	22 605.78	10.56	1 111.86	0.52	9 853.71	4.60	1 133.11	0.53
2	6 745.78	3.15	91.89	0.04	1 234.74	0.58	390.30	0.18
3	20 482.81	9.56	516.54	0.24	15 633.18	7.30	4 342.95	2.03
4	279.46	0.13	6.69	0.00	91.10	0.04	43.37	0.02
5	15 902.15	7.43	788.20	0.37	11 032.06	5.15	4 943.65	2.31
Total	66 015.98	30.83	2 515.18	1.17	37 844.79	17.67	10 853.38	5.07
Total area of suitability class	155 654.12	72.68	3 913.98	1.83	43 347.28	20.24	11 246.62	5.25
Total BAP land	117 229.35							
Total area of Snowdonia	214 162							

*The numbers relate in order to the BAP Priority Habitat types as given in Table 6.11.

Table 6.13. Results from linking the *NVC Model* with the *Woodland Restoration Model.*

BAP Priority Habitat*	Woodland Restoration Score																	
	8		9		10		11		12		13		14		15		16	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)		(ha)	(%)
1	24.30	0.01	109.46	0.05	63.63	0.03	117.73	0.05	24.65	0.01	10.57	0.00	16.30	0.01	1.50	0.00	0.00	0.00
2	23.59	0.01	52.83	0.02	38.90	0.02	21.09	0.01	6.21	0.00	2.65	0.00	1.03	0.00	0.00	0.00	0.12	0.00
3	42.07	0.02	111.75	0.05	256.27	0.12	247.17	0.12	113.65	0.06	39.49	0.02	81.95	0.04	1.11	0.00	3.01	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.36	0.00	0.51	0.00	0.20	0.00	0.12	0.00
5	66.40	0.03	321.29	0.15	332.53	0.16	323.15	0.15	147.41	0.07	82.98	0.04	127.82	0.06	0.44	0.00	34.03	0.02
Total	156.36	0.07	595.33	0.27	691.33	0.32	710.09	0.33	291.92	0.14	136.05	0.06	227.61	0.11	3.24	0.00	37.27	0.02
Total area of score class	160.15	0.07	612.11	2.86	720.06	0.34	750.81	0.35	292.99	0.14	136.45	0.06	235.14	0.11	3.24	0.00	37.27	0.02
Total area of Snowdonia	214162																	

*The numbers relate in order to the BAP Priority Habitat types as given in Table 6.11.

6.5.5 Validation

Twenty four survey sites in Snowdonia (Figure 6.17) with information on NVC woodland present were used to evaluate the performance of the *NVC Model*. For each site, estimates of each NVC woodland sub-community present were supplied from the Countryside Council for Wales. Information on the name of each site, location and date of survey is given in Appendix 4. Because these sites did not have full NVC maps showing the distribution of each woodland type, the point map in Figure 6.17 was overlayed with the predicted NVC woodland sub-community distribution maps, and the NVC sub-communities detected within a circle of 300m radius around each point-survey site were recorded.

Table 6.14 shows the NVC sub-communities found in the survey sites and estimates of their area. There was some ambiguity over the identification of sub-communities (Latham, 2001b). In some instances surveyors did not identify sub-communities because none were considered to fit, whereas in others they simply only recorded to community level. Both these types have been referred to 'u' (unidentified) sub-communities. W10c and W16b oak woodland sub-communities although found present in these sites were not recorded in the survey sites with mapped NVC woodland distribution (Table 6.3), therefore attention focused on the remaining sub-communities. Those NVC sub-communities predicted correctly in each site are shown in yellow, whereas those predicted equally likely to be present in each site are indicated with a red tick (√).

Thirty one out of the forty four NVC sub-community records of presence were accurately predicted within the survey sites by the *NVC Model* (Table 6.14). The presence of W10e, W11a, W17a, W14, W9a and W7c sub-communities, in particular was correctly predicted in all sites. Statistical testing was necessary, however, to compare correct (presence and absence) with incorrect predictions to provide a true measure of the model's success. This was done by performing a chi-squared (X^2) analysis for the overall model to test for association between the predicted classification and the true classification, and a Kappa (K) statistic analysis, described in detail in section 4.3.1, across all sites to assess overall agreement, and also, agreement between sub-communities. The computation of X^2 was performed in

MINITAB rel. 13.1 software (MINITAB, 2000) and of K statistic manually. The results are given in Appendix 4.

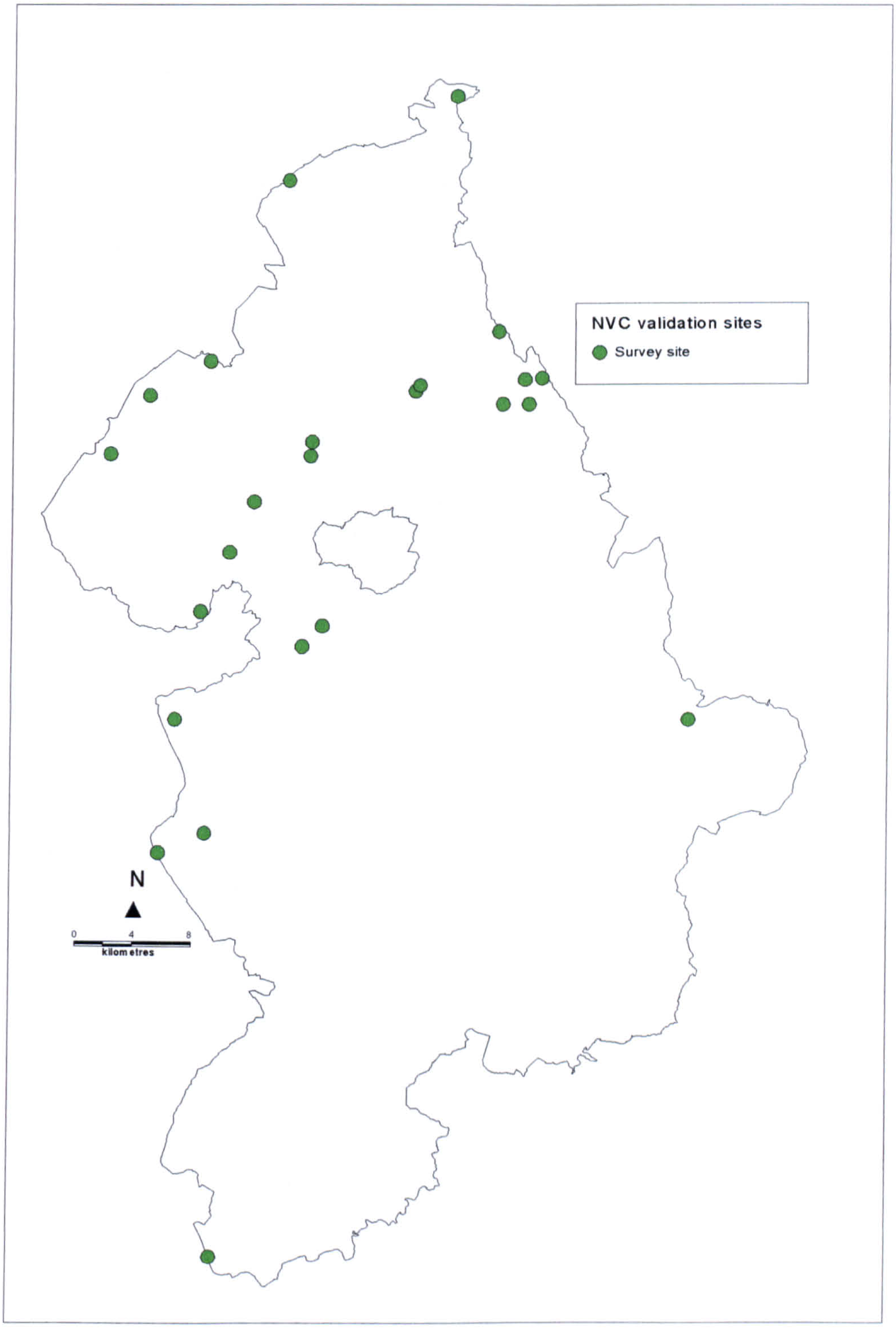


Figure 6.17. Survey sites in Snowdonia with NVC woodland data used in validation.

Table 6.14. NVC woodland sub-communities and estimates of their area recorded in survey sites used for validation (all values in hectares).

Survey sites	NVC woodland sub-communities																				
	W1	W4b	W4c	W7u	W7a	W7b	W7c	W8u	W8e	W9a	W9b	W10a	W10e	W11a	W11b	W14	W15u	W17a	W17b	W17c	**Total**
1	-		-	-		-	-	-	1.00	√-	-	0.25	4.00	√-	-	-	-	√-	4.00	√-	9.25
2	-		-	-		-	-	0.05	-	√-	-	√-	0.10	√-	-	1.90	0.10	√-	0.20	√-	2.85
3	-		-	-		-	-	-	-	-	-	-	√-	2.20	-	-	-	√-	√-	√-	2.20
4	3.01		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.01
5	-		0.05	-		-	-	-	0.40	√-	√-	5.80	√-	0.05	√-	-	-	-	16.60	-	22.90
6	-		-	-	√	-	√-	-	-	√-	-	-	√-	4.60	√-	-	-	-	√-	√-	4.60
7	-		-	-		-	-	-	-	-	-	-	√-	-	-	-	-	-	-	4.70	4.70
8	-	√	1.00	-	√	-	-	-	-	√-	-	-	√-	5.00	-	-	-	√-	√-	√-	6.00
9	2.93		-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.93
10	-		√-	-		0.10	√-	-	-	√-	-	2.50	2.50	√-	-	√-	√-	√-	√-	-	6.65
11	-	√	-	-	√	√-	√-	-	-	√-	-	10.00	√-	√-	√-	-	-	√-	√-	√-	10.00
12	-	√	-	-	√	-	√-	-	-	√-	√-	-	√-	√-	√-	-	√-	1.40	80.50	√-	81.90
13	-	√	-	-	√	√-	√-	-	-	√-	-	6.30	√-	1.00	√-	-	-	√-	9.40	√-	16.70
14	-	√	-	-	√	√-	√-	-	-	0.20	√-	-	2.10	√-	√-	-	√-	√-	1.30	0.50	4.10
15	6.60		-	-		-	√-	-	√-	√-	-	-	√-	√-	-	-	-	√-	√-	√-	6.60
16	-		-	1.00	√	-	-	-	-	√-	-	-	-	√-	4.00	-	-	-	√-	√-	5.00
17	-	√	-	-		-	√-	-	√-	√-	-	-	√-	√-	-	√-	-	√-	√-	12.00	12.00
18	-	√	-	4.00	√	√-	√-	-	-	√-	√-	-	√-	2.00	√-	-	-	√-	√-	√-	6.00
19	-	√	-	-	√	√-	√-	-	-	√-	√-	-	√-	√-	√-	-	-	√-	4.00	√-	4.00
20	-		-	-		8.00	8.00	-	-	√-	8.00	-	√-	√-	-	√-	-	√-	√-	-	24.00
21	√-	√	-	-	√	-	-	-	-	√-	-	√-	√-	√-	-	√-	-	√-	√-	7.00	7.00
22	-		-	-		√-	12.80	-	-	√-	-	-	√-	√-	-	√-	-	√-	√-	-	12.80
23	-		-	-		-	-	-	-	-	-	-	-	-	-	-	-	5.10	-	-	5.10
24	√-	√	-	-	√	-	-	-	-	√-	-	√-	√-	50.00	-	√-	-	√-	√-	√-	50.00

(yellow) NVC sub-communities predicted correctly in the survey site.
√ NVC sub-communities predicted equally likely to be present in the site.

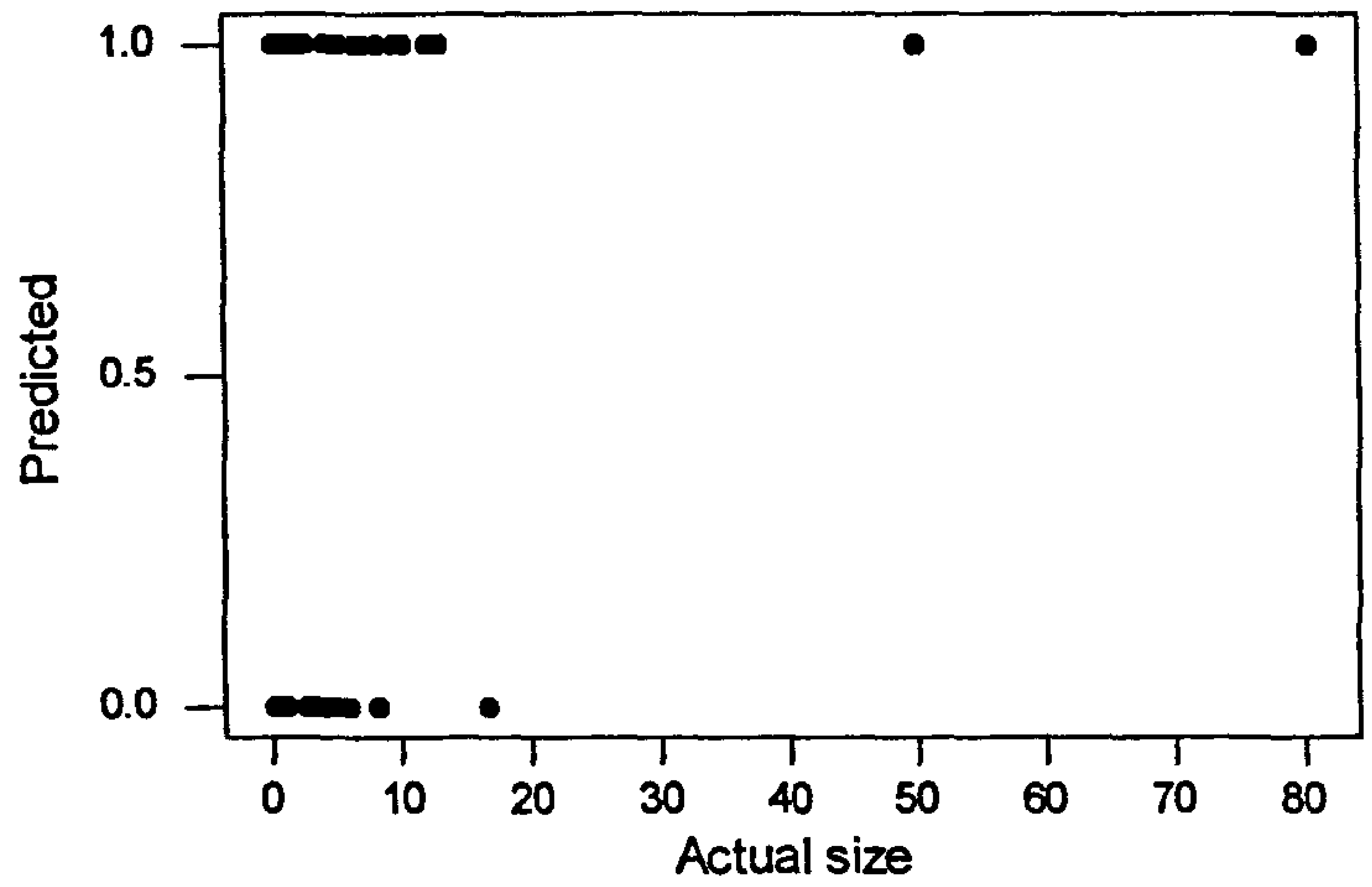


Figure 6.18. Plot of predicted present (with a value of 1) or absent (with a value of 0) NVC sub-communities versus their actual size.

Table 6.15. Assessing the matching of predicted and observed NVC communities.

Predictions	NVC woodland															Overall Model
	W1	W4c	W7b	W7c	W8e	W9a	W9b	W10a	W10e	W11a	W11b	W14	W17a	W17b	W17c	
Correct	20	21	17	14	20	6	18	19	8	11	15	18	8	10	10	215
Incorrect	4	3	7	10	4	18	6	5	16	13	9	6	16	14	14	145
X^2																12.824***
K (Kappa statistic)	0.24	-0.06	0.11	0.17	-0.09	0.02	-0.08	0.41	0.08	0.15	-0.08	0.19	0.06	0.06	0.05	0.13
Agreement	Poor	None	Very Poor	Very Poor	None	None	None	Fair	Very Poor	Very Poor	None	Very Poor	Very Poor	Very Poor	Very Poor	Very Poor

*** = significant at P<0.001.

The X^2 analysis provided very strong evidence in favour of some kind of association between the predicted NVC classification and the observed classification; $X^2_1=12.824$, $P<0.001$ (Table 6.15). Although the majority of presence/absence NVC data (215 predictions) was accurately predicted within the survey sites, the K statistic for the overall model received a very low value (0.13), indicating a very poor agreement between the predicted and observed NVC classification according to the Monserud and Leemans (1992) K thresholds given in section 4.3.1. If there is complete agreement, K=+1. If observed agreement is greater than or equal to chance agreement $K\geq0$, and if observed agreement is less than or equal to chance agreement $K\leq0$ (Fleiss, 1981).

The situation appeared no better, overall, for the individual NVC sub-communities (Table 6.15). The agreement ranged from none (W4c, W8e, W9a, W9b and W11b) to fair (W10a). Most of the NVC types were very poorly predicted apart from W1 wet woodland community, showing a poor agreement, and W10a oak woodland sub-community, indicating a much better than the rest fair agreement.

To examine if the low agreement between the predicted and the observed NVC classification was related to the actual size of the NVC sub-communities surveyed in the 24 validation sites, a binary logistic regression was performed in MINITAB (MINITAB, 2000). Binary logistic regression performs logistic regression on a binary response variable[1]. In this study, the response variable y_i was defined to be 0 if a sub-community was predicted absent from site i whereas was present, and 1 if the sub-community was predicted present. Binary logistic regression examined if the probability p_i (the logistic regression equation is provided in session 4.3.1) that a sub-community was predicted present in site i was likely to depend on the surveyed size (covariate) of the sub-community.

The size of the NVC sub-communities ranged from 0.05ha to 80.50ha (Figure 6.18). Fitting the logistic regression indicated that there is no relationship between woodland

[1] A binary variable only has two possible values, such as presence or absence of a particular species.

area and the predicted community value. All MINITAB outputs and an interpretation of the results is provided in Appendix 4.

In order to validate the predicted NVC distributions more objectively the potential distribution of woodland communities was compared with their present distribution in the surveyed sites (Figure 6.3). The cross-tabulation results for each woodland type are given in Appendix 4. The results suggested a very good match between the present and predicted NVC sub-communities in the 29 survey sites in Snowdonia (Table 6.16). The relationship was not perfect, especially for W7b and W14 communities, as some areas within the digitised boundaries of NVC sub-communities were found outside the boundary of the National Park or fall into the water category in the soil map or into areas with no geological data. In all these cases, these areas were excluded from the subsequent analysis.

6.6 Discussion of results

The aim of this study was to examine the environmental relationships of NVC woodland communities and sub-communities present in Snowdonia, and develop a site suitability model that predicts and maps their occurrence for current environmental conditions. The results produced from the analysis are further examined in this session. The focus of this examination is to discuss the methods used to create the model, and also, to examine the considerable geographical overlap detected between the NVC communities.

6.6.1 Methodology applied

About 17% of the woodland cover of Snowdonia has been surveyed using the National Vegetation Classification over the past decade (Latham, in press). In this study, information for all survey sites was assessed, and distribution maps were digitised for use within a GIS. A GIS analysis was carried out to explore the spatial correlations of NVC communities with topography (altitude, slope, aspect), soil and geology type, and climate (temperature, rainfall). The derived relationships were then used to develop a site suitability model (*NVC Model*) that predicted and mapped the occurrence of NVC woodland communities and sub-communities throughout Snowdonia.

Table 6.16. Results from comparing present with predicted NVC woodland sub-communities in the survey sites.

NVC code	Area (ha)		Percentage (%)
	Present	Predicted	
W1	2.37	2.33	98.31
W4b	10.41	10.25	98.46
W4c	2.61	2.61	100.00
W7a	12.58	12.54	99.68
W7b	12.11	10.41	85.96
W7c	20.58	18.92	91.93
W8e	18.04	18.04	100.00
W9a	45.15	41.91	92.82
W9b	9.42	8.86	94.06
W10a	4.00	3.92	98.00
W10e	93.31	87.61	93.89
W11a	113.10	113.06	99.96
W11b	24.69	24.50	99.23
W14	7.08	5.66	79.94
W15c	3.01	3.01	100.00
W17a	167.47	164.94	98.49
W17b	283.22	270.16	95.39
W17c	150.30	144.16	95.91
W17a+W17b	3.36	3.32	98.81
W17a+W17c	3.64	3.60	98.90
W17b+W17c	10.01	9.97	99.60
W17c+W4b	0.99	0.91	91.92
W10a+W10e	0.59	0.59	100.00
W7b+W7c	0.95	0.95	100.00
Unclassified land	13.22	-	-
Total	1 014.43	962.23	

None of the NVC sub-communities was found, as indicated in the matrices produced for each sub-community in Table 6.2, at a greater altitude of 400m. W9a sub-community, and W11a, W17a and W17c oak sub-communities were those found at the highest elevation of 400m and 350m respectively. Presently the altitudinal limit for upland ash woodland within Snowdonia is at *c*450m, at Ffridd Cors y Garnedd (SNPA, 1999). This altitude represents the present distribution of most upland broadleaved woods in the National Park. This present 'anthropogenic tree-line' is mainly a result of woodland clearance and the maintenance of upland rough grasslands with livestock, mainly sheep. To investigate where the 'natural tree-line' would be for upland woodland, altitude was excluded as an environmental factor for W9 and W17 sub-communities, and their distribution was re-examined.

The new distribution of W9 and W17 communities and sub-communities is shown in Figures 6.19 and 6.20. Excluding elevation as an environmental variable limiting their distribution resulted in an increase of their suitable area in Snowdonia (comparing to that in Table 6.6) (Table 6.17). A cross-tabulation of the maps showing the new distribution of these sub-communities against altitude gave an indication of where their tree line would be. All suitable areas for W9 ash woodland fall into 0-600m elevation (Table 6.18). This altitudinal limit seems reasonable given the fact that the 'natural tree-line' is close to 600m (Hale *et al.*, 1998). Suitable sites for W17 oak community were found at a higher altitude (0-450m) than that indicated in the surveyed sites (0-350m).

The results of the NVC woodland analysis proved complex, and indicated that many locations were suitable for more than one NVC community. If all variables of significance in determining the presence of individual sub-communities were included in the model, overlap would be minimal. Variables such as grazing levels and land use management of the sites in the National Park could be incorporated as in the study of Sanderson *et al.* (1995). Furthermore, more detailed soil and geology classification data (maps at 1:50 000 and 1:25 000 scale) would have allowed a better agreement between the predicted and observed NVC types. In the current model, the 1:250 000 scale soils and geology maps were compared with NVC sub-community data digitised from maps at a much finer scale (1:10 000 and 1:5 000). This resulted, as Figure 6.21 indicates for a part of the digitised NVC survey sites, in assigning the sub-communities into the same broad soil and geology types.

Table 6.17. Predicted area of W9 and W17 sub-communities in Snowdonia after excluding altitude as an environmental factor.

NVC type	Suitable area (ha)	Percentage (%)
W9a	89 296.56	41.70
W9b	11 081.21	5.17
W9	89 296.56	41.70
W17a	57 733.81	26.96
W17b	62 638.01	29.25
W17c	79 328.60	37.04
W17	90 033.71	42.04
Total area of Snowdonia	214 162	

Table 6.18. Area analysis of elevation classes for W9 and W17 communities without considering altitude as an environmental factor.

Elevation class (m)	Area (ha)	
	W9	W17
0-50	8 276.68	7 339.05
50-100	7 369.56	6 466.56
100-150	10 150.70	9 627.08
150-200	12 353.97	13 317.64
200-250	14 641.53	18 955.59
250-300	12 822.51	18 695.09
300-350	9 565.98	12 603.95
350-400	6 151.05	2 954.51
400-450	4 579.96	74.24
450-500	2 652.06	-
500-550	712.14	-
550-600	20.42	-
>600	-	-
Total	89 296.56	90 033.71

6.6.2 NVC woodland overlap

The NVC woodland analysis indicated many overlaps between the NVC communities. These overlaps may be a consequence of unaccountable management differences, or perhaps be due to microhabitat variations (*e.g.* bryophytes, rocks) that could not be detected by the data sets used.

Although the majority of NVC communities closely relate to climatic and edaphic parameters, there are some which are affected by management, especially grazing. At low levels of grazing in W11, W16 and W17, species such as *Vaccinium myrtillus* and *Luzula sylvatica* are likely to be prominent, whereas high levels of grazing favours some grasses and bryophytes. These shifts in relative abundance may not affect the classification, but where grazing differences have been maintained for many years the boundaries between sub-communities may be determined by these grazing patterns. Recently grazing by deer in lowland woods has become an issue as well. Grasses such as *Brachypodium sylvaticum* and *Deschampsia cespitosa* have spread through W8 type woodland, blurring the sub-community differences (Hall *et al.*, 2001).

In this study, 5.8% of the total area of Snowdonia was found equally suitable for both W17c and W11a oak sub-communities, whereas W17, W11a and W10e sub-communities were predicted equally likely to be present in 9.3% of the study area.

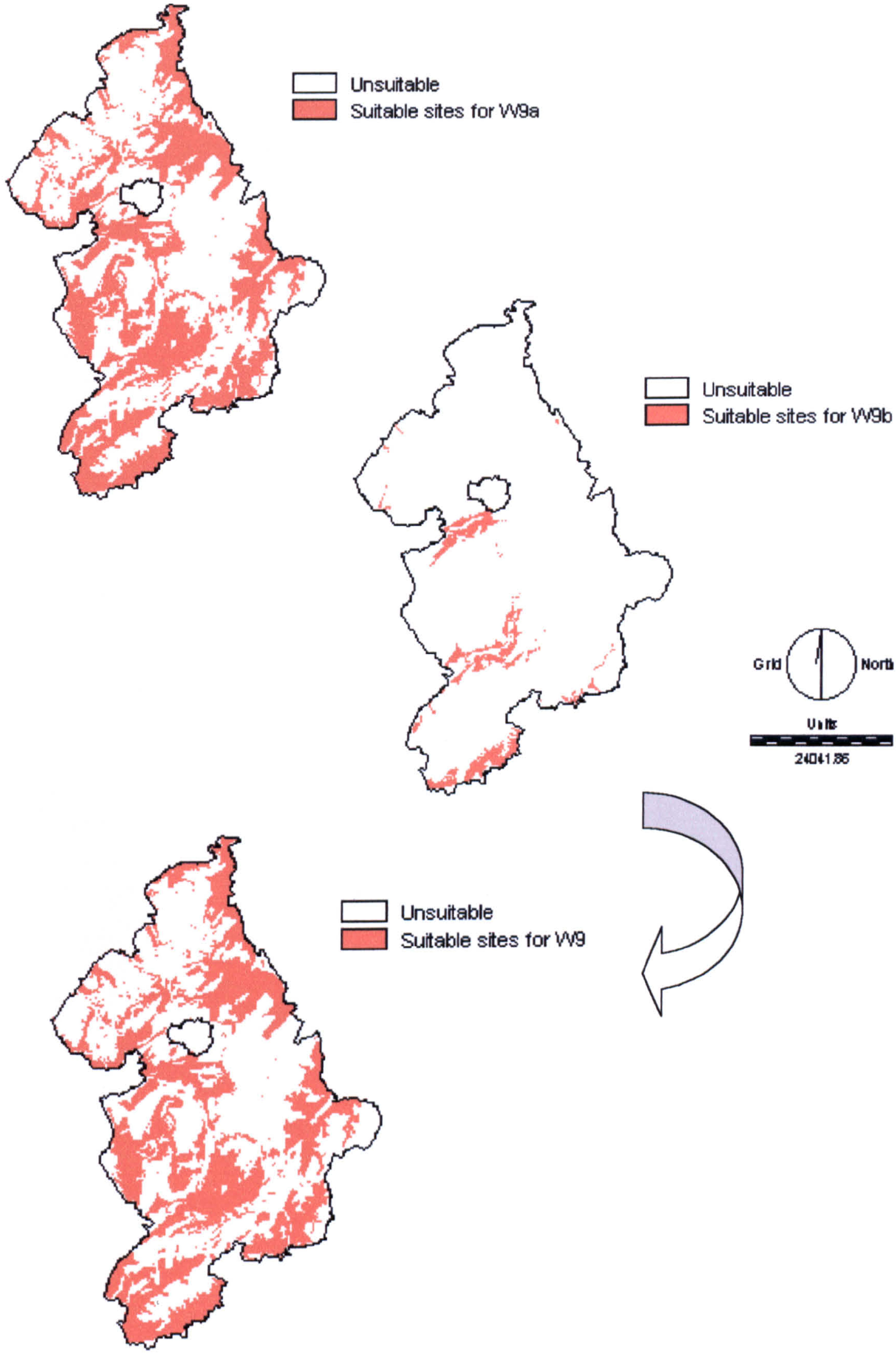


Figure 6.19. Suitable sites for W9 ash community without considering altitude.

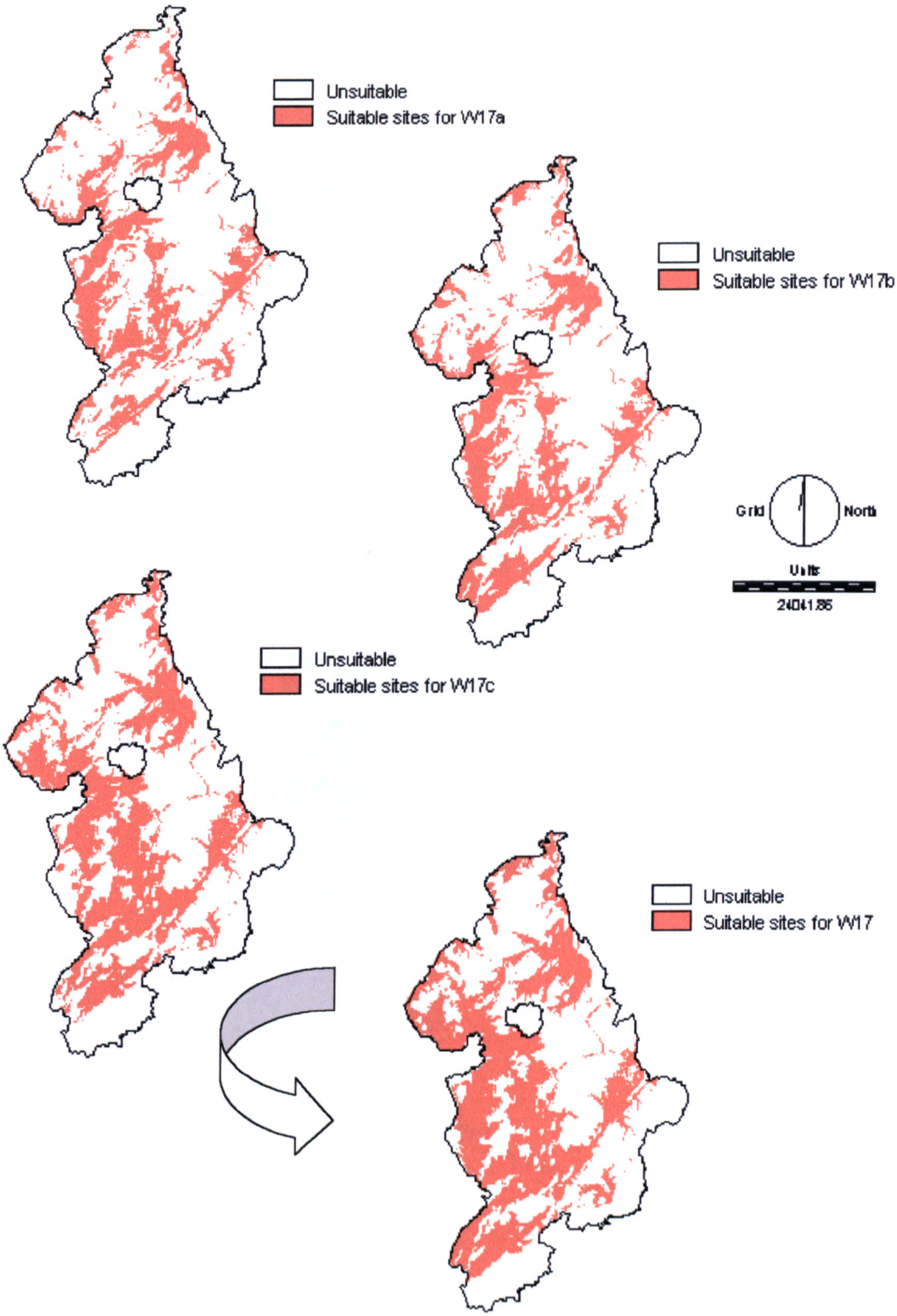


Figure 6.20. Suitable sites for W17 oak community without considering altitude.

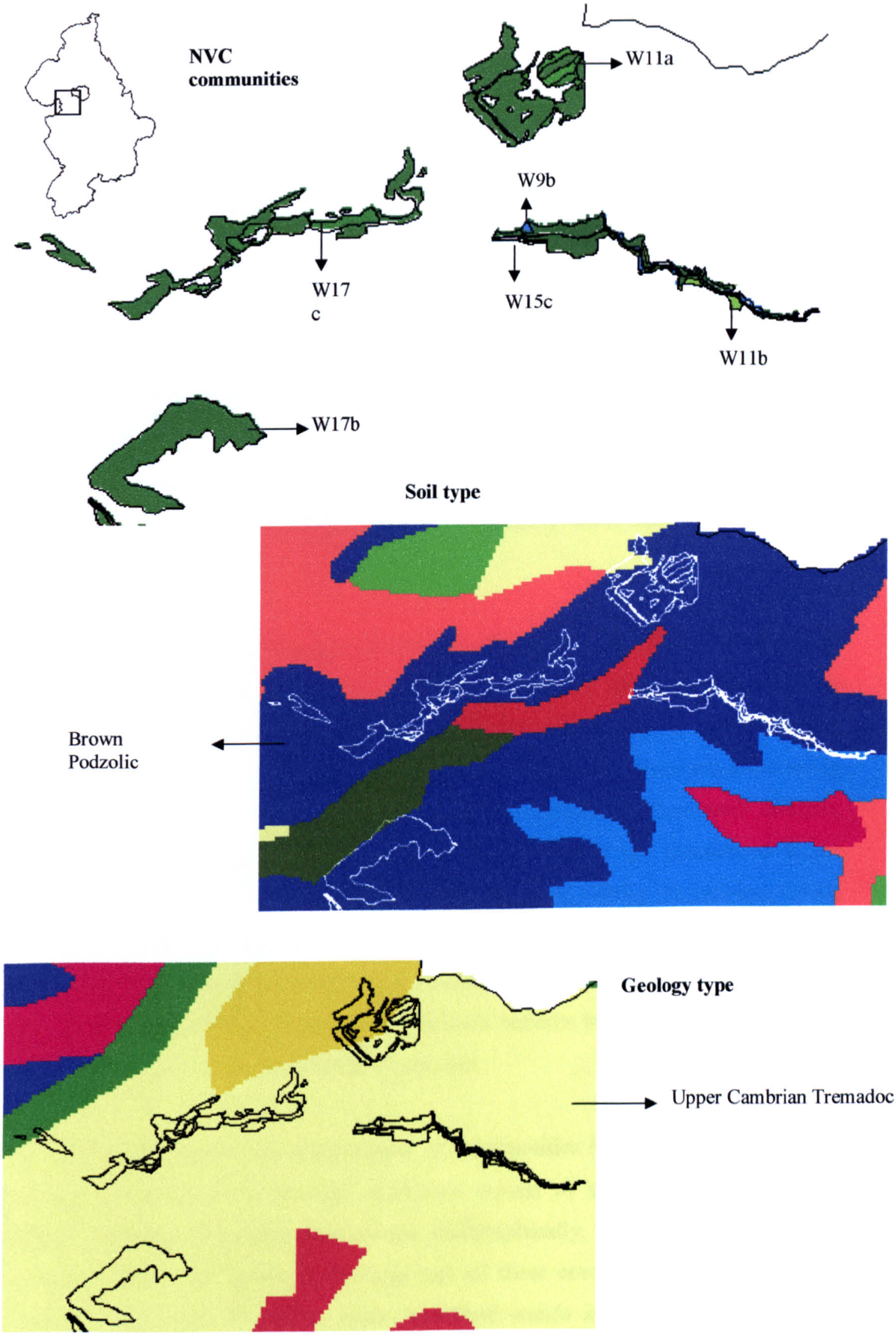


Figure 6.21. Soil and geology types assigned into a number of NVC woodland sub-communities present in a part of the Snowdonia National Park.

W17c is the closest sub-community to W11 (Hall *et al.*, 2001). Castle and Mileto (1998), the surveyors who have done most of the field-work in Wales, reported that the relative richness of bryophytes in the surveyed stands of W11a sub-community was a result of a transition to the W17 community which was often also present and adjacent to the W11 stand. They also stated that, in some cases, where the bryophyte flora was fairly rich but not exceptionally so, it was difficult to distinguish between the W11 or W16 communities and W17. In addition, the W17a sub-communtiy was assigned to stands with an exceptionally rich bryophyte flora whereas the W17b and W17c sub-communties were assigned to stands less rich in bryophytes but with *Vaccinium myrtillus* usually present for W17b and richer in grasses for W17c (Castle and Mileto, 1998). Furthermore, bracken dominated stands of W11 community may be difficult to separate from W10 community, especially W10e sub-community (Hall *et al.*, 2001).

All sites predicted suitable in the *NVC Model* for W10a oak sub-community were equally suitable for W10e. During the validation procedure, also, the W10a records not predicted by the model were found on areas indicated suitable for W10e and W11a. In Wales, W10a (the typical sub-community) stands often contain a scattering of species preferential to the W10e sub-community (including *Dryopteris dilatata*, *Eurhynchium praelongum* and *Holcus mollis*) and several are considered to be transitional to W10e (Castle and Mileto, 1998; Hall *et al.*, 2001). In addition, Castle and Mileto (1998) reported that some times the distinction between W10a and W10e relies on whether the site is grazed or not. Basically, the species which would define it as W10a are grazed out, and the sub-community defaults to W10e. Therefore, these two sub-communities can be difficult to separate.

The NVC classification has several pairs of communities (*e.g.* W8/W9, W10/W11) that are counterparts for lowland conditions typical of southeastern Britain, and upland conditions of northwestern Britain. Geographically, Wales is on the interface between lowland and upland conditions, and all these communities are represented (Latham, in press.a). Therefore, many woodland stands in Wales are likely to be transitional between upland and lowland types. The analysis of ash woodland types indicated that for some sites in the National Park W8e and W9a are equally likely to be present.

About 5.8% of the study area was predicted to have the potential to sustain all oak wood types (W10, W11 and W17), W9 ashwood community and W4 and W7 wet woodland types. Upland oak woodland is characterised by a predominance of oak and consists mainly of W11 and W17 in their entirety, W10e and W16b. Locally, however, other sub-communities of W10 and W16 may occur in a mosaic with the main types. On more base-rich soils patches of Upland ash woodland (W8, W9) may also occur along with the oak stands, while on wet areas such as along stream sides Wet woodland patches (mainly W4, W7) may be common (Hall and Kirby, 1998). Furthermore, in many upland woods small areas of W9 occur at the base of slopes or along flush lines, and there may be a graduation from oak communities (W11, W17) through W9 to W7 woodland over quite short distances (Hall *et al.*, 2001).

W1, W4 and W7 wet woodland types present in Snowdonia were predicted on sites equally suitable for oak or oak and ash woodland types. Wet woodlands are distributed throughout the UK, typically on flood-plains, as successional habitats on fens, mires and bogs, and forming mosaics with other woodland types in peaty hollows and hill-side flushes. In upland areas, in particular, alder stands occur in valley bottoms, or flushed hill-sides and water-logged plateaux, frequently forming a mosaic with Upland oak woodland. Ash is often important in these situations, and transitions to Upland mixed ash woodland occur (Hall and Kirby, 1998). W7 community is widespread in Snowdonia, and is very common as tiny fragments on seepage lines on valley sides. Some flushes may be a mosaic of types with, for example, W7b in the centre grading into W7c on drier ground (Hall *et al.*, 2001). Small stands can also occur in association with many other wet woodland types (Latham, 2001b). W7c, particularly, often occurs as a transition between small flushes and the neighbouring vegetation, which is often W10 or W11, or may grade into W9 around flushes in upland woods (Hall *et al.*, 2001).

The relationships between upland woodland NVC communities, therefore, are clearly complex, with subtle variations occurring over small distances in response to local edaphic variations. This complexity must go along way in explaining the large degree of overlap in communities observed in this predictive exercise.

About 38% of the land in Snowdonia was predicted as suitable to sustain upland ashwood, which is much higher than estimated to be actually present (7%-Latham, in press.b). It may reflect long-term management for oak timber crops at expense of ash, so that many oak sites would naturally be ash; or it may be that the sites with richest soils (*i.e.* ash sites) have been preferentially converted to pasture.

In Wales, beech records are concentrated in the southeast, although scattered records occur throughout Wales where beech has been planted on (or has colonised) appropriate soils (Latham, 2001b). Beech communities were poorly represented in the surveys, and presumably are present where people 'decided they should be', rather than where they might naturally occur. Any predictions from them will inevitably have lots of error associated with them (Latham, 2001a). In this study, suitable sites for beech appeared to overlap with all other woodland communities. W14 stands can form transitions or mosaics with W10 (the edaphic equivalent to W14). Oak has a colonising advantage in younger woods, and beech takes over in older stands (Hall *et al.*, 2001). W15 forms on acidic soils and in upland conditions is the equivalent to W17. W15c sub-community found in Snowdonia is characteristically healthy and with great proportion of oak, and something of a transition to Upland oakwood. Indeed, at several sites it co-exists with oak stands. W15c might be expected to form during beech colonisation of Upland oakwood (Latham, 2001b).

To view the NVC woodland overlaps in relation to topography, a 3-dimensional (3D) image of the NVC predicted sites was produced for a part of Snowdonia. The predicted NVC woodland communities for the area around Beddgelert and the mountainous areas surrounding the valley of river Glaslyn are shown in Figure 6.22. The 3D image was produced after exporting the NVC map from the IDRISI GIS to MapInfo GIS and importing it then into Vertical Mapper (Northwood Geoscience, 1999) software. The area of each NVC community predicted in this area of the National Park is given in Table 6.19. W17 or both W17 and W11 oakwood types account for most of the area. The remaining NVC suitable sites have the potential to sustain a combination of oakwood types (W10, W11, W17) with W9 ash woodland

and, in most cases, a wet woodland type (W1, W4, W7). It seems that W17, W11 (or a mosaic of both) and W9 are concentrated as individual communities in the upland sites of the sample area. As elevation decreases these communities grade into transitions between them. Some upland sites, probably flushed hill-sides, have the potential to sustain also W4 and W7 wet woodland types. In the valley sides of river Glaslyn, a mosaic of Upland oak woodland, Upland ash woodland and Wet woodland types is predicted to form.

Table 6.19. Area analysis of each NVC woodland community predicted for the part of Snowdonia shown in the 3D image.

NVC type	Suitable area (ha)	Percentage (%)
W9	507.48	0.24
W11	57.58	0.03
W17	1 547.95	0.72
W11/W9	30.39	0.01
W17/W7	3.09	0.00
W17/W9	310.41	0.14
W17/W11	1 709.41	0.80
W17/W9/W7	6.45	0.00
W17/W11/W7	0.75	0.00
W17/W10/W9	84.29	0.04
W17/W11/W9	665.25	0.31
W17/W10/W9/W7	57.06	0.03
W17/W11/W9/W7	65.37	0.03
W17/W11/W10/W9	467.55	0.22
W17/W11/W10/W9/W1	90.78	0.04
W17/W11/W10/W9/W4	593.03	0.28
W17/W11/W10/W9/W7	798.61	0.37
W17/W11/W10/W9/W4/W1	70.68	0.03
W17/W11/W10/W9/W7/W4	401.54	0.19
W17/W11/W10/W9/W7/W4/W1	1.82	0.00
Total suitable NVC area	7 469.49	3.48
Total area of Snowdonia	214 162	100.00

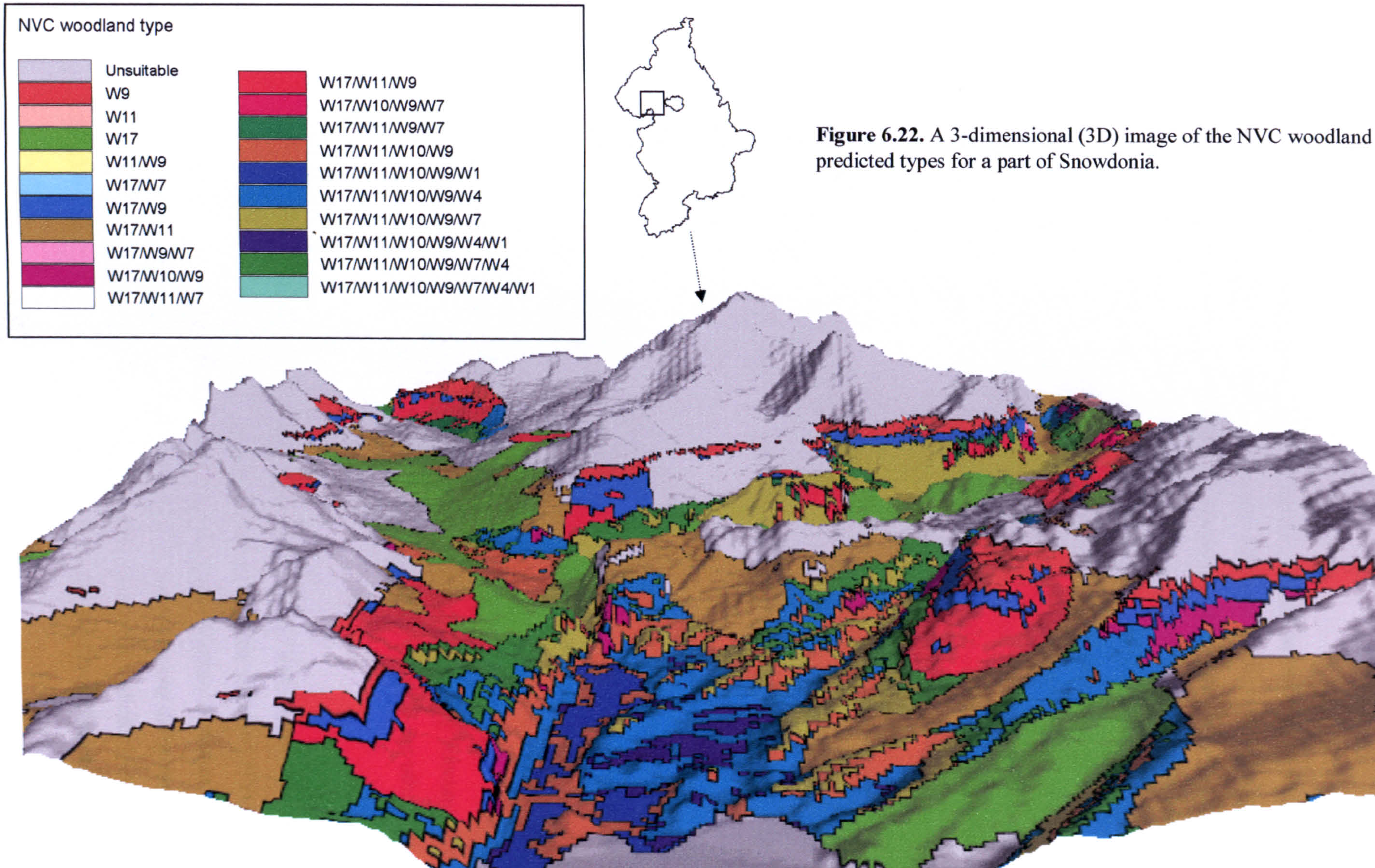


Figure 6.22. A 3-dimensional (3D) image of the NVC woodland predicted types for a part of Snowdonia.

6.6.3 Validation procedure

The *NVC Model,* as a vegetation suitability model, should be seen as a decision support tool and the results produced must be used with care. As Ray *et al.* (in press) noted for the Ecological Site Classification, the existence of a high suitability score for a particular community certainly does not guarantee the community will be found on the site. Neither does it guarantee that the community will develop on the site. There are many other factors that would need to be investigated to predict regeneration likelihood. However, if all other factors important to regeneration are suited on a site, then the suitability model predicts the site is capable of sustaining the woodland community, because, in general, throughout Britain the suited woodland is often found on similar sites.

The model was validated by comparing the predicted distribution of NVC sub-communities with those observed at twenty four sites in the National Park, and with the map showing NVC present distribution in the surveyed sites used for the development of the model.

The results indicated a very good match between the present and predicted NVC sub-communities in the 29 survey sites in Snowdonia with full NVC maps available. However, they suggested a failure of the model to detect the presence of NVC sub-communities at a good level in the 24 validation sites with presence/absence data. The agreement between the predicted and observed sub-communities ranged from none to poor. Only the agreement on W10a seemed to be fair and apparently substantially better than on others. This woodland type showed fewer overlaps with the other sub-communities.

The validation emphasized the multi-overlaps between the NVC types, the most important issue emerging from this study. Since the size of the surveyed NVC sub-communities had no significant effect on their accurate prediction, it seems that the overlaps, which indicated many locations suitable for more than one sub-community, caused the poorly performance of the model. With such 'over-prediction', especially for W9a, W10e and W11a, it was inevitable that at many sites the prediction was right by chance alone.

The agreement on ashwood types (W8e, W9a, W9b) appeared equal to chance agreement (none) as a result of the 'over-prediction', especially for W9a type. This situation was also indicated in Scotland (Gray and Stone, in prep.) where the majority of predicted ashwood was found in existing oakwoods. It was made clear that the resolution of the *Native Woodland Model* was too coarse to pick up all the numerous small fragments of ashwoods which exist as ravine and gorge woodlands across the examined area. The poor correlation was attributed to past management favouring oak. To explain the difference between the NVC survey and the results of the model, the study concluded that both datasets were correct and what they were suggesting was a transition from oakwood to ashwood.

The NVC data for the validation sites were only available as qualitative information. Having detailed mapped distributions for each NVC sub-community currently present in these sites would have allowed the percentage match of the predicted NVC woodland types with those present to be precisely defined.

In addition, further work is necessary to validate the model. About 73% of the total forested area in Snowdonia was predicted to be suitable for a BAP Priority Habitat Type. Some test broadleaved sites could be selected throughout Snowdonia to compare the predicted NVC classification with that observed at these sites. The NVC sub-communities present in these sites could be mapped. This is necessary in order to precisely compare the simulated with the observed woodland types. These test sites could be located on areas the *NVC Model* predicted multi-overlaps of NVC types to detect any transitions or mosaics of different woodland types.

6.7 Conclusions and potential applications

The analysis of NVC woodland sub-communities indicated that W11a oak sub-community has the greatest potential (41% of the area) in the Snowdonia National Park. W9a ash sub-community has also a great potential with 38% of the study area predicted as suitable. W17 is predicted to be the most extensive single woodland type with W17c sub-community accounting for most of the area (36%).

Reclassifying all the NVC sub-communities to form communities and overlaying all predicted NVC maps together revealed that many locations were suitable for more than one NVC community. W17 oak community is predicted as the most extensive single woodland type (7% of the study area), and some of its suitable areas overlap with other oak, ash and wet woodland types in lower altitudes. 5.7% of the total area of Snowdonia has the potential to sustain both W17 and W11 oakwood types whereas about 5.8% of the area has also potential for W9 ashwood type. Furthermore, in some areas (5.8% of the total land) all oak communities (W10, W11, and W17), W9 ash woodland, and W4 and W7 wet woodland types are predicted as equally likely to be present.

As an alternative to targeting NVC woodland types it might be better to consider broader Habitat Action Plan woodland types (*e.g.* as in SNPA (1999) and Latham (2000)). Of the total area of the National Park, about 16% has the potential to sustain the Upland oakwood habitat and 4% the Upland mixed ashwood type. For the majority of the land predicted suitable for a Priority Habitat (about 19%) both habitats appear to be equally suitable. Wet woodland overlapped with both other categories.

The results of the NVC woodland analysis were complex, and indicated multi-overlaps between the communities. These overlaps may be a consequence of unaccountable management differences (*e.g.* grazing management), or perhaps be due to microhabitat variations. The data sets used to derive the environmental relationships of NVC woodland types proved unable, especially the soil and geology data at a scale of 1:250 000, to detect the distinctive floristics of the NVC sub-communities. The results are important as they show that it is hard to predict vegetation communities precisely at a small scale. In addition, they indicate that if the analysis is extended to the entire Wales using all the available NVC records and 1:250 000 soil and geology data, the geographic patterns of the NVC distribution may be shown, but similar overlaps in other locations throughout Wales may be shown as well.

Comparing the *NVC Model* outputs with NVC survey qualitative data indicated a low agreement for most of the NVC woodland sub-communities as a result of the overlaps between the NVC types. A full comparison of the model outputs with NVC mapped survey data has not been possible, since there are not other digitised surveys apart from those used for the development of the model. In any case, however, direct read-across may not be appropriate, as also expressed by Gray and Stone (in prep.), as the model predictions for a site should not be expected to necessarily fit with current woodlands which have been altered, in some cases profoundly, by human actions. Furthermore, the *NVC Model* should not be intended as a tool for detailed site use (the Ecological Site Classification decision support system could be used for this), but rather as a tool to identify patterns and opportunities at wider scales.

It has to be stressed that the predicted NVC woodland maps do not represent a vision for woodlands in Snowdonia, do not prescribe landowners what to do, nor do they make recommendations as to the best use of land. Woodland potential should be balanced with other interests on every site.

In addition to providing useful information about potential distribution of native woodland communities in Snowdonia, the results of the model could also find application in woodland expansion plans and be employed to guide local native woodland restoration projects. Approximately 42% of the unwooded land has the potential to sustain a BAP Priority Habitat Type. 5% of the total area of Snowdonia is of high suitability for woodland creation and has the potential for a Priority Habitat. This could be mainly Upland oakwood, Upland mixed ashwood or Wet woodland. About 18% of the land with moderate suitability value is predicted chiefly suitable for Upland oak and mixed ash woodland types. Almost all of the ancient woodland replanted sites having a high restoration score appeared suitable for a BAP Priority Habitat, mainly Upland oakwood, Upland mixed ashwood and Wet woodland. Furthermore, the *NVC Model* could provide an objective assessment of woodland composition and distribution (including the identification of the 'natural' tree-line for W9 and W17) required for grant applications under the Woodland Grant Scheme.

6.8 Future development

The *NVC Model*, developed in this study is written in the IDRISI Macro Language. A major advantage of this modelling approach is that it can readily be altered or extended to make it more meaningful. More detailed soil and geology data at 1:50 000 and 1:25 000 scale could be used, and unaccountable management variables (*e.g.*

grazing) could be incorporated in the model to improve its accuracy and minimise the overlap between the NVC woodland types.

Around 11 500ha (15% of the total area) of semi-natural broadleaved woodland at 802 sites have been surveyed in Wales, since 1985, using the NVC classification (Latham, 2001b). These NVC records, held in the Countryside Council for Wales, could be used to extend the approach presented in this study for the whole of Wales. Snowdonia as a study area was of small geographic extent with very variable topography. Extending the analysis to the whole of Wales would help to understand the clear geographic patterns that the distribution of NVC records shows (Latham, 2001b), which will often be closely linked to environmental factors such as climate and geology. However, the analysis will have to make use of the soil and geology National maps for Wales at 1:250 000 scale as in this study. Therefore, extending the analysis opens up the possibility of exploring any similar overlaps in other locations throughout Wales.

Analysing the environmental relationships of NVC communities and sub-communities should improve understanding of the NVC woodland distribution. As well as being intrinsically interesting, this sort of information could be used to explore the possible effects of different climate change scenarios on Welsh woodland, and the implications for woodland habitat maintenance, restoration and expansion. Wales is interesting in this respect, with its transitions between British 'upland' and 'lowland' conditions, often over small distances. This may mean that changes in communities in Wales can be more easily detected than elsewhere in Britain (Latham, in press.a).

Ash woodland types (W8, W9) are among those communities restricted to soils whereas W11 and W17 oak woodland types are characteristic of the cooler and wetter north-west of Britain. Climate and topography have an important influence on these vegetation types. To investigate potential future shifts in oak woodland distribution associated with projected climate change, a small experiment was conducted for W17 in Snowdonia. W17 forms in cool, damp, upland conditions on acidic soils, and it is notable for its rich and diverse bryophyte flora with many nationally and internationally rare species. The environmental relationships of W17 (Table 6.2) were used in combination with the UK Climate Impacts Programme (UKCIP98) Low and

High scenarios for the next thirty years (Hulme and Jenkins, 1998) to assess the potential distribution of oakwood in the National Park. The Low and High scenarios, for the next thirty year period centred on the 2020s, predict an increase of 0.5^0C and 1.3^0C in mean annual temperature, and an increase of 2% and 5% in mean annual rainfall respectively. Altitude was not included in the process to allow for altitudinal flexibility in response to climate change.

A greater area of W17 oak woodland is predicted under future projected climatic conditions (Figures 6.23 and 6.24) than for current environmental conditions (Figure 6.20). The majority of the total land of Snowdonia is predicted as suitable for W17 under both climate change scenarios (Table 6.20). A cross-tabulation of the distribution maps against elevation indicated, also, an increase in altitude (Table 6.21). All suitable areas fall into 0-600m elevation. These results may suggest that oak woodland would increase and shift in altitude in response to temperature and rainfall increases. However, this is an area requiring more research.

Table 6.20. Predicted suitable sites for W17 oak community in Snowdonia under the UK Climate Impacts Programme Low and High scenarios for the next thirty years.

NVC type/Climate change scenario	Suitable area (ha)	Percentage (%)
2020s Low scenario		
W17a	69 721.10	32.56
W17b	72 376.05	33.80
W17c	114 061.88	53.26
W17	127 348.69	59.46
2020s High scenario		
W17a	69 749.79	32.57
W17b	71 930.50	33.59
W17c	111 675.31	52.15
W17	126 065.08	58.86
Total area of Snowdonia	214 162	

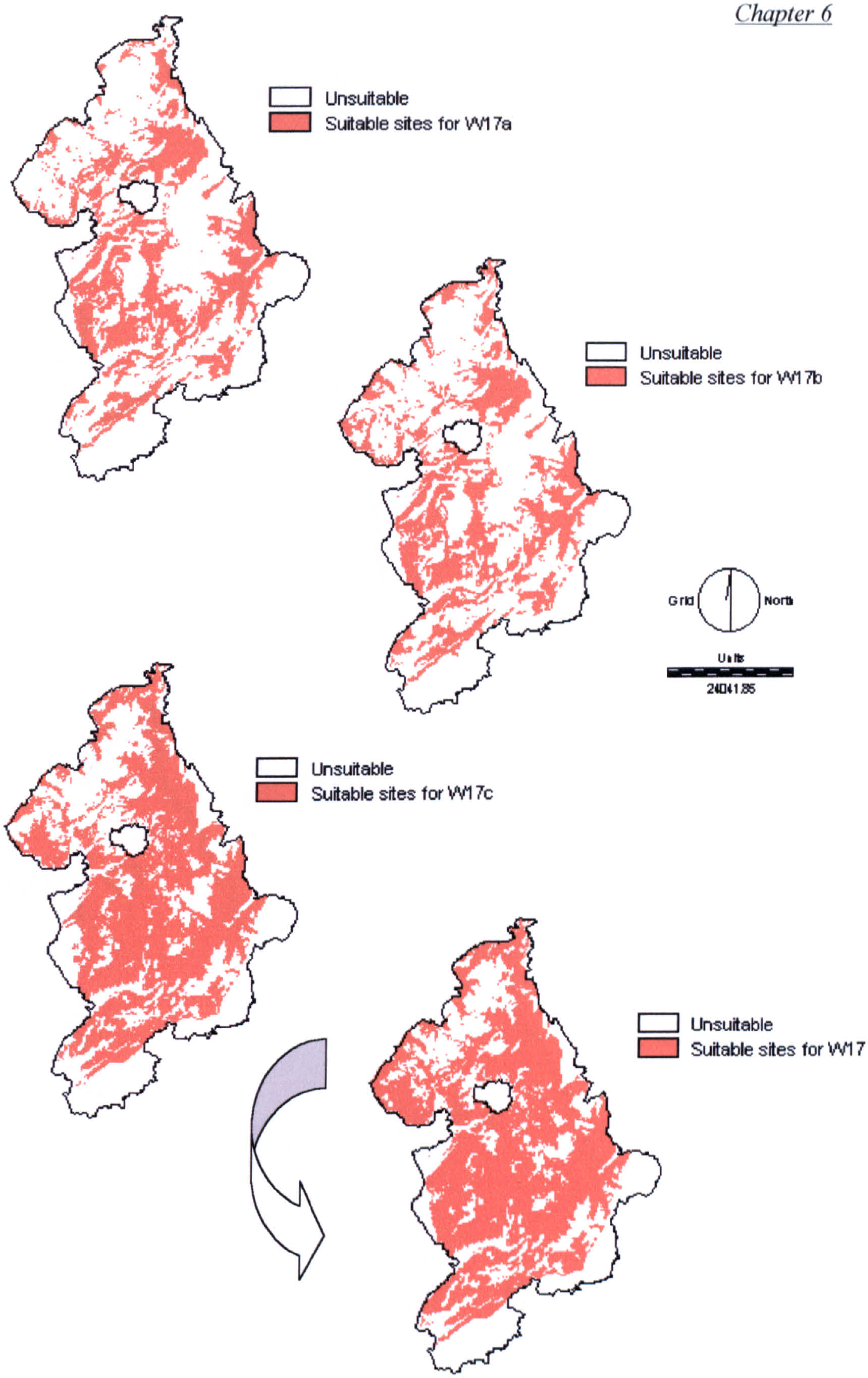


Figure 6.23. Predicted suitable sites for W17 sub-communities under the UK Climate Impacts Programme Low scenario for the next thirty years centred on the 2020s (↑0.5^{0}C in mean annual temperature and ↑2% in mean annual rainfall).

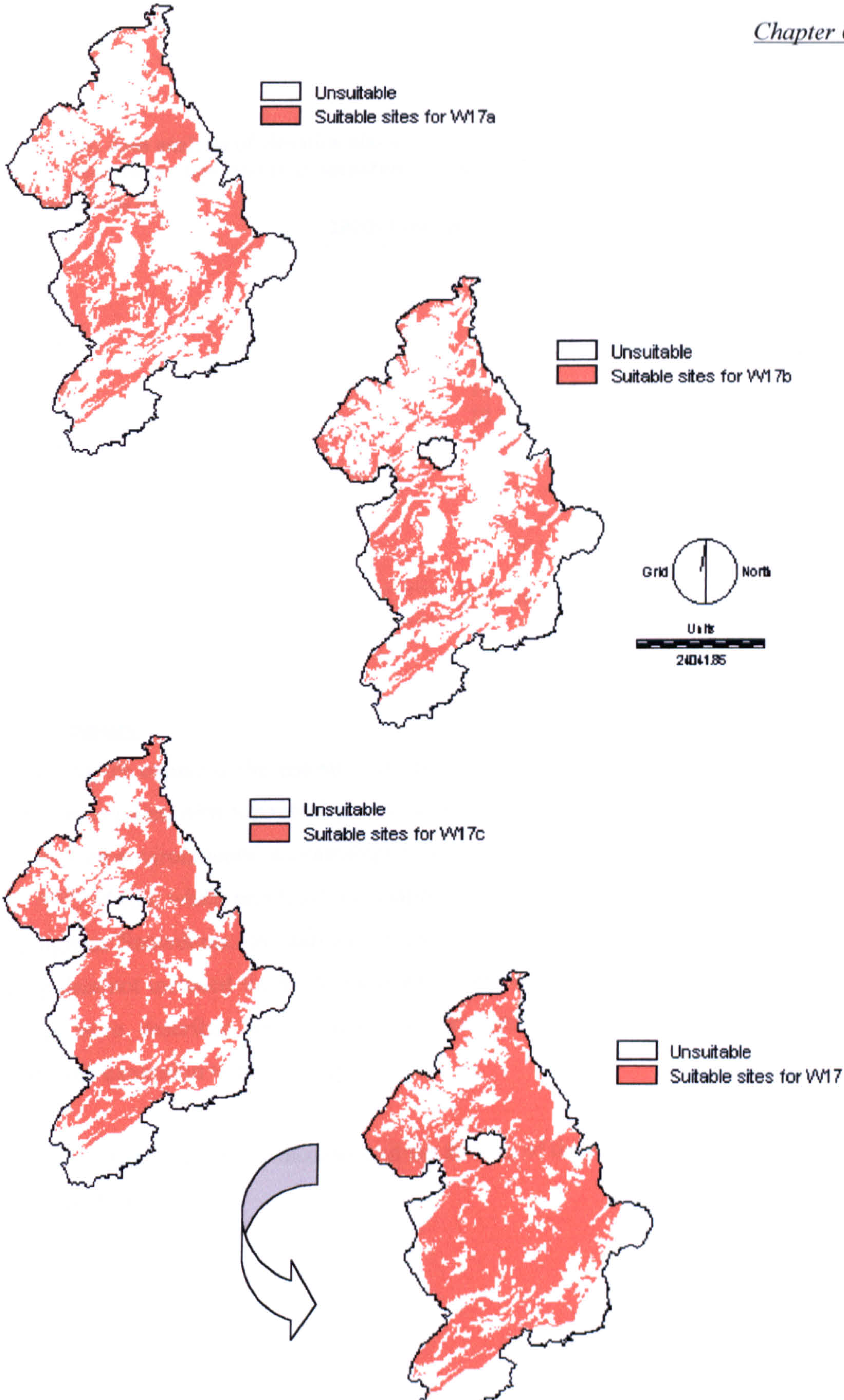


Figure 6.24. Predicted suitable sites for W17 sub-communities under the UK Climate Impacts Programme High scenario for the next thirty years centred on the 2020s (↑1.3^{0}C in mean annual temperature and ↑5% in mean annual rainfall).

Table 6.21. Area analysis of elevation classes for and W17 community under the UK Climate Impacts Programme Low and High scenarios for the next thirty years.

Elevation class (m)	Area of W17 (ha)	
	2020s Low scenario	**2020s High scenario**
0-50	401.94	402.09
50-100	4 480.03	4 489.36
100-150	9 553.75	9 560.13
150-200	13 322.11	13 327.97
200-250	18 963.35	18 933.03
250-300	19 620.92	19 508.65
300-350	18 441.27	18 201.54
350-400	15 456.52	15 142.60
400-450	15 798.31	15 476.51
450-500	9 539.15	9 305.72
500-550	1 731.41	1 677.63
550-600	39.93	39.85
>600	-	-
Total	127 348.69	126 065.08

6.9 Summary

This Chapter explored the spatial correlations of NVC woodland communities and sub-communities with topography, soil, geology and climate. It also described how the derived environmental relationships were used to develop a site suitability model, the *NVC Model*, which predicted and mapped the occurrence of NVC woodland types throughout Snowdonia. In addition, it indicated the way the model was validated using data not included for its development. Furthermore, future developments of the model were described and potential applications of the model to guide native woodland expansion were highlighted.

The next Chapter generally discusses all the finding of the research for the Snowdonia National Park.

CHAPTER 7

'Currently, habitat loss through direct destruction,
changes in land use and various
forms of exploitation is more important than
the effects of climate change, but in the
long-term, the combination of the two
could be devastating...preventing
loss of biodiversity in the word's
protected areas will require careful
planning and management'.

Anon. (1997)
(cited in Dockerty, 1998).

7.0 DISCUSSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

There are areas where there were, for various reasons, limitations in the work or in the conclusions that could be drawn.

GIS procedures were used in Chapter 3 to compare different map-based surveys and look in detail at changes in woodlands of the National Park from 1970 to 2000. This was done by comparing cross-tabulations of the land cover categories in maps for each decade and landscape indices for additional information on patch spatial distribution and shape. The maps from the 1970s and 1980s generated by Silsoe College did not compare well with that from 1990s done by the Forestry Commission because the survey methodologies were markedly different with different interpretations and classification schemes used by the two organisations. As a result, no meaningful changes could be measured.

Rhododendron (*R. ponticum*) forms a significant element of the woody canopies in some parts of Snowdonia. It is not a native species and it was not included in analysis for the expansion of scrub. To the contrary, there have been major attempts to reduce the areas of rhododendron in the National Park. Most land where it is cleared is returned to native woodland. Rhododendron was not identified as a separate class in the Silsoe College surveys and it was excluded from the Forestry Commission surveys. In practice, it is very difficult to distinguish rhododendron from broadleaved scrub unless you have air photographs available for inspection that were taken in winter when the deciduous broadleaves have lost their leaves. Clearly, this is a weakness in the data and may be improved in future surveys.

As other studies suggest (Ball *et al.*, 1982; Bürgi, 1999) changes in the demands of society can be directly linked to changes in land use and land cover. The results of the analysis of woodland changes over the past decade, however, indicated limited evidence for expansion despite current polices to increase the area of native woodlands. This may be attributed to the likely planting of small woods (less than 2ha size) on former agricultural land which were not mapped in the Forestry Commission's survey, and the short time period between the 1980s and 1990s woodland cover maps examined. The 1980s map is from aerial photographs taken in

1990 and the 1990s from 1997. This gives at most 7 years between the two surveys to detect reliably any differences in woodland. Similar results were given in the report launching the Countryside Survey 2000 (Haines-Young *et al.*, 2000). Although the stock of broadleaved woodland in the UK seems to have increased by about 5% since 1990, some continuing losses of broadleaved woodland to coniferous woodland have also occurred. They concluded that it may be too early to detect the effects of recent changes in forestry policy in these data.

Two different surveys were examined in this study. Previous Forestry Commission inventories and the Countryside Survey 2000 which has repeated and extended previous surveys undertaken at intervals over the last 20 years (1978, 1984,1990 and 1998) could also possibly be used for woodland change examination.

The results from the Silsoe College surveys and the Forestry Commission's woodland inventory proved difficult to compare because of the different size of the minimum mapping unit in each survey. A possible development would have been to sieve out of the Silsoe surveys the small woods (less than 2ha) to improve the comparison with the most recent Forestry Commission survey. However, this would mean that any major changes that took place below this size, especially for broadleaved and scrub habitats, could not be detected and important information would be lost. In addition, landscape indices such as the number of patches, mean patch size and mean nearest-neighbour distance would be difficult to interpret and only trends, for example fragmentation over time, could be observed.

The mean distance from a woodland patch to the nearest neighbouring patch of the same type was computed by FRAGSTATS. There might be occasions, however, when distance to any wood is significant. For instance, for species within glades and those which use clear felled areas such as squirrels. This could be further studied. Furthermore, in an attempt to review the effects of inter-fragment distance on the value of fragments as habitat for particular organisms in section 3.5.2. examples of studies in south-east England were used. The SE England situation is not really comparable with that in Wales. The English landscape has been altered more and it is likely that the situation in Wales is not that extreme. Unfortunately no references were found describing the Welsh situation. This work emphasizes the lack of studies in Wales linking habitat diversity with species.

Chapter 4 explored the consequences of climate change on woodland cover. The potential changes in broadleaved and scrub woodland area were modelled consequent on a number of climate change scenarios. The first step was to develop models of temperature and rainfall for the period 1961-1990. These were created using multiple linear regression models with a range of geographic and topographic variables. The variables selected for inclusion in the present study were latitude, longitude, altitude, aspect, slope and distance to the sea. However, preliminary analysis of the rainfall data showed that an additional variable might be added in order to get a better predictive rainfall model.

The mountains of Snowdonia are a major topographic feature with Snowdon, forming the highest and relatively central peak in the region. Distance from Snowdon was included as a variable to see if it improved the rainfall model. There was a small improvement from including this factor and further work would be needed to investigate the reasons for this.

The validity of the temperature and rainfall models was determined by exploring the residuals. Plotting residuals is only one way of testing the validity of a model. Another possible testing would have been a plotting of the variables to check the variance explained by each of the variables used. Because they were so few sites recording climate data in Snowdonia, it was not possible to find additional climate stations to verify the models independently. Clearly this would be desirable for any future work. Climate data are recorded by non-Meteorological Office sites in Snowdonia and these data could possibly be used for verification.

The temperature and rainfall models were used as the basis for logistic regressions (presence/absence) of woodland type and distribution. Changing the models to reflect the 2020 and 2080 UKCIP98 Low and High climate change scenarios for temperature and rainfall gave predictions of the probability of presence and absence of woodland in Snowdonia with climate change. The results emphasized the conceptual difficulties in using fragments of woodland within the realised niche rather than the fundamental niche as the basis for environmental modelling of plant community distributions.

The declining trend in probability of presence for broadleaved and scrub woodland shown under the High climate change scenario may not be likely. The predictive modelling reported here was based on the small geographic area of Snowdonia. Also, the broad environmental tolerances of each species or community in the general woodland types considered were not examined. Perhaps a better approach would have been to look at some individual species in North Wales that could act as climate change indicators, or make use of local expert knowledge to draw conclusions about future woodland change.

In the models produced in this study only climatic and physical geography were used and it was assumed that these were the most important factors controlling the distribution of broadleaved and scrub woodland types. Socio-economic factors and public policy that influence the presence of woodland (Chapter 3), although not taken into account, would have been a possible development and could be examined in future work.

Chapter 5 generated a GIS-based model to address the key question in the biodiversity action plan process of where should new woodland be created or plantations be converted. The criteria developed to identify the priority areas for native woodland expansion took account of the requirements for successful woodland expansion from the nature point of view and specific policy aims (HMSO, 1994; Anon, 1998a; National Assembly for Wales, 2001). The results were interesting and suggested that there is ample land potentially suitable in Snowdonia for new native woodland.

The models developed may be used to aid broad and quantitative decision-making for new native woodlands in the National Park. The approach taken may be further developed by consulting a greater sample of expert people with special interest and good knowledge on the subject to indicate the suitability ranking and weight of native woodlands created on a range of sites. Questionnaires could be sent to a number of people in different organizations in Wales for expert consultation. Local peoples' opinion could also be considered. Ultimately, site visits with a range of these people will be required in order to develop the best options for each site. This would make it easier to identify those landscape and agri-ecomonic constraints that may be of considerable significance in determining whether land is made available for woodland expansion in particular cases. However, the ecological potential only of sites to sustain woodland was considered here. It was outside the scope of this project to examine social and political issues. Another possible development would have been to look at some individual new woodland schemes to see to what extent their location corresponded with the suitability for woodland creation ratings developed here. The new woodland schemes from recent years in Snowdonia are small and few in number, generally unrepresentative of the large extent of land potentially available. It would, however, be interesting to see where they lie on the maps created here.

Chapter 6 developed a further extension of GIS based modelling to the prediction of individual NVC types and BAP priority woodland types. The approach taken was to define the environmental spaces occupied by the fragments of NVC woodland types currently present in the National Park. The environmental spaces were then used as a template to produce maps of similar, potentially suitable sites for the occurrence of each NVC type. There is a problem with this technique, in that the existing examples of NVC woodlands are but a small fragment of the broad tracts of woodland present in the Atlantic period. These small remnants may not be on sites that are typical for that NVC type; indeed they may be at the margins of that niche (see section 4.1.8.7). This modelling approach is different from the studies of Sanderson *et al.* (1995) in England, Macmillan *et al.* (1997) and Towers *et al.* (2000b) in Scotland, and Pyatt *et al.* (2001) for the whole of Britain. It examined the distribution of NVC woodland sub-communities that have been surveyed by CCW in the National Park for current environmental conditions and is not based on expert knowledge and published data.

The results were not as clear-cut as had been hoped because of overlaps in the predicted occurrences of various woodland types. Independent verification of the predictions using non-spatial data for 24 sites revealed that the model produced was very poor. This was not, however, a fault of the modelling but a reflection of the fact that some of the environmental data was at too coarse a scale and that NVC types are not solely determined by environmental factors.

The NVC sub-communities occur and have been mapped at a higher resolution (1:10 000 and 1:5 000 scale) than the environmental parameters used in the analysis, especially soil and geology data (1:250 000 scale), so perhaps it is unreasonable to expect them to be accurately predicted using these data. More detailed soil and geology data, not available currently for Snowdonia, would have allowed a better agreement between the predicted and observed NVC types. In addition, microhabitat variations, such as bryophytes and rocks, that determine the diversity of NVC types could not be detected by the data sets used. The results are important as they show that it is hard to predict vegetation communities precisely at a small scale, and suggest that ecologists and conservation planners have to either accept these limitations to predictability, or invest in much better environmental data sets.

Rodwell (1991a) pointed out that, very often, the diversity between NVC woodland types is overlain by the effects of silvicultural treatments, such as the removal or planting of timber trees, the selective coppicing of underwood crops, grazing and browsing by stock. Information on grazing levels and land use management was not available at the time of this study and was not incorporated as in the study of Sanderson *et al.* (1995). If all variables of significance in determining the presence of individual sub-communities were included in the model, overlap would perhaps be minimal.

This study examined the potential application of the NVC record data held by CCW to predict the occurrence of different NVC types in Snowdonia. Given the current availability of data, it seems that the approach taken here would be unsuccessful in predicting communities at exact locations. Overlaps between NVC types were also indicated on similar work in Scotland (Macmillan *et al.* 1997; Towers *et al.* 2000b), but then expert opinion in combination with detailed information on existing flora were applied to determine the most likely NVC type.

The distribution of NVC types in Snowdonia has been altered over the years and those sites surveyed are likely to be examples of them at the edge of their environmental conditions. Because the approach taken here models the actual rather than the ideal distribution of NVC woodland, perhaps, it would be more useful in countries which have retained a large proportion of their native woodland. In regions like the UK where all vegetation types are highly modified expert knowledge may be a better approach to decide the potential of a native woodland type on a particular site. The ESC decision support system (Ray, 2000) which makes use of expert opinion, could be used as an alternative basis for a predictive model, although not examined here. These approaches could be tested in future research.

In spite of some weaknesses in the data, the use of GIS for modelling these scenarios proved useful. In this period (2000-2002), forest policies in Wales, Europe and elsewhere are changing rapidly to meet modified global, national, and local objectives. GIS is, and will increasingly be so, proving to be a useful and flexible tool for translating forest policy into practical application on the ground.

The results of this work will be presented to the Snowdonia National Park Authority and the Countryside Council for Wales. The additional work which the author would most like to see undertaken is the use of this research as a basis for informing policy and management aimed at enhancing native woodland cover and quality in the National Park and elsewhere.

The final Chapter presents the overall conclusions regarding this work.

CHAPTER 8

'Creating new farm woods
can make a major contribution
towards enhancing the
biodiversity of the countryside'.

Kirby *et al.* (1999).

8.0 CONCLUSIONS

The analysis of woodland change in Snowdonia over the past showed that the proportion of land carrying woodland and forest increased from the 1970s to the 1980s by 13%. These forests developed from areas that were formerly moor and heath land as well as agricultural land. Broadleaved and scrub habitats showed no significant change, but coniferous and mixed forests increased in the landscape by as much as 33% and 11% respectively over this period.

The increase in mixed forest was not caused by an increase in the number of patches, but rather by expansion and fusion of existing patches. Patch size standard deviation for scrub is several times smaller than in other classes in both time periods, due to the many small and similar-sized patches. In contrast, conifer forest is more clumped, in all time periods, containing larger patches with higher variability in size, as would be expected given its origins as uniform plantations.

Mean distance decreased among coniferous patches from the 1970s to the 1980s as they increased in area. Conversely, mean distance increased among mixed forest and scrub patches as they declined in number. In both time periods, the distance between mixed forest patches was greater than for other classes suggesting that patches were more isolated in this habitat. The broadleaved forest patches seem to be the least isolated. This trend was consistent with the higher and lower values of nearest-neighbor standard deviation in mixed and broadleaved forest respectively, implying a more irregular distribution of patches of the former and a more uniform distribution of patches of the latter across the landscape.

There seems to be no significant change in overall woodland area between the 1980s and 1990s. This overall 'no change' situation does not mask any significant change in the proportions of different woodland types; there was no major change in area of either conifers or broadleaves, although there is some suggestion that broadleaves may have increased. Any increase is likely to reflect the fact that broadleaved category is likely to include many of the new broadleaved plantings made over the past decade. The evidence does not also seem to support a real doubling of the mixed forest area, or even a real increase come to that. The inconsistency between Silsoe

College and Forestry Commission surveys probably results from differences in interpretation in the two surveys, as they were carried out by different organisations, personnel and technology.

This study presented the first large-area analysis of landscape structure and change combining data from different sources in the Snowdonia National Park. The results from the Silsoe College project and the Forestry Commission's woodland inventory proved difficult to compare due to problems of trying to reconcile different classifications and definitions. The results from the NIWT's survey of small woods and trees provided extra information and were useful for comparisons of woodland changes in Snowdonia over the past three decades. Without this extra information, however, the results from the NIWT digital map alone would be misleading. Unfortunately, the small woods survey was sample-based only, so it could not contribute to the spatial analysis. Although the indices of each forest category in the 1990s follow similar trends to those of the 1970s and the 1980s decades the results of the last decade are not directly comparable to those of the previous decades because of the minimum mapping unit in this survey being 2ha and over. This work emphasized the need for a series of landscape surveys using the same minimum mapping unit, classification scheme, and the same methods in general.

In Snowdonia about 5 768ha of land are believed to be ancient woodland; 2 820ha of ancient semi-natural woodland and 2 948ha of ancient replanted woodland. 52% of the ancient woodland sites cleared over the past is presently occupied by woodlands, predominantly broadleaves, and the remaining 48% by other habitats.

Of the total area of the National Park of 214 162ha, 82 894ha (39%) fall into the 'potentially suitable' category and 131 268ha (61%) into the 'unsuitable' category. About 2% (3 914ha) was given a low suitability score, 20% (4 3347ha) a moderate suitability value and 5% (11 247ha) a high suitability score for woodland creation. In total, approximately a quarter of the land in Snowdonia was given a suitability value for woodland expansion by the *Woodland Creation Model*. The dominant land cover types in all suitability classes were improved and rough pasture. All suitable areas for woodland creation fall into the 0-650m elevation.

There are 121ha of ancient woodland sites in Snowdonia that have been lost since the production of the First Series OS 1:25 000 maps and are not presently occupied by woodland. These cleared sites might be considered to provide some of the most appropriate opportunities for native woodland creation in the National Park.

The majority of ancient replanted woodland sites (40%) lies at <300m distance from ancient semi-natural stands (mapped as woodland in the 1980s land cover map of Snowdonia). However, an appreciable proportion of replanted sites (25%) are at a distance greater than 900m from the nearest semi-natural stand. There are replanted ancient woodland sites even at a distance of 5 000-5 100m from the nearest ancient semi-natural woodland.

Of the total area of replanted ancient woodland sites (2 948ha), 86% (2 536ha) received by the *Woodland Restoration Model* values ranging from 8-12 (8-16 scale) and the remaining 14% (412ha) obtained values ranging from 13-16. Only 1% (37ha) of the replanted sites obtained a value of 16, the score that those sites considered most suitable for native woodland restoration should have.

150 100ha (70%) of the total area of Snowdonia have a similar combination of site characteristics with those of the ancient semi-natural woodland sites. It was mainly the highest elevation areas and some coastal areas that were excluded. Only 2% (67ha) of the total area of replanted ancient woodland showed a different combination of site characteristics to those of semi-natural stands.

W10, W11 and W17 oak NVC types account for most of the surveyed area (82%) in Snowdonia. W17 community represents 59% of the total area surveyed, with W17b sub-community accounting for most of the area (about 28%). The only other woodland sub-communities with appreciable areas and percentages were W9a (4.5%), W8e (1.8%) and W7c (2%).

The analysis of NVC woodland sub-communities with the environmental data sets indicated that W11a oak sub-community has the greatest potential (41% of the study area). W9a ash sub-community has also a great potential with 38% of the study area predicted as suitable. W17 seemed to be the most extensive single woodland type with W17c sub-community accounting for most of the area (36%).

W17 was predicted as the most extensive single community (7% of Snowdonia), and some of its suitable areas appeared to overlap with other oak, ash and wet woodland types in lower altitudes. 5.7% of the total area of Snowdonia has the potential to sustain both W17 and W11 oakwood types whereas about 5.8% of the area has also potential for W9 ashwood type. Furthermore, in some areas (5.8% of the total land) all oak communities (W10, W11, and W17), W9 ash woodland, and W4 and W7 wet woodland types were predicted as equally likely to be present.

Of the total area of the National Park, about 16% has the potential to sustain the Upland oakwood habitat and 4% the Upland mixed ashwood type. For the majority of the land predicted suitable for a Priority Habitat (about 19%) both habitats appear to be equally suitable. Wet woodland overlapped with both other categories.

In addition to providing useful information about potential distribution of native woodland communities in Snowdonia, the results of the *NVC Model* could also find application in woodland expansion plans and be employed to guide local native woodland restoration projects. Approximately 42% of the unwooded land has the potential to sustain a BAP Priority Habitat Type. 5% of the total area of Snowdonia is of high suitability for woodland creation and has the potential for a Priority Habitat. This could be mainly Upland oakwood, Upland mixed ashwood or Wet woodland. About 18% of the land with moderate suitability value is predicted chiefly suitable for Upland oak and mixed ash woodland types. Almost all of the ancient woodland replanted sites having a high restoration score appeared suitable for a BAP Priority Habitat, mainly Upland oakwood, Upland mixed ashwood and Wet woodland. Furthermore, the *NVC Model* could provide an objective assessment of woodland composition and distribution (including the identification of the 'natural' tree-line for W9 and W17) required for grant applications under the Woodland Grant Scheme.

The results of the NVC woodland analysis were complex, and indicated multi-overlaps between the communities. These overlaps may be a consequence of unaccountable management differences (*e.g.* grazing management), or perhaps be due to microhabitat variations.

The logistic regression analysis identified seven variables important for broadleaved distribution from an initial set of eleven variables. These were elevation, aspect, geology, soil type, rain, mean annual and summer temperature. A significant model was also obtained for scrub with elevation, aspect, slope, geology and temperature identified as important for its distribution. In addition, the simulated present-day distributions for broadleaved and scrub woodland showed a very good and good agreement respectively with their recorded distribution after selecting a probability threshold $p>0.50$ for presence.

Applying the 2020 and 2080 UKCIP98 Low and High scenarios indicated a 'no change' situation for broadleaves with a slight decline in probability of presence for scrub in the 2980s under the Low scenario. The High scenario (in the 2080s) showed a declining trend in probability of presence for both woodland types, suggesting the potential of the eventual loss of some woodland from these sites.

Forests, however, are composed of individual species and communities, and modelling work of others has shown that each species responds differently to changing climatic parameters (Huntley *et al.*, 1995; Sykes *et al.*, 1996). A simulation experiment with W17 oak community, furthermore, suggested the potential for oak woodland to increase in area and shift in altitude in response to temperature and rainfall increases. So perhaps these indicate how complex the climate change issue is and that more work is required before making any firmer conclusions.

Despite uncertainties relating to climate change issue it is necessary to put forward evaluations of potential climate change impacts on sites of conservation importance in order to stimulate debate and trigger further research with improved methods and more refined prognoses.

The main task of this research was to find a means of implementation of all the studies that could be made by accessing existing data and utilising the GIS resources of the University of Bangor. GIS enabled to combine spatial data sets from different sources to assess woodland changes in Snowdonia from 1970 to 2000, model the current distribution of woodland, and carry out the simulation experiment and examine any changes in response to climate changes. GIS also helped to produce the *Woodland Creation Model*, the *Woodland Restoration Model* and the *NVC Model*, and was used as a decision support system in order to identify priority areas in the National Park for native woodland expansion, and the suitable NVC woodland communities and BAP Priority Habitat Types for current environmental conditions. This study did not produce a comprehensive forest management system concerning all the issues that may contribute to forest management. It did, however, suggest that spatial data sets and GIS may contribute significantly in forest management, particularly when it considers issues such as conservation, restoration, biodiversity priorities, temporal and climate change.

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APPENDICES

APPENDIX 1

APPENDIX 1.1. Description of each land cover category in the 1980s land cover map of Snowdonia (Taylor, 1991).

1. **Broadleaved High Forest.** Areas greater than 0.25ha, wider than 20m and having a tree canopy cover of at least 20% by area. At least 80% of the canopy should be of broadleaved species.
2. **Coniferous High Forest.** Areas greater than 0.25ha, wider than 20m, and have a tree canopy cover of at least 20%. At least 80% of the canopy should be of coniferous species.
3. **Mixed High Forest.** Areas greater than 0.25ha which are wider than 20m and have a tree canopy of at least 20% by area. Composed of an intimate mixture of broadleaved and coniferous species, where the minority group comprises more than 20%.
4. **Scrub.** Areas with diffused boundaries with less than 20% cover by area of mature timber species with a rough understory of shrubs and grasses. Trees such as Birch (*Betula spp.*), Alder (*Alnus glutinosa*), Willow (*Salix spp.*) and Hazel (*Corylus avellana*) must be less than 3.5m high although shrubs such as Blackthorn (*Prunus spinosa*) and Hawthorn (*Crataegus spp.*) may be higher.
5. **Clear felled/new plantings.** Areas with hard boundaries, generally integral with stands of high forest and which have recently been felled or planted. Evidence of logging, rowing up trash and drainage may be present.
6. **Upland Heath.** Areas with grater than 80% cover of heather (*Calluna vulgaris* and *Erica spp.*) and/or Bilberry (*Vaccinium myrtilus*) species.
7. **Upland Grassmoor.** Unenclosed upland areas with greater than 80% cover of grass species. Areas are in general unenclosed for the purpose of controlling livestock grazing although property boundaries around large areas may be present.
8. **Blanket Peat Grassmoor.** Unenclosed upland areas (overlying a peat substrate) with greater than 80% cover of grass species. Areas are in general unenclosed for the purpose of controlling livestock grazing although property boundaries around large areas may be present.
9. **Bracken.** Areas having at least an 80% cover of bracken (*Pteridium aquilinum*).
10. **Lowland Rough Grassland.** Unenclosed lowland areas dominated by grass species.
11. **Lowland Heath.** Unenclosed lowland areas dominated by mixed heath species *e.g.* gorse (*Ulex spp.*).

Upland mosaics. Areas of transition between upland heath and other moor and heath categories. The boundary with heath will be drawn where heath species comprise more than 80% of the cover and with the other categories where they in turn constitute more than 80% of the cover.

12. **Heath/Grass.**
13. **Heath/Bracken.**
14. **Heath/Blanket Peat.**

15. **Peat (eroded).** Areas of eroding peat in upland situations where dare peat is the dominant cover type, or there is heavy dissection by eroding channels to give a mosaic appearance.
16. **Mineral Soil (eroded).** Areas of eroding mineral soils.
17. **Coastal Heath.** Areas of mixed heath species along coastal slopes and exposed headlands.
18. **Cultivated land.** Areas of ploughed and cropped land, including cereals, ley grasses, legumes, field vegetables, potatoes and root crops, rape and fodder crops. The category also covers market gardens, orchards, *etc.*

19. **Improved Pasture.** Grassland that is intensively managed for grazing and/or fodder production. Characterised by significantly modified swards produced by the use of fertilisers, herbicides, drainage and/or occasional reseeding.
20. **Rough Pasture.** Enclosed areas subject to little or no management. Characterised by a high density of native grasses and often containing invasive species such as bracken, bramble, thistle, rushes and scattered trees.
21. **Open Water, coastal.** The boundary of this category will be taken as the mean low water mark.
22. **Open Water, inland.** Natural and man-made water bodies greater than 0.25ha in extent. The category does not include rivers.

Wetland vegetation. Areas of vegetation which are controlled by the permanent or frequent periodic presence of water.
23. **Pet Bog.**
24. **Freshwater marsh.**
25. **Saltmarsh.**

26. **Inland Bare Rock.** Areas of bare rocks, such as scree.
27. **Sea Cliffs/ Bare Rock.** Areas of sea cliffs or rock exposed to coastal erosion.
28. **Dunes.** Areas bare or vegetated with coastal grasses.
29. **Sandy Beach.**
30. **Shingle Beach.**
31. **Mudflats.**
32. **Urban Boundary.** Areas of buildings, including gardens, car parks, *etc.*, and urban open spaces such as parks, playing fields, *etc.*
33. **Transport Routes.** Transport routes which cover a significant area, defined as multi-carriageway roads, functioning multi-track railways, railyards, and airports.
34. **Quarries/Mineral workings.** Quarries and mineral workings which are still in regular use.
35. **Derelict Land.** Disused quarries and mineral workings, and other significantly disturbed land which would need reclamation before it could be used.

Isolated rural developments. Developments consisting of only one group of buildings but covering an area greater than 0.25ha.
36. **Farmsteads.** A farm house and associated farm buildings.
37. **Garages and public houses, *etc.***

38. **Unclassified land.** Areas which cannot be legitimately included in any other category, *e.g.* rivers, or areas which cannot be reliably identified on the photographs due to cloud, shadow, military restrictions *etc.*

APPENDIX 1.2. Description of each Interpreted Forest Type (IFT) in the 1990s woodland map of Snowdonia provided by the Forestry Commission.

Descriptions of Interpreted Forest Types

1. Conifer (C) Area polygon
Coniferous woodland often occurs as large plantations with trees in regular rows and the stand edges may be regular and sharply defined. Some broadleaved trees may also be present but greater than 80% of the area will consist of conifers.

2. Broadleaved (B) Area polygon
The canopy of broadleaved woodland is generally more uneven than that of coniferous woodland being made up of rounded crowns but with variations according to species, age, height, and season. Boundaries with adjacent internal polygons are generally less clearly defined than with conifers and naturally occurring stands may grade into adjacent ones with no sharp division. Some coniferous trees may be present but greater than 80% of the area will consist of broadleaved trees.

3. Mixed (M) Area polygon
The interpretation of Mixed woodland can be very difficult as it exhibits intermediate characteristics between Conifer and Broadleaved woodland. The Coniferous component may project above the canopy of the broadleaves or a 'striped' appearance may be produced by a plantation of alternate rows of conifer and broadleaves. The proportion of both Conifer and Broadleaves will be greater than 20%.

4. Coppice (O) Area polygon
The most important characteristic of coppice areas on aerial photographs is its very even, smooth appearance. The coppice area may be made up of a patchwork of different ages (heights) but all show this very even character. Areas recently cut may appear to have a very clear floor with little felling debris.

5. Coppice-with-Standards (P) Area Polygon
Some areas of coppice also include larger broadleaved trees set in the coppice matrix. These broadleaved trees, often oak, are known as standards and show very clearly over the even coppice as large rounded crowns. The distribution of the standards will also be fairly even.

6. Shrub Land (S) Area polygon
This category is intended to include areas that may possibly be woodland, where the growth is close to the ground and shows a rough character but no clear differentiation between Conifer and Broadleaved can yet be made. Areas being colonised by woody species may fall into this category. The cover will be at least 20%.

7. Young Trees (N) Area polygon
Areas where planting is clearly visible but the trees cannot yet be allocated between Conifer and Broadleaved due to their immaturity. These areas can be on either land new to woodland or where a felled crop has been replaced.

8. Ground Prepared for New Planting (G) Area polygon
Land in this category is area recently converted from some other land use to woodland and will show plough furrows or mounding but the new planting (if present) cannot yet be discerned.

9. Felled Woodland (F) Area polygon
Areas of woodland where the trees have been harvested or felled. Stumps or felled trees may be visible and there may be long heaps of felling debris ('windrows'). The edges of the felled

area will probably be sharply defined and the **canopy cover will be less than 20%**. Some standing trees within this limit may also be present but should be disregarded. This category should not be confused with Coppice or Coppice with Standards. The areas concerned may also have been re-stocked but the new trees are not yet visible.

Note: Orchards, and species such as Rhododendron are not regarded as woodland and should therefore be excluded.

APPENDIX 2

APPENDIX 2.1. Altitude, Grid reference, slope, aspect and distance from the sea for each of the stations used to predict the temperature for the period 1961-1990.

No.	Station name	Altitude (m)	Grid Reference	Slope (^{0})	Aspect (^{0})	Distance to the sea (km)
	Gwynedd					
1	BALA	163	SH 935 356	3	180	26.904
2	BETWS Y COED	22	SH 802 570	6	330	15.664
3	BOTWNNOG	34	SH 262 313	5	220	3.263
4	PEN Y FFRIDD	84	SH 563 705	2	50	1.097
5	TRAWSFYNYDD	193	SH 695 390	3	270	4.855
6	VALLEY	10	SH 3087 7571	1	220	0.806
	Clwyd					
7	ALWEN	335	SH 957 529	6	170	25.632
8	COLWYN BAY	36	SH 858 784	3	25	0.806
9	HAWARDEN BRIDGE	4	SJ 314 694	1	220	0.320
10	LOGGERHEADS	210	SJ 201 622	7	220	11.063
11	RUTHIN	76	SJ 133 584	1	10	18.253
12	**Powys (North)** MOEL CYNNEDD	358	SN 843 877	2	160	18.147
	Dyfed					
13	CWMYSTWYTH	301	SN 773 749	6	130	20.097
14	COGERDDAN	31	SN 628 838*	7	200	4.152

* = estimated Ordnance Survey grid reference.

APPENDIX 2.2. Monthly and annual averages of temperature (^{0}C) for the period 1961-1990. All data were compiled from the monthly weather reports of the Meteorological Office.

No.	Location	Altitude (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual
	Gwynedd														
1	BALA	163	3.4	3.2	4.8	6.8	9.7	12.4	14.2	14.0	12.0	9.5	5.8	4.2	**8.3**
2	BETWS Y COED	22	4.2	4.1	5.9	7.9	10.9	13.8	15.5	15.1	12.9	10.3	6.5	4.9	**9.3**
3	BOTWNNOG	34	5.2	4.9	6.2	8.0	10.6	13.4	14.9*	14.9*	13.4	11.3	7.9	6.3*	**9.8**
4	PEN Y FFRIDD	84	4.8	4.8	6.2	8.1	11.0	13.7	15.3	15.3	13.6	11.1	7.4	5.8	**9.8**
5	TRAWSFYNYDD	193	3.8	3.5	5.1	7.2	10.2	12.9	14.4	14.3	12.5	10.0	6.3	4.8	**8.8**
6	VALLEY	10	5.4	5.1	6.4	8.3	11.0	13.6	15.3	15.4	13.8	11.5	8.1	6.4	**10.0**
	Clwyd														
7	ALWEN	335	2.0	1.8	3.4	5.3	8.4	11.2	12.9	12.8	10.9	8.3	4.6	2.9	**7.0**
8	COLWYN BAY	36	5.2	4.8	6.3	8.1	10.9	13.7	15.4	15.4	13.8	11.3	7.8	6.1	**9.9**
9	HAWARDEN BRIDGE	4	4.3	4.3	6.3	8.4	11.6	14.5	16.3	16.0	13.9	10.8	7.0	5.1	**9.9**
10	LOGGERHEADS	210	2.9	2.7	4.5	6.4	9.5	12.4	14.1	14.0	12.0	9.3	5.5	3.8	**8.1**
11	RUTHIN	76	4.1	4.0	5.8	7.6	10.6	13.4	15.2	15.1	13.1	10.4	6.6	4.8	**9.2**
	Powys (North)														
12	MOEL CYNNEDD	358	2.1	1.8	5.0	5.5	8.5	11.4	13.1	12.9	10.8	8.3	4.6	2.9	**7.2**
	Dyfed														
13	CWMYSTWYTH	301	2.9	2.7	4.2	6.1	9.2	11.8	13.5	13.5	11.5	9.2	5.5	3.9	**7.8**
14	COGERDDAN	31	4.8	4.6	6.0	7.8	10.8	13.5	15.3	15.3	13.3	10.9	7.3	5.5	**9.6**

* = estimated monthly average of temperature (^{0}C) for the period 1961-1990.

APPENDIX 2.3. Altitude, slope, aspect, distance from the sea and distance from Snowdon for each of the stations used to predict rainfall for the period 1961-1990. Rainfall data for 14 stations (the same as for temperature) were compiled from the monthly weather reports of the Meteorological Office and for the rest 44 stations from the Environment Agency for Wales.

No.	Station name	Altitude (m)	Slope (°)	Aspect (°)	Distance to the sea (km)	Distance from Snowdon (Km)
1	BONTGOCH S WKS	174	8	17	8.130	68.600
2	TROED Y FOEL	171	6	246	19.052	46.028
3	LLANYMAWDDW Y	229	24	33	17.094	46.547
4	ABERANGELL ESG	130	7	90	14.081	49.022
5	PENTRE CELYN	180	3	45	21.891	56.190
6	LLANBRYNMAIR	244	14	148	23.699	56.798
7	CEMMAES ROAD	29	15	219	15.030	51.158
8	DAROWEN	201	11	205	15.943	57.824
9	ABERLLEFENI CYMAU FM	191	26	150	10.132	46.707
10	GLASPWLL	128	7	132	10.133	67.736
11	ABERDYFI GOLF CLUB	3	0	0	0.335	58.361
12	LLYN CAU	365	21	173	6.424	43.509
13	GRAIG DDU GANOL	247	6	45	10.063	26.296
14	BUARTHRE NEWYDD	198	8	163	6.937	31.495
15	RHYDYMAIN-CAER DEFAI	366	10	167	8.840	35.909
16	LLYN CYNNWCH	225	21	312	2.401	35.950
17	DOLGELLAU	84	3	270	1.082	37.573
18	LLYN BODLYN	384	3	225	6.184	30.473
19	LLYN EIDDEW	375	7	180	4.290	20.307
20	MINAFON, Ffestiniog	229	9	215	7.626	15.314
21	LLYN MORWYNION	413	4	219	7.434	24.441
22	CRIB GOCH	713	33	180	15.024	1.412
23	DELTA	437	16	205	14.422	1.354
24	CWM DYLI(M)	94	3	270	14.217	4.405
25	HAFOD WYDR	130	8	236	10.700	5.671
26	BRAICH DINAS CWM.P.	152	28	118	10.179	9.522
27	CWMYSTRADLLY N	204	3	90	5.338	11.473
28	BWLCHDERWIN	145	3	315	5.127	16.752
29	MARCHLYN BACH	472	8	339	9.406	8.454
30	CONWY MUSSEL TANKS	8	17	33	0.112	28.746
31	YSBYTY IFAN S WKS	390	10	135	17.285	21.945
32	PLAS FOELAS	195	9	215	21.796	24.265

APPENDIX 2.3. Continued.

33	LLWYN COWLYD	408	5	180	14.125	12.324
34	BETWS-Y-COED	22	6	315	15.664	19.427
35	TROFARTH	299	3	90	4.269	28.524
36	LLANUWCHLLYN	173	0	315	18.954	36.420
37	ARENIG	411	11	28	19.176	27.572
38	TRYWERYN	253	12	323	23.603	30.960
39	BALA SLUICES STAND	163	3	180	26.904	37.576
40	LLANDRILLO	251	6	80	33.527	46.607
41	ALWEN RES	335	6	0	25.632	34.841
42	PEN-Y-FFRIDD	84	2	50	1.097	16.789
43	TRAWSFYNYDD	193	3	270	4.855	17.568
44	COLWYN BAY	36	3	25	0.806	34.552
45	MOEL CYNNEDD	358	2	160	18.121	70.663
46	COGERDDAN	31	7	198	4.152	70.634
47	INTAKE	451	23	315	14.771	2.624
48	COPPERMINE	451	27	139	14.951	2.208
49	TEYRN	329	14	189	14.452	3.401
50	OLD ROAD	99	11	245	14.022	4.518
51	TAN Y GRAIG	85	10	254	10.302	4.677
52	HAFOD RUFFYDD	150	3	135	10.458	6.154
53	BEDDGELERT	41	3	0	8.904	6.597
54	GLASLYN	625	20	340	14.602	0.906
55	LLIWEDD	455	32	348	13.913	1.645
56	LLYDAW	488	27	234	15.062	2.875
57	RHYD	134	7	180	2.450	12.291
58	PORTHMADOG P.STA.	3	0	0	0.158	15.855

APPENDIX 2.4. Monthly and annual total averages of rainfall (mm) of the stations used to predict the distribution of rainfall in Snowdonia for the period 1961-1990.

No.	Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
1	BONTGOCH S WKS	136	99	124	77	73	100	103	121	131	157	154	161	**1436**
2	TROED Y FOEL	243	167	197	128	110	115	121	153	178	218	240	256	**2126**
3	LLANYMAWDDWY	229	182	198	115	110	111	102	117	166	177	211	253	**1971**
4	ABERANGELL ESG	260	189	230	117	106	112	112	164	179	239	244	293	**2245**
5	PENTRE CELYN	183	132	153	98	86	99	97	126	143	170	189	198	**1674**
6	LLANBRYNMAIR	213	158	161	113	95	106	101	121	138	159	181	205	**1751**
7	CEMMAES ROAD	176	113	144	88	79	91	94	122	132	158	195	191	**1583**
8	DAROWEN	145	101	118	74	73	83	82	102	119	142	147	161	**1347**
9	ABERLLEFENI CYMAU FM	307	229	268	142	112	133	141	155	164	226	243	314	**2434**
10	GLASPWLL	172	126	155	97	91	104	110	139	141	177	185	202	**1699**
11	ABERDYFI GOLF CLUB	96	67	88	55	59	59	68	81	83	111	114	108	**989**
12	LLYN CAU	372	157	275	130	185	182	146	220	201	243	310	293	**2714**
13	GRAIG DDU GANOL	309	196	291	161	109	125	131	172	214	295	211	292	**2506**
14	BUARTHRE NEWYDD	222	151	183	101	91	114	101	135	163	210	213	241	**1925**
15	RHYDYMAIN-CAER DEFAI	248	178	182	139	109	119	138	130	141	185	240	254	**2063**
16	LLYN CYNNWCH	159	138	164	88	63	112	92	154	111	167	171	188	**1607**
17	DOLGELLAU	200	140	163	105	91	105	98	128	142	176	200	209	**1757**
18	LLYN BODLYN	155	113	147	106	105	133	141	159	177	174	198	204	**1812**
19	LLYN EIDDEW	171	139	169	120	109	131	148	170	174	199	205	233	**1968**
20	MINAFON, Ffestiniog	205	142	180	134	96	118	134	146	167	214	228	245	**2009**
21	LLYN MORWYNION	206	152	209	137	101	132	127	176	171	232	251	253	**2147**
22	CRIB GOCH	410	344	316	247	211	312	314	374	421	416	461	454	**4280**
23	DELTA	439	337	379	265	200	507	271	320	362	465	463	488	**4496**
24	CWM DYLI(M)	365	239	248	193	162	205	210	244	267	319	343	356	**3151**
25	HAFOD WYDR	267	190	223	157	122	153	152	182	197	256	274	287	**2460**
26	BRAICH DINAS CWM.P.	236	162	198	128	112	139	141	175	179	235	241	254	**2200**
27	CWMYSTRADLLYN	180	140	159	125	125	150	134	148	120	197	221	195	**1894**

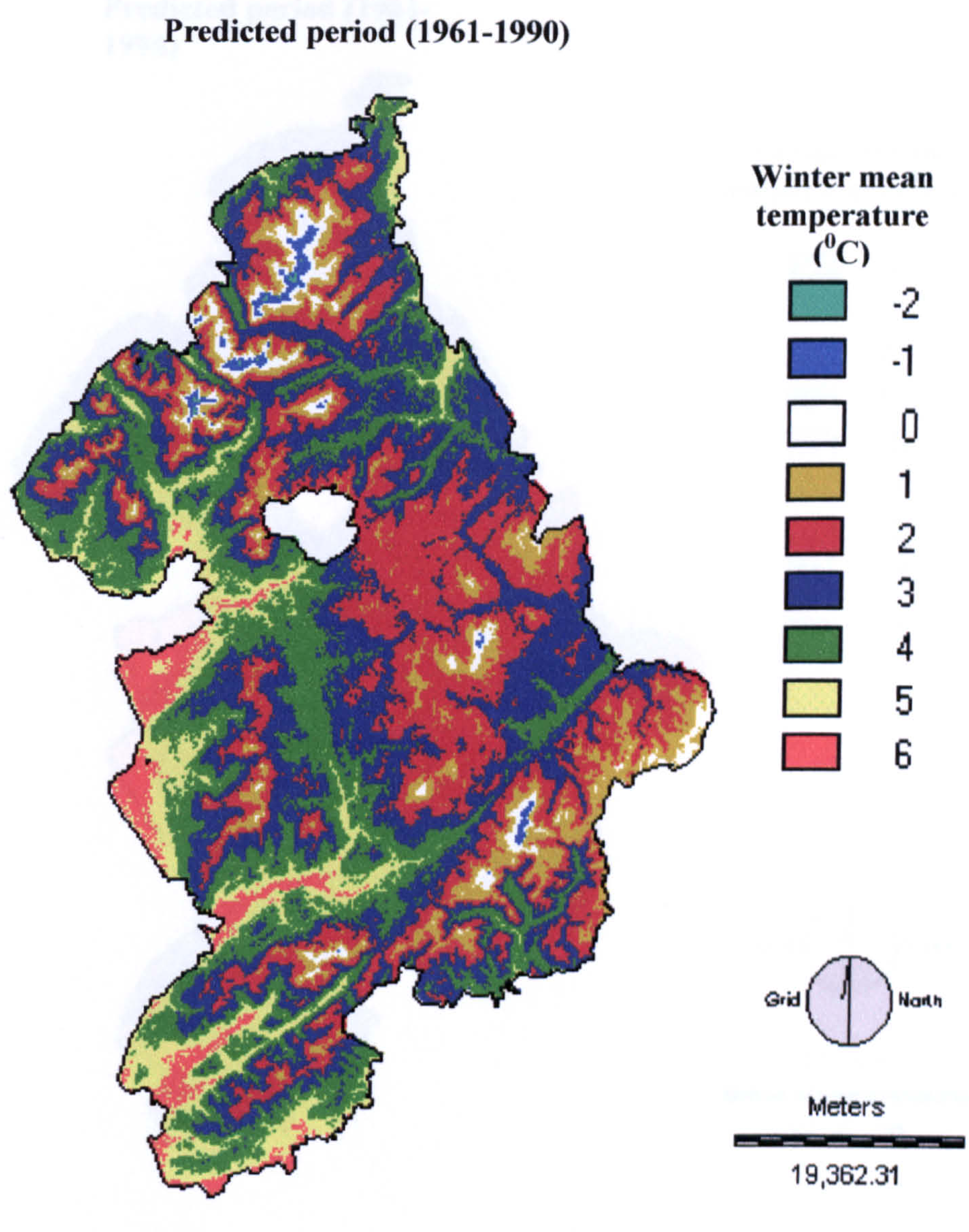
APPENDIX 2.4. Continued.

28	BWLCHDERWIN	176	130	171	100	86	113	101	140	140	196	194	206	**1753**
29	MARCHLYN BACH	315	180	225	147	127	126	127	140	193	224	220	239	**2263**
30	CONWY MUSSEL TANKS	95	63	71	57	61	60	52	69	72	94	110	105	**909**
31	YSBYTY IFAN S WKS	238	160	208	145	112	126	133	148	187	214	256	268	**2195**
32	PLAS FOELAS	152	107	115	84	82	78	69	100	115	144	159	173	**1378**
33	LLWYN COWLYD	289	162	325	147	110	145	180	199	199	221	331	220	**2528**
34	BETWS-Y-COED	181	125	129	75	81	76	62	96	120	150	172	186	**1453**
35	TROFARTH	110	82	86	63	69	77	62	83	99	112	132	115	**1090**
36	LLANUWCHLLYN	189	132	141	105	91	84	82	109	132	168	175	208	**1616**
37	ARENIG	236	157	177	124	112	110	124	141	186	210	226	255	**2058**
38	TRYWERYN	201	146	154	98	88	83	81	105	137	178	199	208	**1678**
39	BALA SLUICES STAND	146	100	103	77	73	69	63	82	106	136	139	160	**1254**
40	LLANDRILLO	166	142	164	78	73	97	61	85	116	133	154	186	**1455**
41	ALWEN RES	144	102	91	83	80	78	82	102	113	138	148	150	**1311**
42	PEN-Y-FFRIDD	108	70	84	65	65	70	78	93	99	122	130	123	**1107**
43	TRAWSFYNYDD	177	117	139	101	96	106	107	132	147	186	189	191	**1688**
44	COLWYN BAY	73	56	56	44	49	54	44	63	67	83	89	83	**761**
45	MOEL CYNNEDD	268	177	206	142	131	122	125	173	199	239	278	308	**2368**
46	COGERDDAN	92	63	77	60	65	67	74	87	92	107	114	111	**1009**
47	INTAKE	392	281	265	219	208	232	269	320	366	381	408	403	**3744**
48	COPPERMINE	445	296	308	231	217	250	286	351	392	410	438	445	**4069**
49	TEYRN	407	286	267	235	219	238	283	339	382	343	372	435	**3806**
50	OLD ROAD	380	262	199	196	156	190	223	265	317	307	312	339	**3146**
51	TAN Y GRAIG	329	204	173	164	125	149	146	212	267	211	251	289	**2520**
52	HAFOD RUFFYDD	238	157	156	135	125	140	164	184	295	186	212	238	**2230**
53	BEDDGELERT	249	167	150	147	131	146	162	203	230	219	221	253	**2278**
54	GLASLYN	422	312	273	252	240	276	353	381	405	378	378	447	**4117**
55	LLIWEDD	368	254	237	214	211	234	277	323	356	335	348	393	**3550**
56	LLYDAW	344	251	219	212	187	211	259	298	327	314	323	363	**3308**

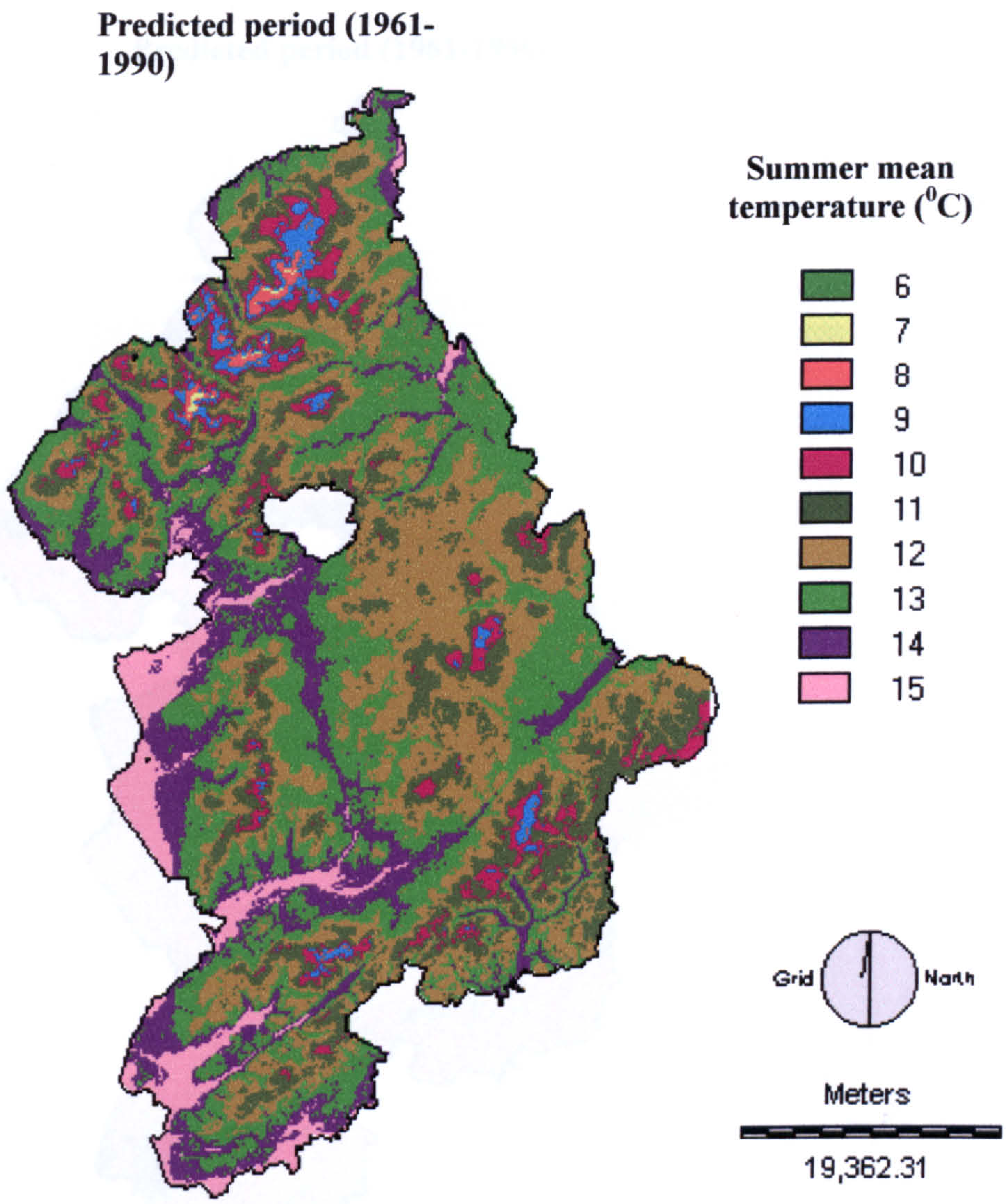
APPENDIX 2.4. Continued.

57	RHYD	177	118	135	96	94	112	116	131	179	191	208	72	**1729**
58	PORTHMADOG P.STA.	137	84	171	45	85	83	51	116	162	166	153	79	**1432**

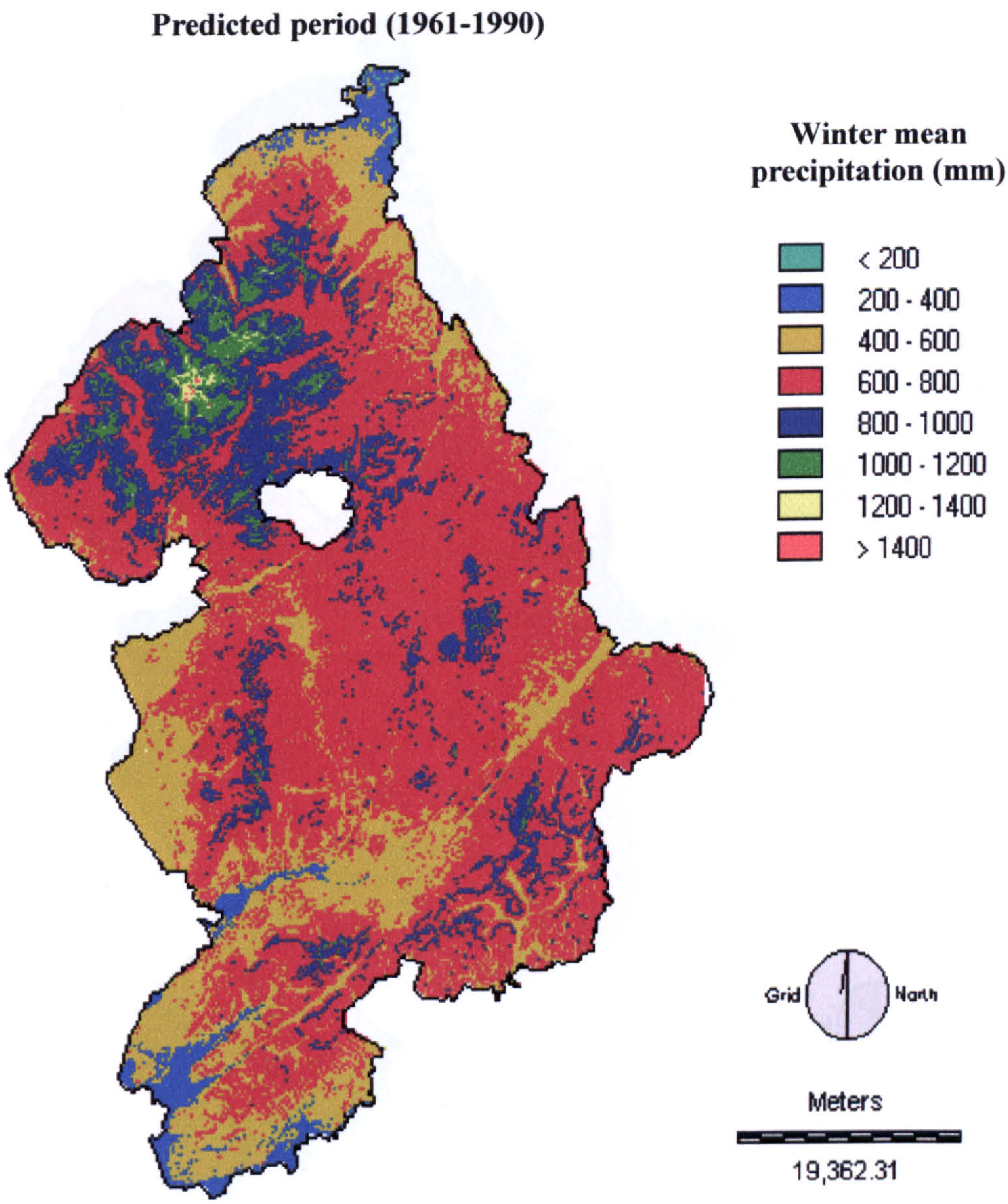
APPENDIX 2.5. Winter mean temperature (^{0}C) predicted for the period (1961-1990).



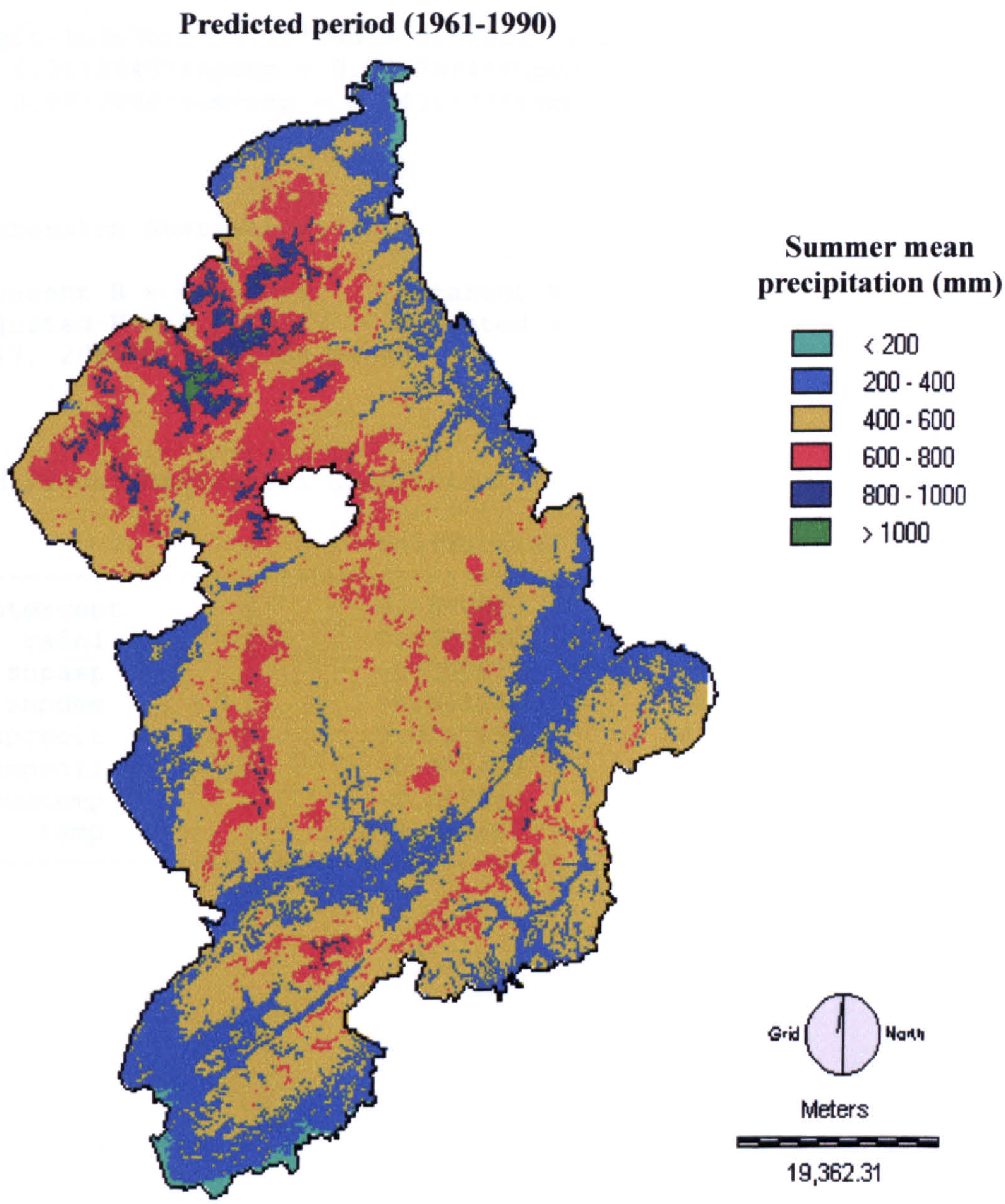
APPENDIX 2.6. Summer mean temperature (^{0}C) predicted for the period (1961-1990).



APPENDIX 2.7. Winter mean precipitation (mm) predicted for the period (1961-1990).



APPENDIX 2.8. Summer mean precipitation (mm) predicted for the period (1961-1990).



APPENDIX 2.9. Multiple logistic regression results for broadleaves.

```
Multiple Regression Results:


Regression Equation:

logit(fm3x3b) = 3.107796 + 0.000015*rain1 - 0.0000732*snpasp
 - 0.0012043*snpdem + 0.0067674*snpgeolt - 0.0024485*snpsoil
 - 0.0872066*sumtemp - 0.0434877*temp



Regression Statistics:

Apparent R = 0.817943     Apparent R square = 0.669031
Adjusted R = 0.817937     Adjusted R square = 0.669022
F (7, 209048) = 60368.066406



Individual Regression Coefficient

                 |       Coefficient         t_test (209048)
-----------------+------------------------------------------
 Intercept       |       3.107796          1065.788696
    rain1        |       0.000015         6.124351
   snpasp        |       -0.000073          -8.808705
   snpdem        |       -0.001204          -85.694389
  snpgeolt       |       0.006767         24.556295
   snpsoil       |       -0.002448          -6.603745
   sumtemp       |       -0.087206          -59.513161
     temp        |       -0.043487          -19.781158
------------------------------------------------------------
```

APPENDIX 2.10. Multiple logistic regression results for scrub woodland.

```
Multiple Regression Results:


Regression Equation:

logit(fm3x3s) = 3.296583 - 0.000198*snpasp - 0.0013702*snpdem
 + 0.0089583*snpgeolt + 0.0019574*snpslope - 0.1959565*temp



Regression Statistics:

Apparent R = 0.783854     Apparent R square = 0.614427
Adjusted R = 0.783825     Adjusted R square = 0.614382
F (5, 34678) = 11052.157227



Individual Regression Coefficient

                 |       Coefficient          t_test  (34678)
-----------------+-------------------------------------------
 Intercept       |       3.296583            335.509430
   snpasp        |       -0.000198            -9.057299
   snpdem        |       -0.001370            -60.321495
 snpgeolt        |       0.008958            12.127877
 snpslope        |       0.001957            7.521655
     temp        |       -0.195956            -187.388565
-------------------------------------------------------------
```

APPENDIX 2.11. Cross-tabulation results of the probability-simulated distribution map of broadleaves (for p>0.50) with their recorded distribution in the 1980s (Taylor, 1991).

Cross-tabulation of probmask (columns) against broad80 (rows)

	0	1	Total
0	14809361	141903	14951264
1	0	209056	209056
Total	14809361	350959	15160320

```
Chi Square = 8944849.00000
        df =         1
Cramer's V =       0.7681
```

Proportional Crosstabulation

	0	1	Total
0	0.9769	0.0094	0.9862
1	0.0000	0.0138	0.0138
Total	0.9769	0.0231	1.0000

Kappa Index of Agreement (KIA)

Using broad80 as the reference image...

Category	KIA
0	0.5900
1	1.0000

broad80

Category	KIA
0	1.0000
1	0.5900

Overall Kappa 0.7422.

APPENDIX 2.12. Cross-tabulation results of the recorded distribution of scrub woodland in the 1980s (Taylor, 1991) with its probability-simulated distribution map (for p>0.50).

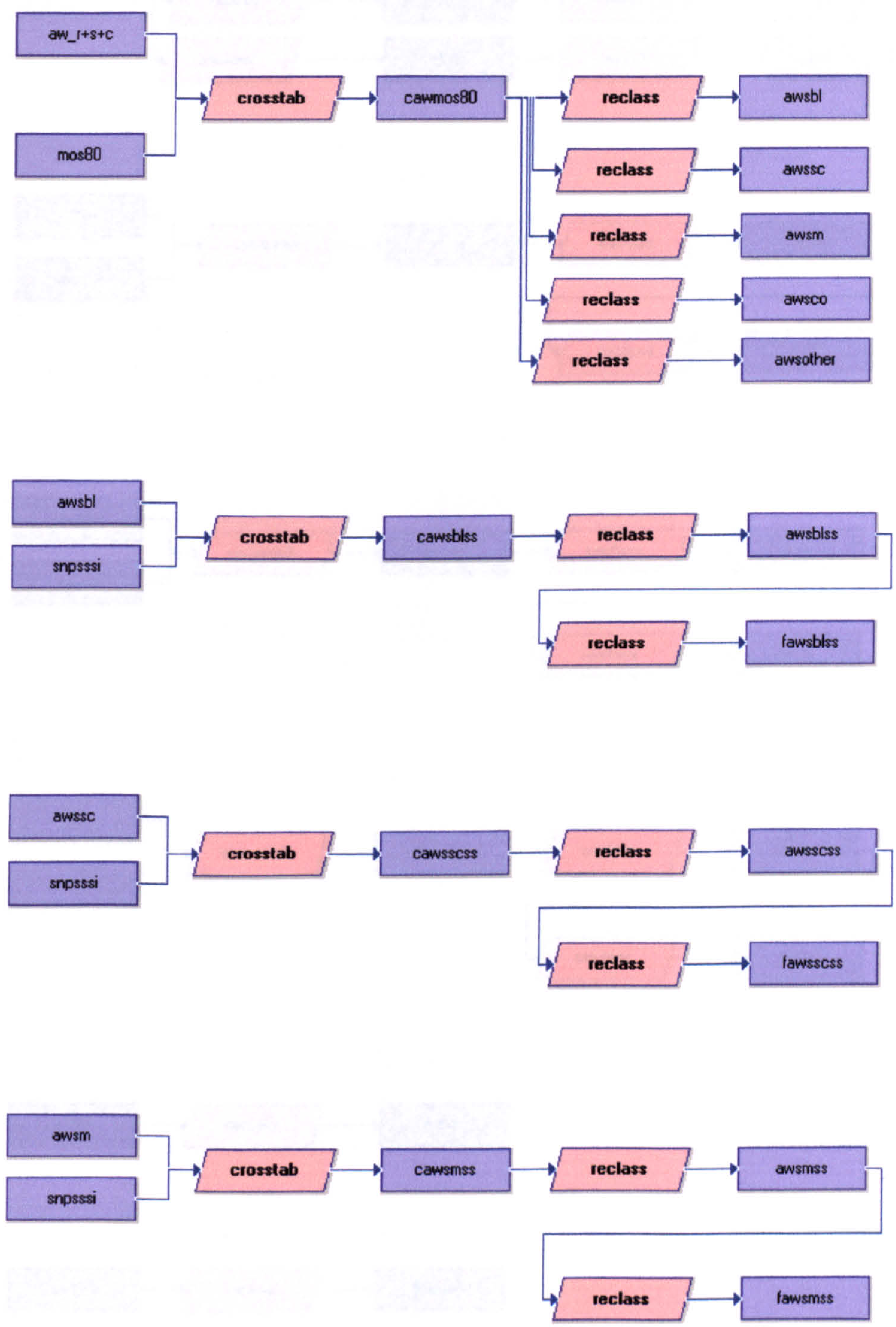
```
Cross-tabulation of scrub80 (columns) against prosmask (rows)

                    0               1          Total
---------------------------------------------------------
   0    |    15090586           0      |    15090586
   1    |       35050       34684      |       69734
---------------------------------------------------------
Total   |    15125636       34684      |    15160320

Chi Square = 7522902.50000
        df =       1
Cramer's V =       0.7044

Proportional Crosstabulation

                    0          1        Total
------------------------------------------------
     0 |       0.9954     0.0000 |    0.9954
     1 |       0.0023     0.0023 |    0.0046
------------------------------------------------
Total |      0.9977     0.0023 |    1.0000


Kappa Index of Agreement (KIA)
------------------------------

Using prosmask as the reference image...

Category        KIA
--------      -------

       0       1.0000
       1       0.4962

prosmask

Category        KIA
--------      -------

       0       0.4962
       1       1.0000
```

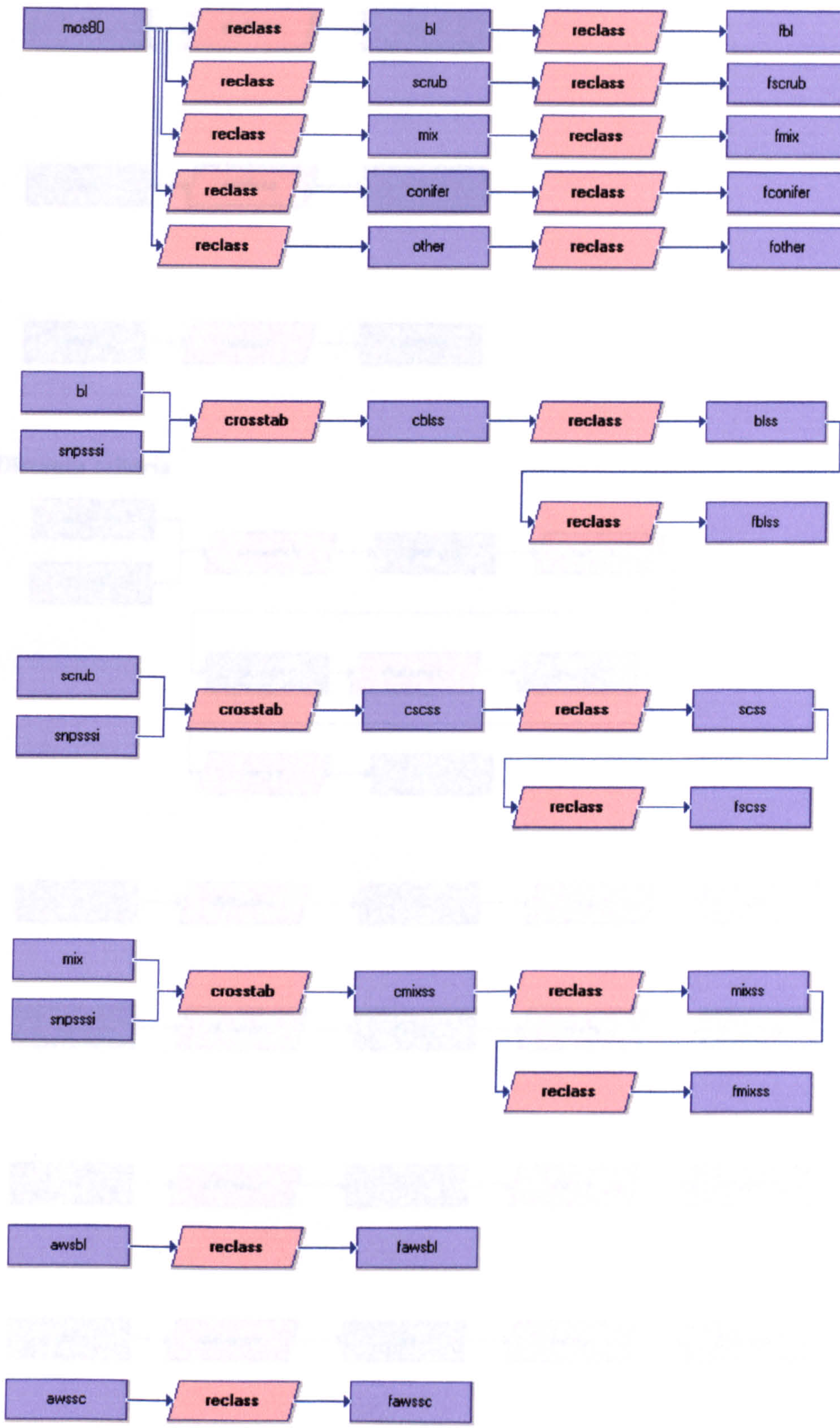
Overall Kappa   0.6633.

APPENDIX 3

APPENDIX 3.1. All sub-models within the *Woodland Creation Model* constructed in IDRISI macro modeller. The blue boxes refer to raster images and the red ones to modules.

Woodland type/Conservation status criteria




mos80
reclass
bl
reclass
fbl
reclass
scrub
reclass
fscrub
reclass
mix
reclass
fmix
reclass
conifer
reclass
fconifer
reclass
other
reclass
fother
bl
snpsssi
crosstab
cblss
reclass
blss
reclass
fblss
scrub
snpsssi
crosstab
cscss
reclass
scss
reclass
fscss
mix
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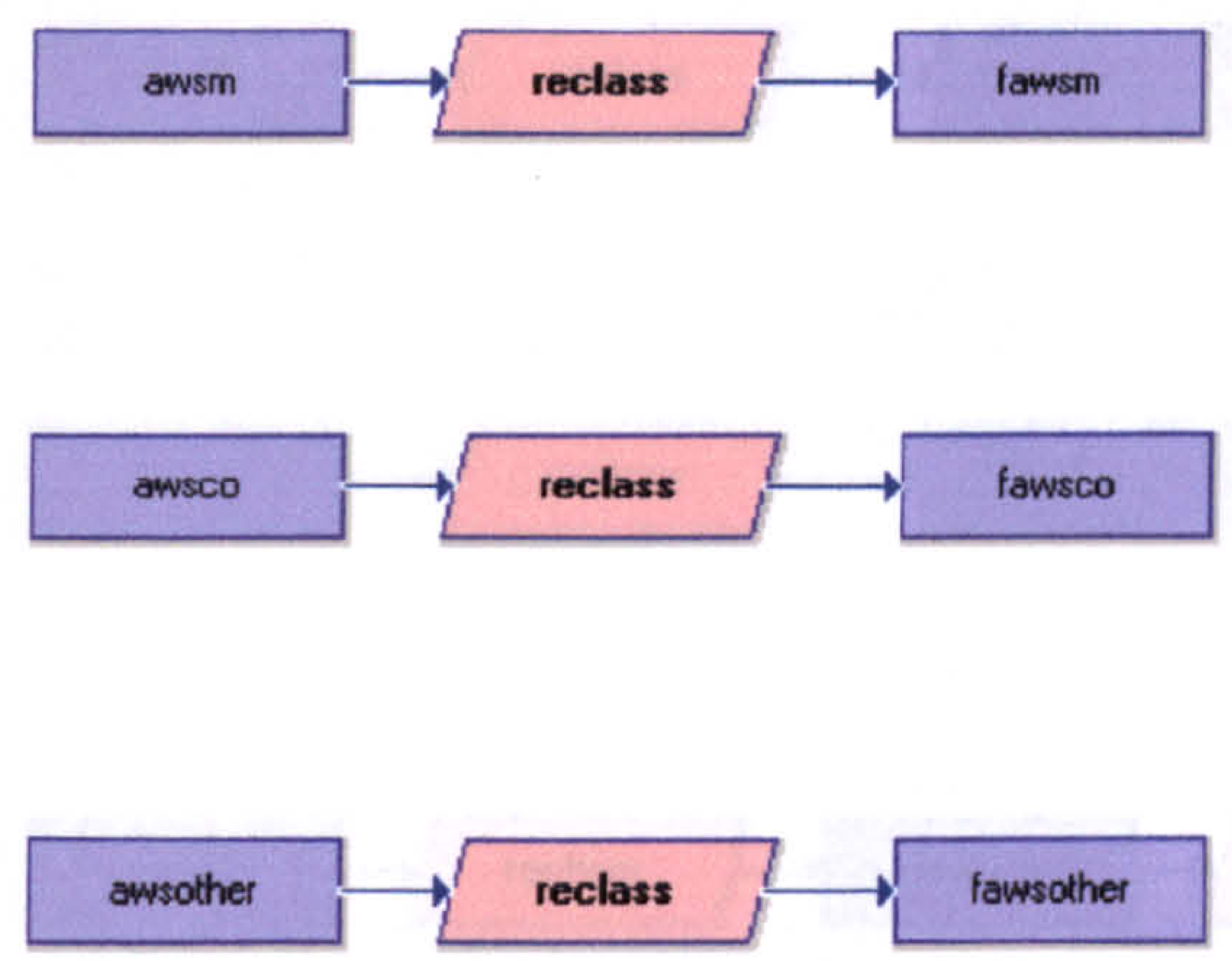
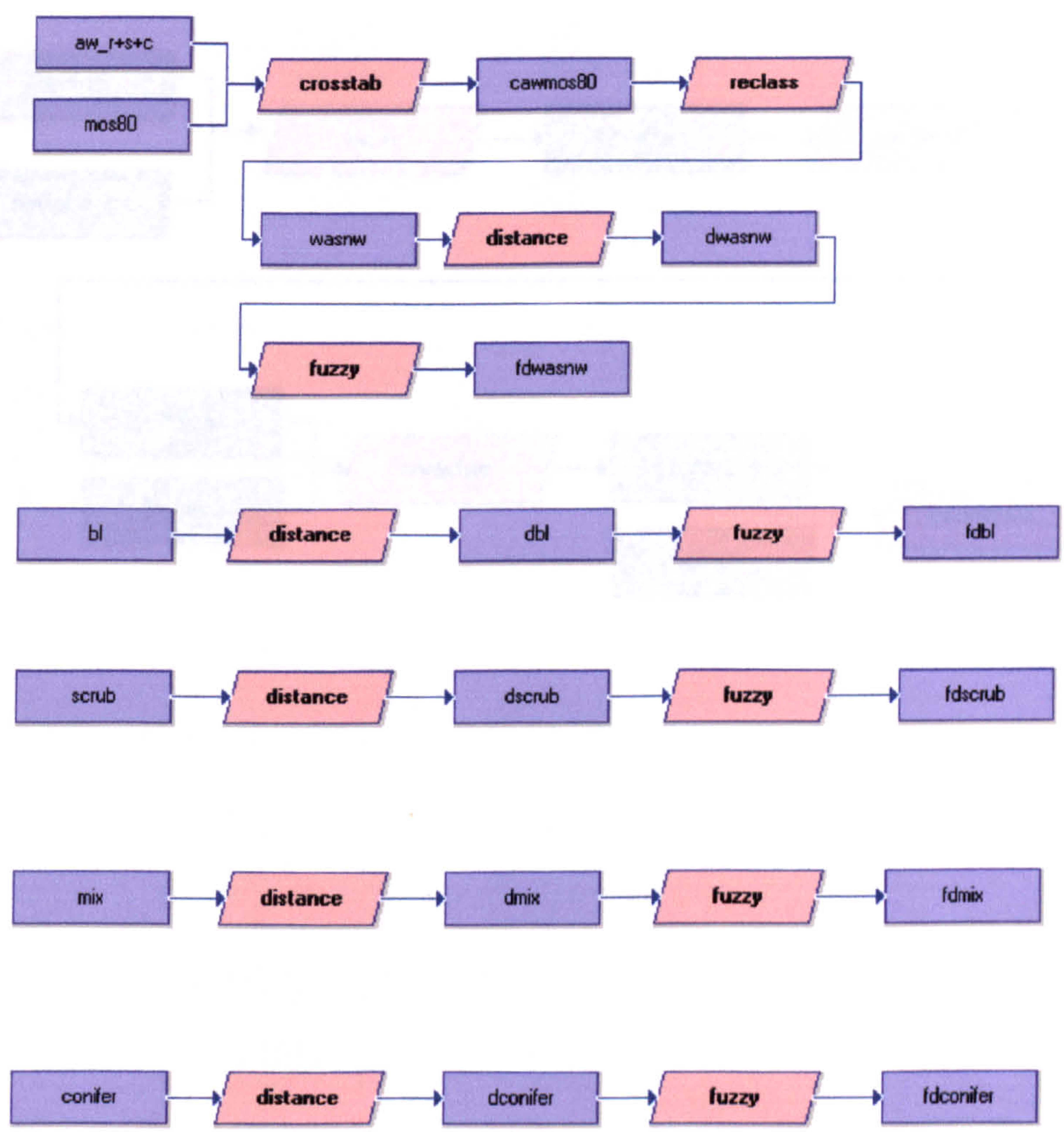
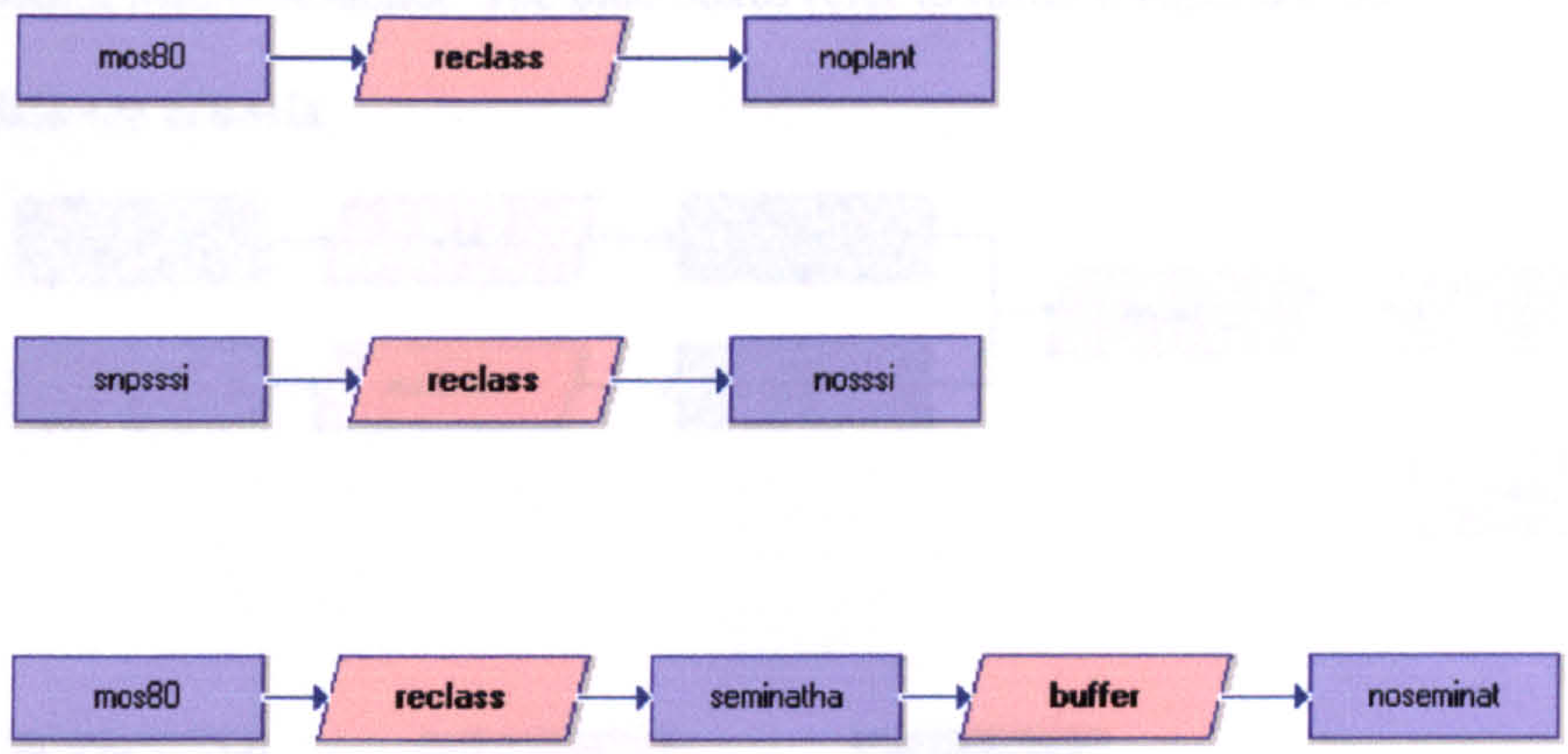
awssc
reclass
fawssc



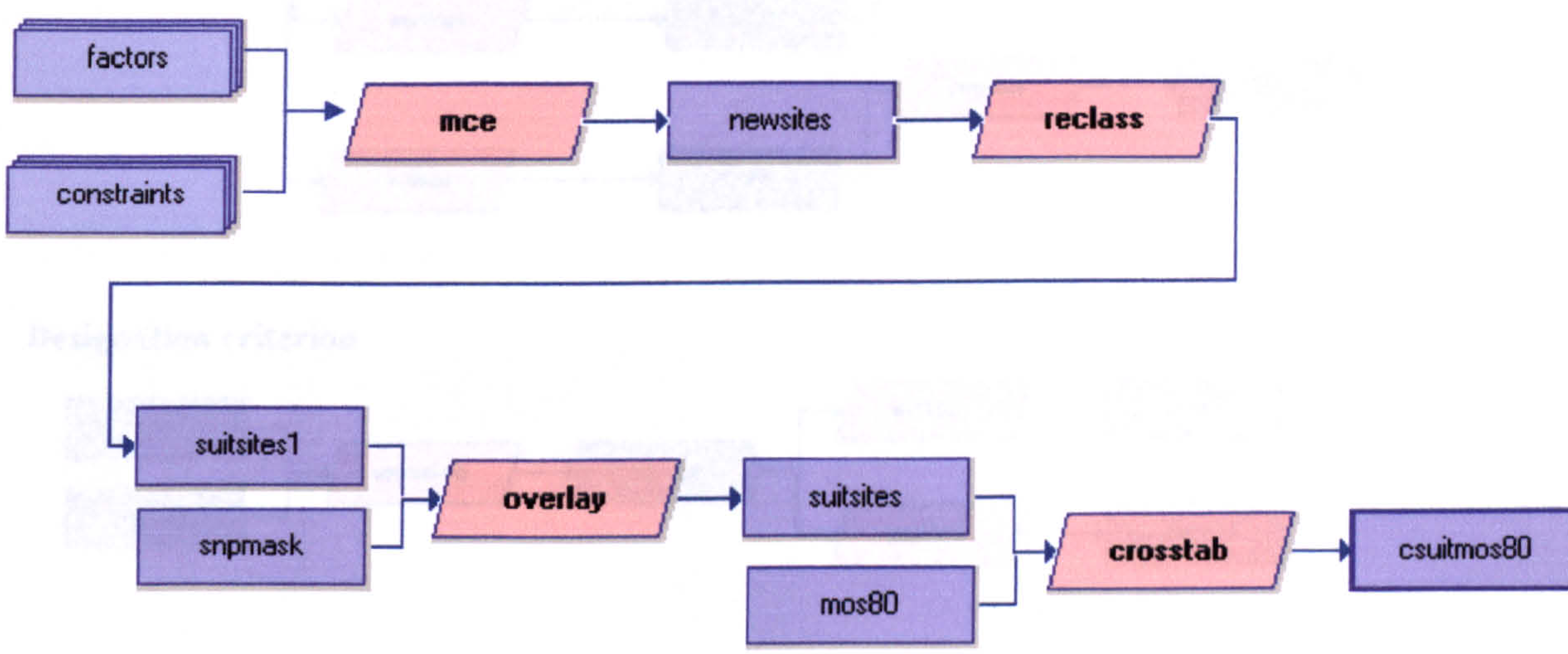
Distance criteria



Constraints

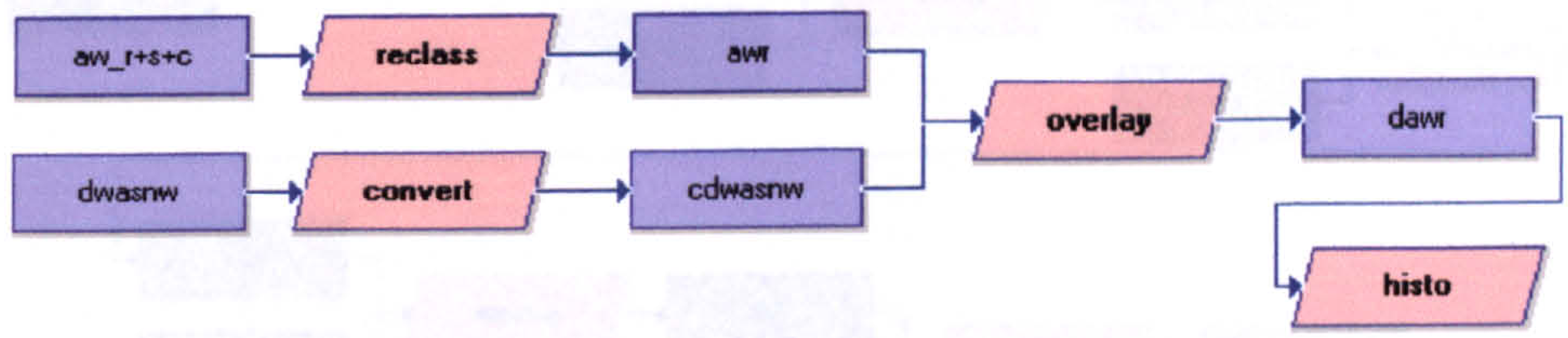


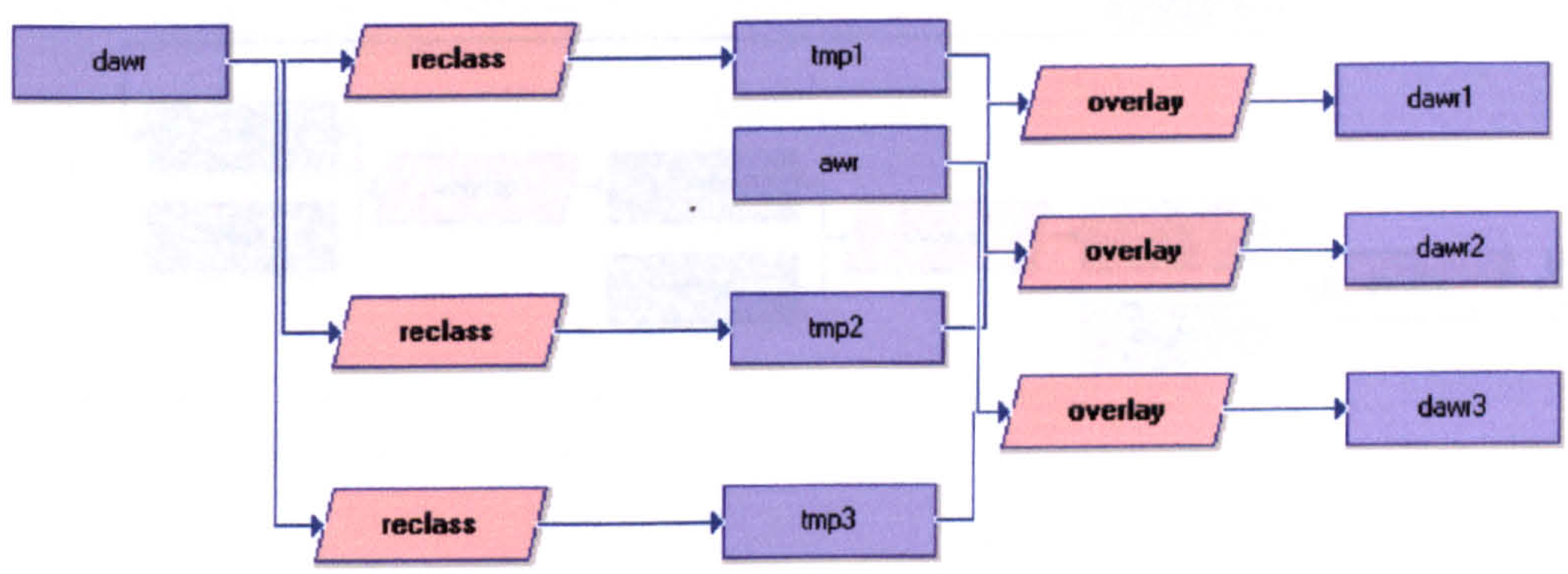
Suitable sites



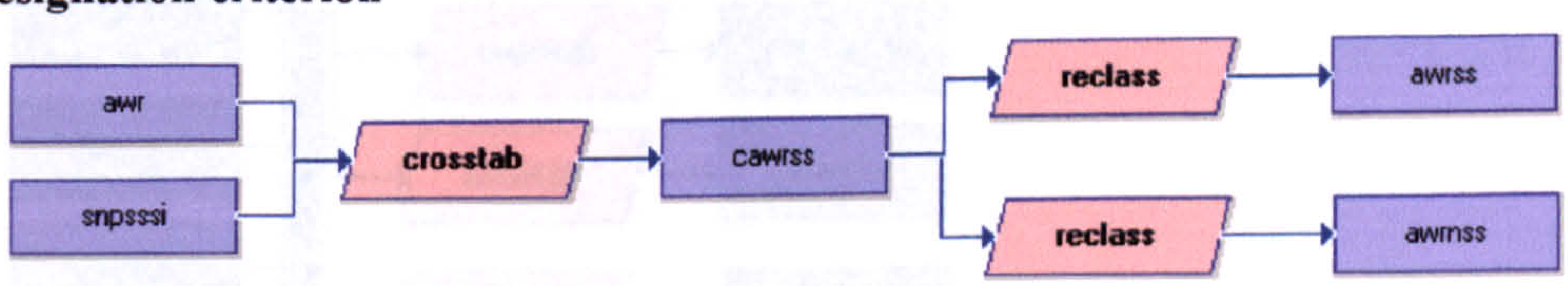
APPENDIX 3.2. All sub-models within the *Woodland Restoration Model* constructed in IDRISI macro modeller. The blue boxes refer to raster images and the red ones to modules.

Distance criteria

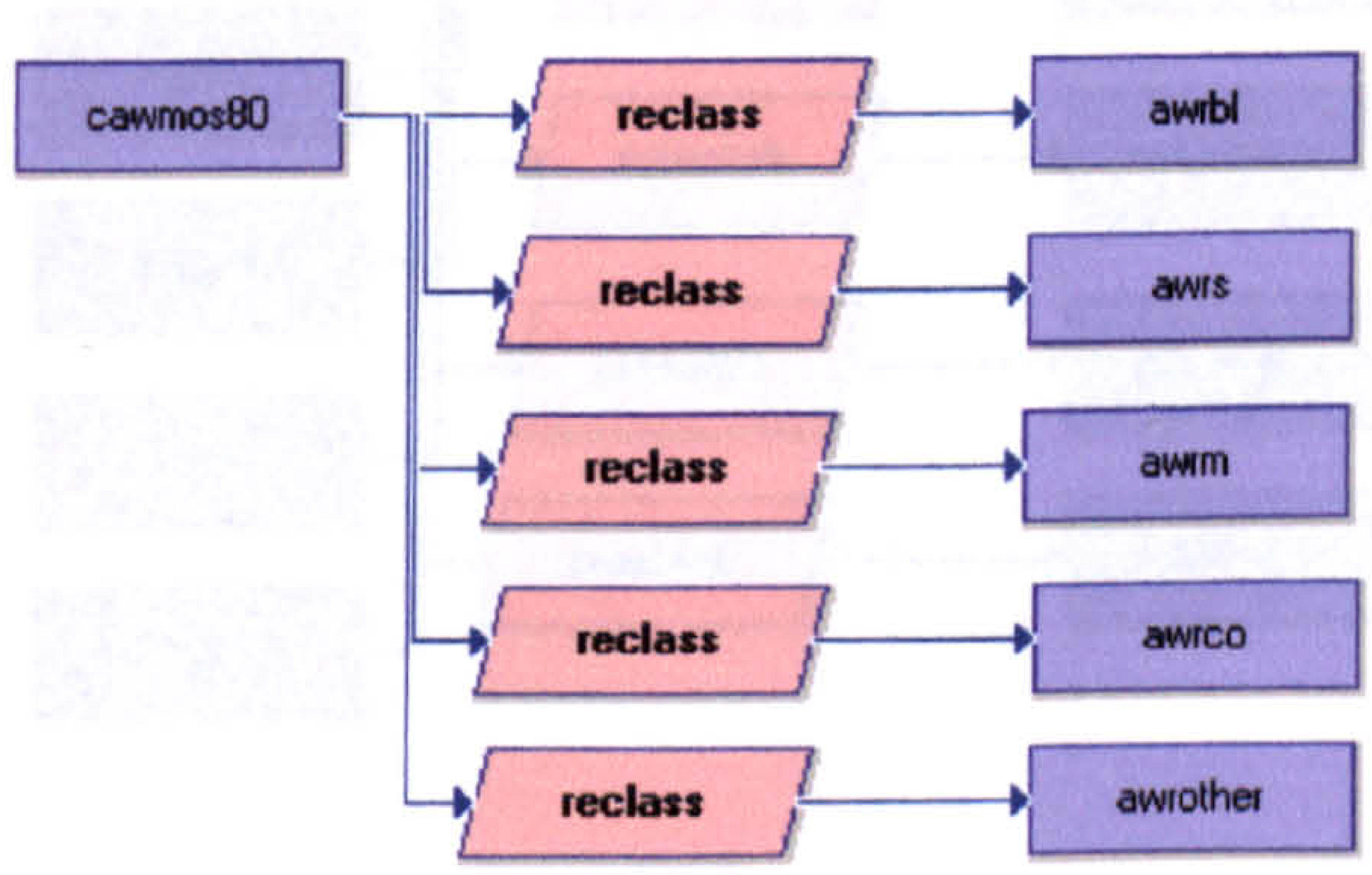




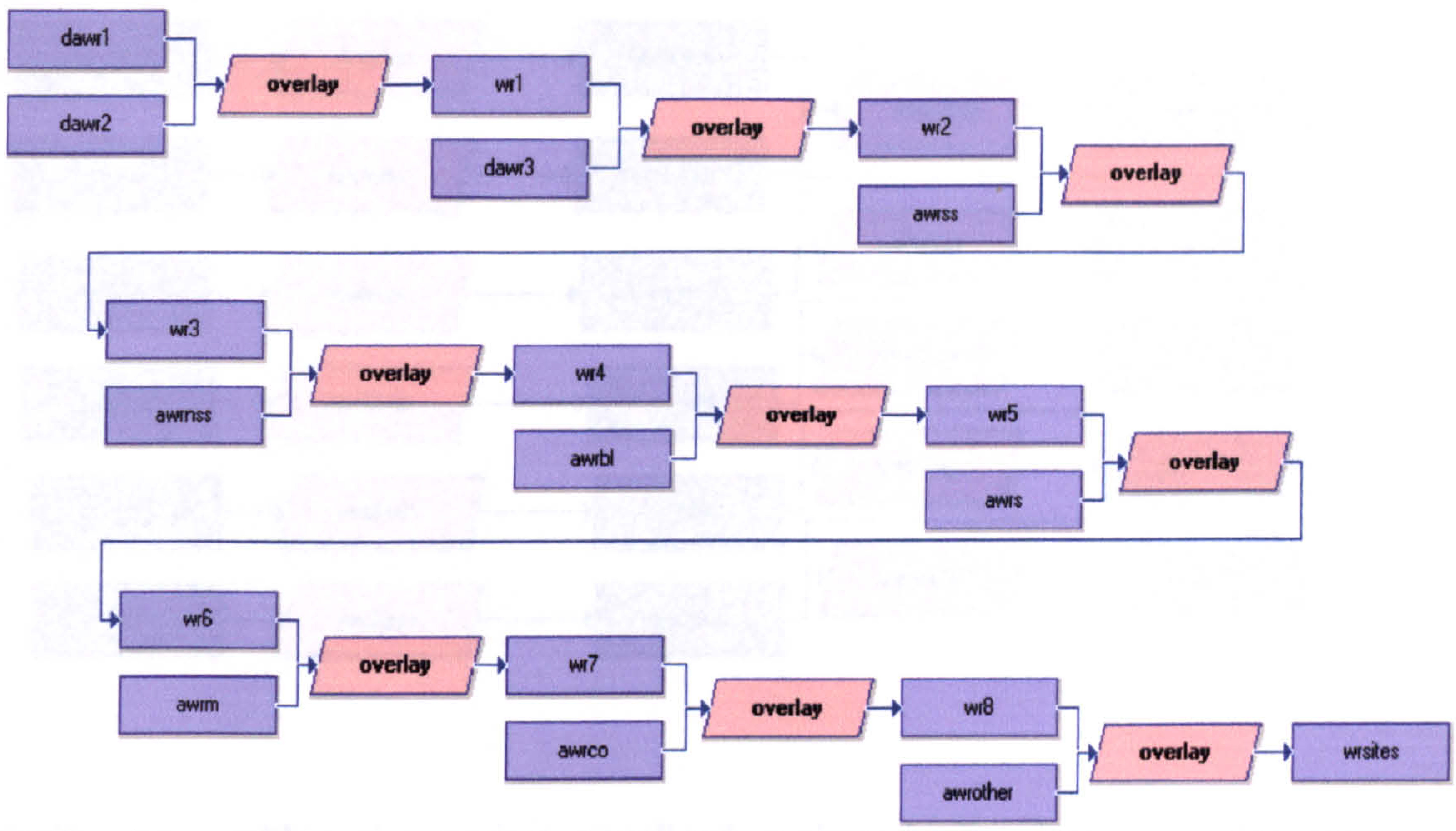
Designation criterion



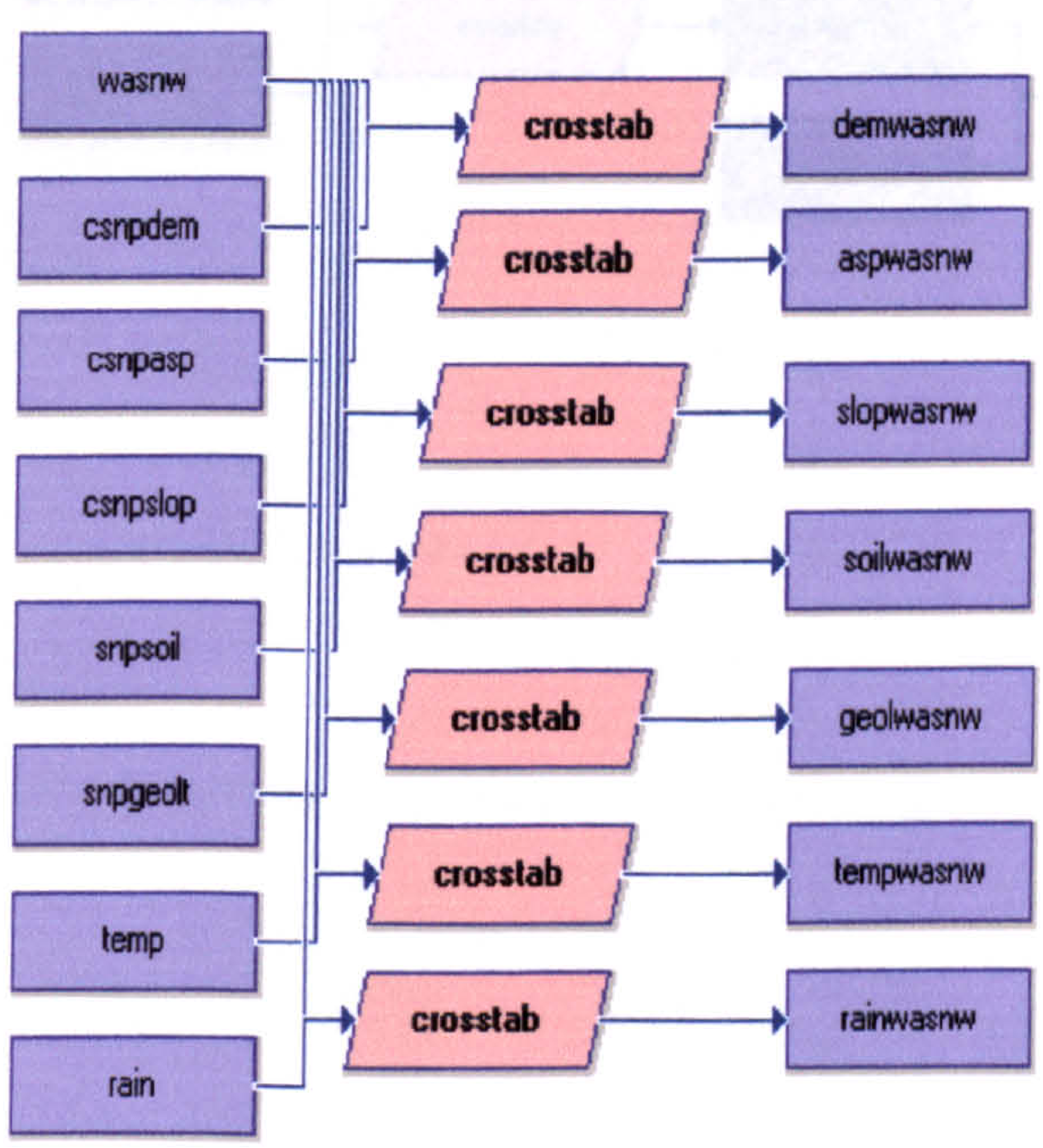
Woodland type criterion



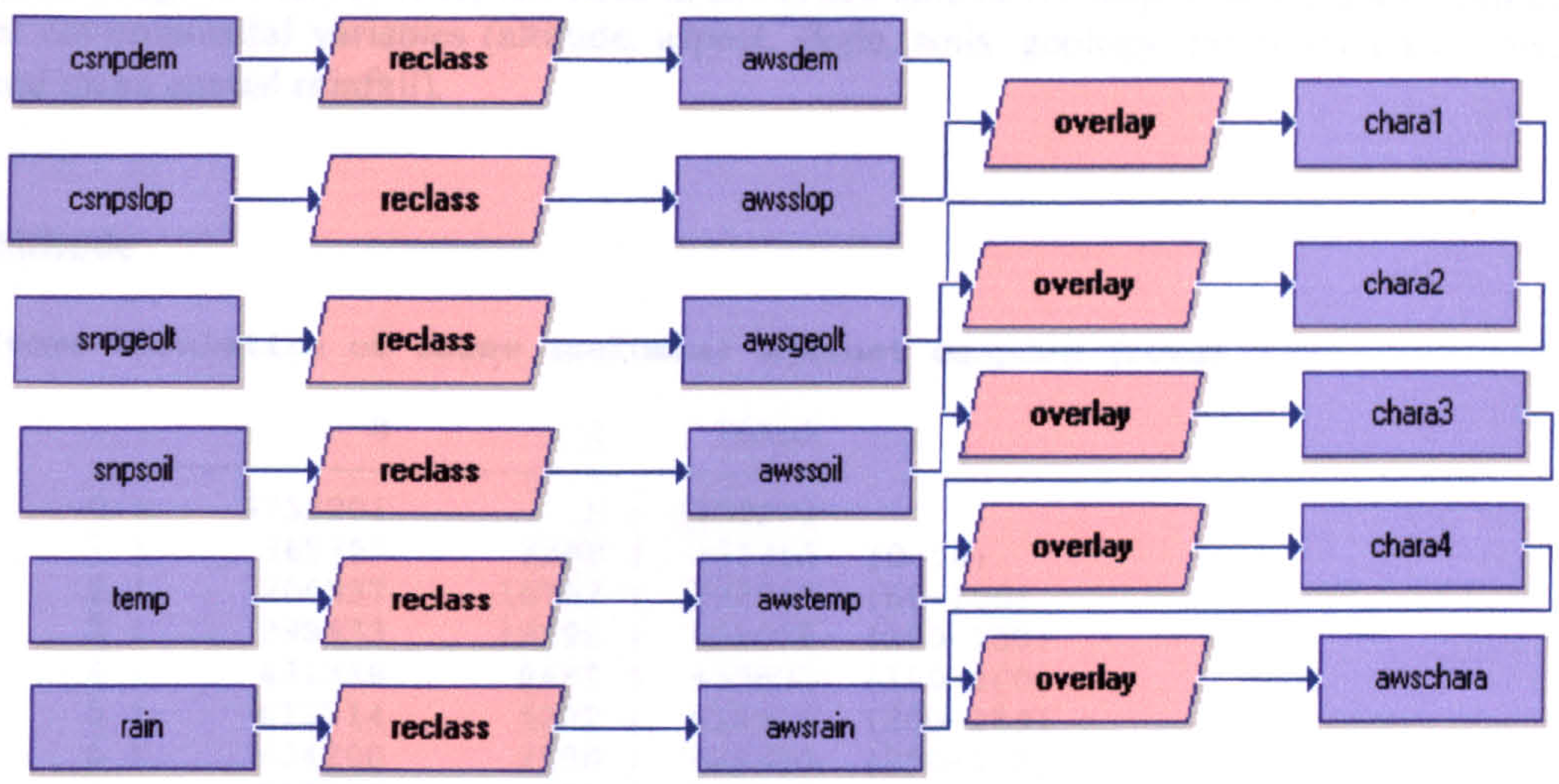
Priority areas within the ancient woodland replanted sites



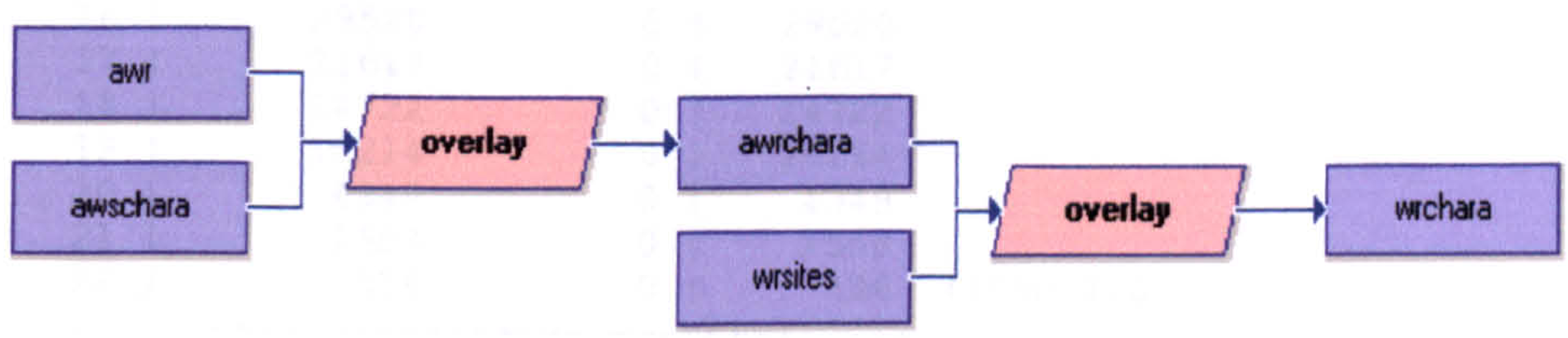
ASNW site characteristics



Areas with a similar combination of site characteristics with those of the ASNW sites



Priority areas within the ancient woodland replanted sites having similar site characteristics to those of the ASNW sites



APPENDIX 3.3. The physical characteristics of the ASNW sites in Snowdonia. Results from overlaying the ASNW sites, recorded in the 1980s land cover map as woodlands, with the set of environmental variables (altitude, aspect, slope, soils, geology, mean annual temperature and mean annual rainfall).

Altitude

Cross-tabulation of wasnw (columns) against csnpdem (rows)

	0	1	Total	
0	9752201	0	9752201	
1	365755	8598	374353	(0-50)
2	206337	16703	223040	(50-100)
3	298633	16895	315528	(100-150)
4	431338	8489	439827	(150-200)
5	613714	5202	618916	(200-250)
6	624200	2100	626300	(250-300)
7	589286	997	590283	(300-350)
8	503682	274	503956	(350-400)
9	533742	191	533933	(400-450)
10	435275	101	435376	(450-500)
11	269024	2	269026	(500-550)
12	165215	0	165215	(550-600)
13	118174	0	118174	(600-650)
14	67945	0	67945	(650-700)
15	43936	0	43936	
16	29520	0	29520	
17	21617	0	21617	
18	14722	0	14722	
19	10214	0	10214	
20	4349	0	4349	
21	1553	0	1553	
22	336	0	336	(1050-1100)
Total	15100768	59552	15160320	

Chi Square = 596919.50000
df = 22
Cramer's V = 0.1984

Overall Kappa 0.0083

Aspect

Cross-tabulation of wasnw (columns) against csnpasp (rows)

	0	1	Total	
0	9752201	0	9752201	
1	904476	7632	912108	(0-45)
2	463062	7406	470468	(45-90)
3	658894	9161	668055	(90-135)
4	661207	10231	671438	(135-180)
5	617667	4442	622109	(180-225)
6	540884	3789	544673	(225-270)
7	791448	7465	798913	(270-315)
8	710929	9426	720355	(315-360)
Total	15100768	59552	15160320	

Chi Square = 122472.87500
df = 8

Cramer's V = 0.0899

Overall Kappa 0.0078

Slope

Cross-tabulation of wasnw (columns) against csnpslop (rows)

	0	1	Total	
0	9752201	0	9752201	
1	1009972	2551	1012523	(0-5)
2	1442987	8158	1451145	(5-10)
3	1172117	11742	1183859	(10-15)
4	757465	12330	769795	(15-20)
5	431754	10261	442015	(20-25)
6	265932	7213	273145	(25-30)
7	148585	4753	153338	(30-35)
8	73499	1861	75360	(35-40)
9	31705	609	32314	(40-45)
10	10715	71	10786	(45-50)
11	2865	3	2868	(50-55)
12	792	0	792	(55-60)
13	175	0	175	(60-65)
14	4	0	4	(65-70)
Total	15100768	59552	15160320	

Chi Square = 195828.96875
df = 14
Cramer's V = 0.1137

Overall Kappa 0.0068

Geology type

Cross-tabulation of wasnw (columns) against snpgeolt (rows)

	0	1	Total	
0	9807206	1006	9808212	
1	9920	0	9920	(Flimston, Mochras & Halkyn Bed)
2	103773	995	104768	
3	298150	4440	302590	
4	291861	2513	294374	
5	1535253	9649	1544902	
6	394456	2786	397242	
7	691878	16652	708530	
8	466400	5856	472256	
9	403724	3872	407596	
10	364673	1447	366120	
11	220825	3417	224242	
12	217720	4202	221922	
13	35088	0	35088	(Andesitic Lava & Tuff)
14	23339	565	23904	
15	31492	0	31492	(Basalt, dolerite, camptonite)
16	54671	1111	55782	
17	150339	1041	151380	
Total	15100768	59552	15160320	

Chi Square = 159167.21875
df = 17
Cramer's V = 0.1025

Overall Kappa 0.0070

Soil type

Cross-tabulation of wasnw (columns) against snpsoil (rows)

	0	1	Total	
0	9830686	956	9831642	
1	686398	2124	688522	
2	20002	0	20002	(Sand-Parendzinas)
3	225065	5181	230246	
4	53427	311	53738	
5	1500639	47411	1548050	
6	103981	83	104064	
7	142205	475	142680	
8	924458	276	924734	
9	351950	1342	353292	
10	393464	398	393862	
11	104669	805	105474	
12	25592	0	25592	(Sandy Gley)
13	46898	0	46898	(Humic Gley)
14	620150	6	620156	(Raw oligo-amorphous peat)
15	22751	151	22902	
16	9688	0	9688	(Urban & Industrial)
17	38745	33	38778	(Water)
Total	15100768	59552	15160320	

Chi Square = 346950.15625
df = 17
Cramer's V = 0.1513

Overall Kappa 0.0069

Mean annual temperature

Cross-tabulation of wasnw (columns) against temp (rows)

°C	0	1	Total
0	9752201	0	9752201
3	4513	0	4513
4	42247	0	42247
5	164303	0	164303
6	632327	45	632372
7	1505148	1205	1506353
8	1641529	7538	1649067
9	940413	35600	976013
10	418087	15164	433251
Total	15100768	59552	15160320

Chi Square = 416781.65625
df = 8
Cramer's V = 0.1658

Overall Kappa 0.0070

Mean annual rainfall

Cross-tabulation of wasnw (columns) against rain (rows)

	0	1	Total	
0	9752201	0	9752201	
1	2060	9	2069	(<600mm)
2	30925	201	31126	
3	189721	1161	190882	
4	569658	10625	580283	
5	1441005	22456	1463461	
6	1836874	17914	1854788	
7	792618	6139	798757	
8	311130	969	312099	
9	123939	78	124017	(3400-3800mm)
10	50637	0	50637	(>3800mm)
Total	15100768	59552	15160320	

Chi Square = 137205.46875
df = 10
Cramer's V = 0.0951

Overall Kappa 0.0070.

APPENDIX 3.4. Geology and soil types present in Snowdonia.

Geology type

1. Flimston, Mochras & Halkyn Bed
2. Wenlock
3. Llandovery
4. Ashgill
5. Caradoc
6. Llandeilo
7. Upper Cambrian & Tremadoc
8. Lower Cambrian
9. Rhyolitic Tuff & Ignimbrite
10. Rhyolitic Lava & Tuff
11. Basalt, Spitite, Hyaloclastite
12. Middle Cambrian
13. Andesitic Lava & Tuff
14. Rhyolite, Trachyte, Felsite Elva
15. Basalt, Dolerite, Camptonite
16. Granite, Syenite & Granophyre

Soil type

1. Humic Rankers
2. Sand-Parendzinas
3. Brown Earth
4. Brown Alluvial
5. Brown Podzolic
6. Humic Brown Podzolic
7. Ironplan Stagnopodzols
8. Ferric Stagnopodzols
9. Cambic Stagno Gley
10. Cambic Stagnohumic Gley
11. Alluvial Gley
12. Sandy Gley
13. Humic Gley
14. Raw oligo-amorphous peat
15. Earthy eutro-amorphous peat
16. Urban & Industrial
17. Water.

APPENDIX 4

APPENDIX 4.1. National Vegetation Classification woodland descriptions (source: Whitbread and Kirby, 1992).

NVC code	Community description
W1	*Salix cinerea-Galium palustre* woodland
W2	*Salix cinerea-Betula pubescens-Phragmites australis* woodland
W3	*Salix pentandra-Carex rostrata* woodland
W4	*Betula pubescens-Molinia caerulea* woodland
W5	*Alnus glutinosa-Carex paniculata* woodland
W6	*Alnus glutinosa-Urtica dioica* woodland
W7	*Alnus glutinosa-Fraxinus excelsior-Lysimachia nemorum* woodland
W8	*Fraxinus excelsior-Acer campestre-Mercurialis perennis* woodland
W9	*Fraxinus excelsior-Sorbus aucuparia-Mercurialis perennis* woodland
W10	*Quercus robur-Pteridium aquilinum-Rubus fruticosus* woodland
W11	*Quercus petraea-Betula pubescens-Oxalis acetosella* woodland
W12	*Fagus sylvatica-Mercurialis perennis* woodland
W13	*Taxus baccata* woodland
W14	*Fagus sylvatica-Rubus fruticosus* woodland
W15	*Fagus sylvatica-Deschampsia flexuosa* woodland
W16	*Quercus spp-Betula spp-Deschampsia flexuosa* woodland
W17	*Quercus petraea-Betula pubescens-Dicranum majus* woodland
W18	*Pinus sylvestris-Hylocomium splendens woodland*

APPENDIX 4.2. IDRISI v.32 rel.2.0. Macro Language files created for the NVC woodland sub-community analysis.

NVC sub-communities

```
RECLASS X I*SNP-NVC*W1*2*1*1*2*0*2*28*-9999
RECLASS X I*SNP-NVC*W4B*2*0*0*2*1*2*3*0*3*28*-9999
RECLASS X I*SNP-NVC*W4C*2*0*0*3*1*3*4*0*4*28*-9999
RECLASS X I*SNP-NVC*W7A*2*0*0*4*1*4*5*0*5*28*-9999
RECLASS X I*SNP-NVC*W7B*2*0*0*5*1*5*6*0*6*28*-9999
RECLASS X I*SNP-NVC*W7C*2*0*0*6*1*6*7*0*7*28*-9999
RECLASS X I*SNP-NVC*W8E*2*0*0*7*1*7*8*0*8*28*-9999
RECLASS X I*SNP-NVC*W9A*2*0*0*8*1*8*9*0*9*28*-9999
RECLASS X I*SNP-NVC*W9B*2*0*0*9*1*9*10*0*10*28*-9999
RECLASS X I*SNP-NVC*W10A*2*0*0*10*1*10*11*0*11*28*-9999
RECLASS X I*SNP-NVC*W10E*2*0*0*11*1*11*12*0*12*28*-9999
RECLASS X I*SNP-NVC*W11A*2*0*0*12*1*12*13*0*13*28*-9999
RECLASS X I*SNP-NVC*W11B*2*0*0*13*1*13*14*0*14*28*-9999
RECLASS X I*SNP-NVC*W11C*2*0*0*14*1*14*15*0*15*28*-9999
RECLASS X I*SNP-NVC*W14*2*0*0*15*1*15*16*0*16*28*-9999
RECLASS X I*SNP-NVC*W15C*2*0*0*16*1*16*17*0*17*28*-9999
RECLASS X I*SNP-NVC*W17A*2*0*0*17*1*17*18*0*18*28*-9999
RECLASS X I*SNP-NVC*W17B*2*0*0*18*1*18*19*0*19*28*-9999
RECLASS X I*SNP-NVC*W17C*2*0*0*19*1*19*20*0*20*28*-9999
RECLASS X I*SNP-NVC*W17AW17B*2*0*0*20*1*20*21*0*21*28*-9999
RECLASS X I*SNP-NVC*W17AW17C*2*0*0*21*1*21*22*0*22*28*-9999
RECLASS X I*SNP-NVC*W17BW17C*2*0*0*22*1*22*23*0*23*28*-9999
RECLASS X I*SNP-NVC*W17CW4B*2*0*0*23*1*23*24*0*24*28*-9999
RECLASS X I*SNP-NVC*W7BW7C*2*0*0*24*1*24*25*0*25*28*-9999
RECLASS X I*SNP-NVC*W10AW10E*2*0*0*25*1*25*26*0*26*28*-9999
```

Cross-tabulation of NVC woodland sub-communities with the environmental variables

```
crosstab x w1*csnpasp*2*none*n
crosstab x w1*csnpdem*2*none*n
crosstab x w1*csnpslop*2*none*n
crosstab x w1*snpgeolt*2*none*n
crosstab x w1*snpsoil*2*none*n
crosstab x w1*temp*2*none*n
crosstab x w1*rain*2*none*n
crosstab x w4b*csnpasp*2*none*n
crosstab x w4b*csnpdem*2*none*n
crosstab x w4b*csnpslop*2*none*n
crosstab x w4b*snpgeolt*2*none*n
crosstab x w4b*snpsoil*2*none*n
crosstab x w4b*temp*2*none*n
crosstab x w4b*rain*2*none*n
crosstab x w4c*csnpasp*2*none*n
crosstab x w4c*csnpdem*2*none*n
crosstab x w4c*csnpslop*2*none*n
crosstab x w4c*snpgeolt*2*none*n
crosstab x w4c*snpsoil*2*none*n
crosstab x w4c*temp*2*none*n
crosstab x w4c*rain*2*none*n
crosstab x w7a*csnpasp*2*none*n
crosstab x w7a*csnpdem*2*none*n
crosstab x w7a*csnpslop*2*none*n
crosstab x w7a*snpgeolt*2*none*n
crosstab x w7a*snpsoil*2*none*n
crosstab x w7a*temp*2*none*n
crosstab x w7a*rain*2*none*n
crosstab x w7b*csnpasp*2*none*n
crosstab x w7b*csnpdem*2*none*n
crosstab x w7b*csnpslop*2*none*n
crosstab x w7b*snpgeolt*2*none*n
crosstab x w7b*snpsoil*2*none*n
crosstab x w7b*temp*2*none*n
crosstab x w7b*rain*2*none*n
crosstab x w7c*csnpasp*2*none*n
crosstab x w7c*csnpdem*2*none*n
crosstab x w7c*csnpslop*2*none*n
crosstab x w7c*snpgeolt*2*none*n
crosstab x w7c*snpsoil*2*none*n
crosstab x w7c*temp*2*none*n
```

```
crosstab x w7c*rain*2*none*n
crosstab x w8e*csnpasp*2*none*n
crosstab x w8e*csnpdem*2*none*n
crosstab x w8e*csnpslop*2*none*n
crosstab x w8e*snpgeolt*2*none*n
crosstab x w8e*snpsoil*2*none*n
crosstab x w8e*temp*2*none*n
crosstab x w8e*rain*2*none*n
crosstab x w9a*csnpasp*2*none*n
crosstab x w9a*csnpdem*2*none*n
crosstab x w9a*csnpslop*2*none*n
crosstab x w9a*snpgeolt*2*none*n
crosstab x w9a*snpsoil*2*none*n
crosstab x w9a*temp*2*none*n
crosstab x w9a*rain*2*none*n
crosstab x w9b*csnpasp*2*none*n
crosstab x w9b*csnpdem*2*none*n
crosstab x w9b*csnpslop*2*none*n
crosstab x w9b*snpgeolt*2*none*n
crosstab x w9b*snpsoil*2*none*n
crosstab x w9b*temp*2*none*n
crosstab x w9b*rain*2*none*n
crosstab x w10a*csnpasp*2*none*n
crosstab x w10a*csnpdem*2*none*n
crosstab x w10a*csnpslop*2*none*n
crosstab x w10a*snpgeolt*2*none*n
crosstab x w10a*snpsoil*2*none*n
crosstab x w10a*temp*2*none*n
crosstab x w10a*rain*2*none*n
crosstab x w10e*csnpasp*2*none*n
crosstab x w10e*csnpdem*2*none*n
crosstab x w10e*csnpslop*2*none*n
crosstab x w10e*snpgeolt*2*none*n
crosstab x w10e*snpsoil*2*none*n
crosstab x w10e*temp*2*none*n
crosstab x w10e*rain*2*none*n
crosstab x w11a*csnpasp*2*none*n
crosstab x w11a*csnpdem*2*none*n
crosstab x w11a*csnpslop*2*none*n
crosstab x w11a*snpgeolt*2*none*n
crosstab x w11a*snpsoil*2*none*n
crosstab x w11a*temp*2*none*n
crosstab x w11a*rain*2*none*n
crosstab x w11b*csnpasp*2*none*n
crosstab x w11b*csnpdem*2*none*n
crosstab x w11b*csnpslop*2*none*n
crosstab x w11b*snpgeolt*2*none*n
crosstab x w11b*snpsoil*2*none*n
crosstab x w11b*temp*2*none*n
crosstab x w11b*rain*2*none*n
crosstab x w11c*csnpasp*2*none*n
crosstab x w11c*csnpdem*2*none*n
crosstab x w11c*csnpslop*2*none*n
crosstab x w11c*snpgeolt*2*none*n
crosstab x w11c*snpsoil*2*none*n
crosstab x w11c*temp*2*none*n
crosstab x w11c*rain*2*none*n
crosstab x w14*csnpasp*2*none*n
crosstab x w14*csnpdem*2*none*n
crosstab x w14*csnpslop*2*none*n
crosstab x w14*snpgeolt*2*none*n
crosstab x w14*snpsoil*2*none*n
crosstab x w14*temp*2*none*n
crosstab x w14*rain*2*none*n
crosstab x w15c*csnpasp*2*none*n
crosstab x w15c*csnpdem*2*none*n
crosstab x w15c*csnpslop*2*none*n
crosstab x w15c*snpgeolt*2*none*n
crosstab x w15c*snpsoil*2*none*n
crosstab x w15c*temp*2*none*n
crosstab x w15c*rain*2*none*n
crosstab x w17a*csnpasp*2*none*n
crosstab x w17a*csnpdem*2*none*n
crosstab x w17a*csnpslop*2*none*n
crosstab x w17a*snpgeolt*2*none*n
crosstab x w17a*snpsoil*2*none*n
crosstab x w17a*temp*2*none*n
```

```
crosstab x w17a*rain*2*none*n
crosstab x w17b*csnpasp*2*none*n
crosstab x w17b*csnpdem*2*none*n
crosstab x w17b*csnpslop*2*none*n
crosstab x w17b*snpgeolt*2*none*n
crosstab x w17b*snpsoil*2*none*n
crosstab x w17b*temp*2*none*n
crosstab x w17b*rain*2*none*n
crosstab x w17c*csnpasp*2*none*n
crosstab x w17c*csnpdem*2*none*n
crosstab x w17c*csnpslop*2*none*n
crosstab x w17c*snpgeolt*2*none*n
crosstab x w17c*snpsoil*2*none*n
crosstab x w17c*temp*2*none*n
crosstab x w17c*rain*2*none*n
crosstab x w17aw17b*csnpasp*2*none*n
crosstab x w17aw17b*csnpdem*2*none*n
crosstab x w17aw17b*csnpslop*2*none*n
crosstab x w17aw17b*snpgeolt*2*none*n
crosstab x w17aw17b*snpsoil*2*none*n
crosstab x w17aw17b*temp*2*none*n
crosstab x w17aw17b*rain*2*none*n
crosstab x w17aw17c*csnpasp*2*none*n
crosstab x w17aw17c*csnpdem*2*none*n
crosstab x w17aw17c*csnpslop*2*none*n
crosstab x w17aw17c*snpgeolt*2*none*n
crosstab x w17aw17c*snpsoil*2*none*n
crosstab x w17aw17c*temp*2*none*n
crosstab x w17aw17c*rain*2*none*n
crosstab x w17bw17c*csnpasp*2*none*n
crosstab x w17bw17c*csnpdem*2*none*n
crosstab x w17bw17c*csnpslop*2*none*n
crosstab x w17bw17c*snpgeolt*2*none*n
crosstab x w17bw17c*snpsoil*2*none*n
crosstab x w17bw17c*temp*2*none*n
crosstab x w17bw17c*rain*2*none*n
crosstab x w17cw4b*csnpasp*2*none*n
crosstab x w17cw4b*csnpdem*2*none*n
crosstab x w17cw4b*csnpslop*2*none*n
crosstab x w17cw4b*snpgeolt*2*none*n
crosstab x w17cw4b*snpsoil*2*none*n
crosstab x w17cw4b*temp*2*none*n
crosstab x w17cw4b*rain*2*none*n
crosstab x w7bw7c*csnpasp*2*none*n
crosstab x w7bw7c*csnpdem*2*none*n
crosstab x w7bw7c*csnpslop*2*none*n
crosstab x w7bw7c*snpgeolt*2*none*n
crosstab x w7bw7c*snpsoil*2*none*n
crosstab x w7bw7c*temp*2*none*n
crosstab x w7bw7c*rain*2*none*n
crosstab x w10aw10e*csnpasp*2*none*n
crosstab x w10aw10e*csnpdem*2*none*n
crosstab x w10aw10e*csnpslop*2*none*n
crosstab x w10aw10e*snpgeolt*2*none*n
crosstab x w10aw10e*snpsoil*2*none*n
crosstab x w10aw10e*temp*2*none*n
crosstab x w10aw10e*rain*2*none*n
```

Reclassification of each environmental variable for each NVC woodland sub-community according to the matrices

W1, W4b, W4c

```
RECLASS X I*CSNPDEM*DEMW1*2*1*1*2*0*2*3*1*3*4*0*4*777*-9999
RECLASS X I*CSNPASP*ASPW1*2*1*1*3*0*3*8*1*8*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW1*2*1*1*6*0*6*777*-9999
RECLASS X I*SNPGEOLT*GEOLW1*2*0*0*5*1*5*6*0*6*8*1*8*9*0*9*777*-9999
RECLASS X I*SNPSOIL*SOILW1*2*0*0*5*1*5*6*0*6*11*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW1*2*0*0*9*1*9*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW1*2*0*0*4*1*4*6*0*6*777*-9999
RECLASS X I*CSNPDEM*DEMW4B*2*1*1*2*0*2*3*1*3*7*0*7*777*-9999
RECLASS X I*CSNPSLOP*SLOPW4B*2*1*1*6*0*6*777*-9999
RECLASS X I*SNPGEOLT*GEOLW4B*2*0*0*5*1*5*6*0*6*7*1*7*10*0*10*777*-9999
RECLASS X I*SNPSOIL*SOILW4B*2*0*0*5*1*5*6*0*6*11*0*11*777*-9999
RECLASS X I*TEMP*TEMPW4B*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW4B*2*0*0*4*1*4*8*0*8*777*-9999
```

```
RECLASS X I*CSNPDEM*DEMW4C*2*1*1*3*0*3*777*-9999
RECLASS X I*CSNPASP*ASPW4C*2*1*1*3*0*3*4*1*4*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW4C*2*1*1*3*0*3*777*-9999
RECLASS X I*SNPGEOLT*GEOLW4C*2*0*0*8*1*8*9*0*9*777*-9999
RECLASS X I*SNPSOIL*SOILW4C*2*0*0*3*1*3*4*0*4*777*-9999
RECLASS X I*TEMP*TEMPW4C*2*0*0*9*1*9*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW4C*2*0*0*4*1*4*6*0*6*777*-9999
```

W7a, W7b, W7c

```
RECLASS X I*CSNPDEM*DEMW7A*2*0*0*2*1*2*5*0*5*777*-9999
RECLASS X I*CSNPASP*ASPW7A*2*1*1*4*0*4*6*1*6*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW7A*2*1*1*6*0*6*777*-9999
RECLASS X I*SNPGEOLT*GEOLW7A*2*0*0*5*1*5*8*0*8*9*1*9*10*0*10*777*-9999
RECLASS X I*SNPSOIL*SOILW7A*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*TEMP*TEMPW7A*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW7A*2*0*0*3*1*3*7*0*7*777*-9999
RECLASS X I*CSNPDEM*DEMW7B*2*0*0*2*1*2*7*0*7*777*-9999
RECLASS X I*CSNPSLOP*SLOPW7B*2*1*1*8*0*8*777*-9999
RECLASS X I*SNPGEOLT*GEOLW7B*2*0*0*7*1*7*8*0*8*9*1*9*10*0*10*11*1*11*12*0*12*777*-9999
RECLASS X I*SNPSOIL*SOILW7B*2*0*0*3*1*3*4*0*4*5*1*5*6*0*6*9*1*9*10*0*10*11
*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW7B*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW7B*2*0*0*4*1*4*9*0*9*777*-9999
RECLASS X I*CSNPDEM*DEMW7C*2*1*1*7*0*7*777*-9999
RECLASS X I*CSNPSLOP*SLOPW7C*2*1*1*9*0*9*777*-9999
RECLASS X I*SNPGEOLT*GEOLW7C*2*0*0*7*1*7*10*0*10*11*1*11*12*0*12*16*1*16*17*0*17*777*-
9999
RECLASS X I*SNPSOIL*SOILW7C*2*0*0*3*1*3*4*0*4*5*1*5*6*0*6*9*1*9*10*0*10*11
*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW7C*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW7C*2*0*0*3*1*3*6*0*6*7*1*7*10*0*10*777*-9999
```

W8e, W9a, W9b

```
RECLASS X I*CSNPDEM*DEMW8E*2*1*1*5*0*5*777*-9999
RECLASS X I*CSNPASP*ASPW8E*2*1*1*2*0*2*7*1*7*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW8E*2*1*1*10*0*10*777*-9999
RECLASS X I*SNPGEOLT*GEOLW8E*2*0*0*8*1*8*9*0*9*12*1*12*13*0*13*777*-9999
RECLASS X I*SNPSOIL*SOILW8E*2*0*0*5*1*5*6*0*6*11*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW8E*2*0*0*9*1*9*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW8E*2*0*0*4*1*4*8*0*8*777*-9999
RECLASS X I*CSNPDEM*DEMW9A*2*1*1*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW9A*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW9A*2*0*0*3*1*3*10*0*10*11*1*11*12*0*12*17*1*17*18*0*18*777*-
9999
RECLASS X I*SNPSOIL*SOILW9A*2*1*1*2*0*2*3*1*3*4*0*4*5*1*5*6*0*6*9*1*9*10*0*10*11
*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW9A*2*0*0*7*1*7*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW9A*2*0*0*2*1*2*10*0*10*777*-9999
RECLASS X I*CSNPDEM*DEMW9B*2*1*1*5*0*5*777*-9999
RECLASS X I*CSNPSLOP*SLOPW9B*2*1*1*8*0*8*777*-9999
RECLASS X I*SNPGEOLT*GEOLW9B*2*0*0*3*1*3*4*0*4*7*1*7*8*0*8*777*-9999
RECLASS X I*SNPSOIL*SOILW9B*2*0*0*5*1*5*6*0*6*9*1*9*10*0*10*777*-9999
RECLASS X I*TEMP*TEMPW9B*2*0*0*9*1*9*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW9B*2*0*0*3*1*3*8*0*8*777*-9999
```

W10a, W10e, W11a

```
RECLASS X I*CSNPDEM*DEMW10a*2*1*1*4*0*4*777*-9999
RECLASS X I*CSNPSLOP*SLOPW10a*2*1*1*8*0*8*777*-9999
RECLASS X I*SNPGEOLT*GEOLW10a*2*0*0*5*1*5*6*0*6*9*1*9*10*0*10*777*-9999
RECLASS X I*SNPSOIL*SOILW10a*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*TEMP*TEMPW10a*2*0*0*9*1*9*10*0*10*777*-9999
RECLASS X I*RAIN*RAINW10a*2*0*0*4*1*4*7*0*7*777*-9999
RECLASS X I*CSNPDEM*DEMW10e*2*1*1*7*0*7*777*-9999
RECLASS X I*CSNPSLOP*SLOPW10e*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW10e*2*0*0*2*1*2*6*0*6*7*1*7*10*0*10*11*1*11*13*0*13*777*-
9999
RECLASS X I*SNPSOIL*SOILW10e*2*0*0*3*1*3*4*0*4*5*1*5*6*0*6*9*1*9*10*0*10*11*1*11*12
*0*12*777*-9999
RECLASS X I*TEMP*TEMPW10e*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW10e*2*0*0*2*1*2*9*0*9*777*-9999
RECLASS X I*CSNPDEM*DEMW11a*2*1*1*8*0*8*777*-9999
RECLASS X I*CSNPSLOP*SLOPW11a*2*1*1*10*0*10*777*-9999
RECLASS X I*SNPGEOLT*GEOLW11a*2*0*0*3*1*3*10*0*10*11*1*11*12*0*12*16*1*16*17
*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW11a*2*1*1*2*0*2*3*1*3*4*0*4*5*1*5*6*0*6*8*1*8*10*0*10*11
```

```
*1*11*12*0*12*14*1*14*15*0*15*777*-9999
RECLASS X I*TEMP*TEMPW11a*2*0*0*7*1*7*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW11a*2*0*0*3*1*3*8*0*8*777*-9999
```

W11b, W14, W15c

```
RECLASS X I*CSNPDEM*DEMW11b*2*0*0*2*1*2*7*0*7*777*-9999
RECLASS X I*CSNPASP*ASPW11b*2*1*1*2*0*2*3*1*3*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW11b*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW11b*2*0*0*3*1*3*4*0*4*7*1*7*8*0*8*9*1*9*10*0*10*11
*1*11*12*0*12*777*-9999
RECLASS X I*SNPSOIL*SOILW11b*2*0*0*5*1*5*6*0*6*11*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW11b*2*0*0*8*1*8*10*0*10*777*-9999
RECLASS X I*RAIN*RAINW11b*2*0*0*3*1*3*10*0*10*777*-9999
RECLASS X I*CSNPDEM*DEMW14*2*0*0*2*1*2*4*0*4*777*-9999
RECLASS X I*CSNPASP*ASPW14*2*1*1*3*0*3*5*1*5*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW14*2*1*1*9*0*9*777*-9999
RECLASS X I*SNPGEOLT*GEOLW14*2*0*0*5*1*5*6*0*6*8*1*8*10*0*10*777*-9999
RECLASS X I*SNPSOIL*SOILW14*2*0*0*3*1*3*4*0*4*5*1*5*6*0*6*9*1*9*10*0*10*777*-9999
RECLASS X I*TEMP*TEMPW14*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW14*2*0*0*4*1*4*8*0*8*777*-9999
RECLASS X I*CSNPDEM*DEMW15c*2*1*1*3*0*3*777*-9999
RECLASS X I*CSNPASP*ASPW15c*2*1*1*3*0*3*6*1*6*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW15c*2*1*1*6*0*6*7*1*7*8*0*8*777*-9999
RECLASS X I*SNPGEOLT*GEOLW15c*2*0*0*7*1*7*9*0*9*777*-9999
RECLASS X I*SNPSOIL*SOILW15c*2*0*0*3*1*3*6*0*6*777*-9999
RECLASS X I*TEMP*TEMPW15c*2*0*0*9*1*9*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW15c*2*0*0*4*1*4*8*0*8*777*-9999
```

W17a, W17b, W17c

```
RECLASS X I*CSNPDEM*DEMW17a*2*1*1*8*0*8*777*-9999
RECLASS X I*CSNPSLOP*SLOPW17a*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17a*2*0*0*5*1*5*6*0*6*7*1*7*13*0*13*14*1*14*15*0*15*16
*1*16*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17a*2*1*1*2*0*2*3*1*3*6*0*6*9*1*9*10*0*10*11*1*11*12
*0*12*777*-9999
RECLASS X I*TEMP*TEMPW17a*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW17a*2*0*0*4*1*4*10*0*10*777*-9999
RECLASS X I*CSNPDEM*DEMW17b*2*1*1*7*0*7*777*-9999
RECLASS X I*CSNPSLOP*SLOPW17b*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17b*2*0*0*5*1*5*11*0*11*12*1*12*13*0*13*16*1*16*17
*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17b*2*1*1*2*0*2*3*1*3*4*0*4*5*1*5*6*0*6*7*1*7*8
*0*8*9*1*9*10*0*10*11*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW17b*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW17b*2*0*0*3*1*3*9*0*9*777*-9999
RECLASS X I*CSNPDEM*DEMW17c*2*1*1*8*0*8*777*-9999
RECLASS X I*CSNPSLOP*SLOPW17c*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17c*2*0*0*5*1*5*13*0*13*15*1*15*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17c*2*1*1*2*0*2*5*1*5*6*0*6*8*1*8*12*0*12*14*1*14*15
*0*15*777*-9999
RECLASS X I*TEMP*TEMPW17c*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW17c*2*0*0*3*1*3*8*0*8*777*-9999
```

W17a+W17b, W17a+W17c, W17b+W17c

```
RECLASS X I*CSNPDEM*DEMW17a+b*2*1*1*5*0*5*777*-9999
RECLASS X I*CSNPASP*ASPW17a+b*2*1*1*2*0*2*5*1*5*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW17a+b*2*1*1*8*0*8*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17a+b*2*0*0*7*1*7*8*0*8*12*1*12*13*0*13*777*-9999
RECLASS X I*SNPSOIL*SOILW17a+b*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*TEMP*TEMPW17a+b*2*0*0*9*1*9*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW17a+b*2*0*0*5*1*5*8*0*8*777*-9999
RECLASS X I*CSNPDEM*DEMW17a+c*2*0*0*3*1*3*5*0*5*777*-9999
RECLASS X I*CSNPASP*ASPW17a+c*2*1*1*4*0*4*5*1*5*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW17a+c*2*1*1*5*0*5*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17a+c*2*0*0*7*1*7*8*0*8*12*1*12*13*0*13*16*1*16*17
*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17a+c*2*0*0*5*1*5*6*0*6*14*1*14*15*0*15*777*-9999
RECLASS X I*TEMP*TEMPW17a+c*2*0*0*9*1*9*10*0*10*777*-9999
RECLASS X I*RAIN*RAINW17a+c*2*0*0*5*1*5*7*0*7*777*-9999
RECLASS X I*CSNPDEM*DEMW17b+c*2*1*1*2*0*2*777*-9999
RECLASS X I*CSNPSLOP*SLOPW17b+c*2*1*1*5*0*5*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17b+c*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*SNPSOIL*SOILW17b+c*2*0*0*5*1*5*6*0*6*11*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW17b+c*2*0*0*10*1*10*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW17b+c*2*0*0*5*1*5*7*0*7*777*-9999
```

W17c+W4b, W7b+W7c, W10a+W10e

```
RECLASS X I*CSNPDEM*DEMW17c+w4b*2*1*1*2*0*2*777*-9999
RECLASS X I*CSNPASP*ASPW17c+w4b*2*1*1*2*0*2*5*1*5*7*0*7*8*1*8*9*0*9*777*-9999
RECLASS X I*CSNPSLOP*SLOPW17c+w4b*2*1*1*2*0*2*3*1*3*4*0*4*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17c+w4b*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*SNPSOIL*SOILW17c+w4b*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*TEMP*TEMPW17c+w4b*2*0*0*10*1*10*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW17c+w4b*2*0*0*5*1*5*7*0*7*777*-9999
RECLASS X I*CSNPDEM*DEMW7b+c*2*0*0*3*1*3*6*0*6*777*-9999
RECLASS X I*CSNPASP*ASPW7b+c*2*0*0*3*1*3*6*0*6*777*-9999
RECLASS X I*CSNPSLOP*SLOPW7b+c*2*1*1*6*0*6*777*-9999
RECLASS X I*SNPGEOLT*GEOLW7b+c*2*0*0*9*1*9*10*0*10*777*-9999
RECLASS X I*SNPSOIL*SOILW7b+c*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*TEMP*TEMPW7b+c*2*0*0*8*1*8*10*0*10*777*-9999
RECLASS X I*RAIN*RAINW7b+c*2*0*0*5*1*5*7*0*7*777*-9999
RECLASS X I*CSNPDEM*DEMW10a+e*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*CSNPASP*ASPW10a+e*2*0*0*4*1*4*5*0*5*777*-9999
RECLASS X I*CSNPSLOP*SLOPW10a+e*2*0*0*4*1*4*7*0*7*777*-9999
RECLASS X I*SNPGEOLT*GEOLW10a+e*2*0*0*9*1*9*10*0*10*777*-9999
RECLASS X I*SNPSOIL*SOILW10a+e*2*0*0*5*1*5*6*0*6*777*-9999
RECLASS X I*TEMP*TEMPW10a+e*2*0*0*8*1*8*9*0*9*777*-9999
RECLASS X I*RAIN*RAINW10a+e*2*0*0*6*1*6*8*0*8*777*-9999
```

Suitable sites for each NVC woodland sub-community

Decision support files

```
7
0
demw1
aspw1
slopw1
geolw1
soilw1
tempw1
rainw1

6
0
demw4b
slopw4b
geolw4b
soilw4b
tempw4b
rainw4b

7
0
demw4c
aspw4c
slopw4c
geolw4c
soilw4c
tempw4c
rainw4c

7
0
demw7a
aspw7a
slopw7a
geolw7a
soilw7a
tempw7a
rainw7a

6
0
demw7b
slopw7b
geolw7b
soilw7b
tempw7b
rainw7b
```

```
6
0
demw7c
slopw7c
geolw7c
soilw7c
tempw7c
rainw7c

7
0
demw8e
aspw8e
slopw8e
geolw8e
soilw8e
tempw8e
rainw8e

6
0
demw9a
slopw9a
geolw9a
soilw9a
tempw9a
rainw9a

6
0
demw9b
slopw9b
geolw9b
soilw9b
tempw9b
rainw9b

6
0
demw10a
slopw10a
geolw10a
soilw10a
tempw10a
rainw10a

6
0
demw10e
slopw10e
geolw10e
soilw10e
tempw10e
rainw10e

6
0
demw11a
slopw11a
geolw11a
soilw11a
tempw11a
rainw11a

7
0
demw11b
aspw11b
slopw11b
geolw11b
soilw11b
tempw11b
rainw11b

7
0
```

```
demwl4
aspwl4
slopwl4
geolwl4
soilwl4
tempwl4
rainwl4

7
0
demwl5c
aspwl5c
slopwl5c
geolwl5c
soilwl5c
tempwl5c
rainwl5c

6
0
demwl7a
slopwl7a
geolwl7a
soilwl7a
tempwl7a
rainwl7a

6
0
demwl7b
slopwl7b
geolwl7b
soilwl7b
tempwl7b
rainwl7b

6
0
demwl7c
slopwl7c
geolwl7c
soilwl7c
tempwl7c
rainwl7c

7
0
demwl7a+b
aspwl7a+b
slopwl7a+b
geolwl7a+b
soilwl7a+b
tempwl7a+b
rainwl7a+b

7
0
demwl7a+c
aspwl7a+c
slopwl7a+c
geolwl7a+c
soilwl7a+c
tempwl7a+c
rainwl7a+c

6
0
demwl7b+c
slopwl7b+c
geolwl7b+c
soilwl7b+c
tempwl7b+c
rainwl7b+c

7
0
```

```
DEMW17c+w4b
ASPW17c+w4b
SLOPW17c+w4b
GEOLW17c+w4b
SOILW17c+w4b
TEMPW17c+w4b
RAINW17c+w4b

7
0
DEMW7b+c
ASPW7b+c
SLOPW7b+c
GEOLW7b+c
SOILW7b+c
TEMPW7b+c
RAINW7b+c

7
0
DEMW10a+e
ASPW10a+e
SLOPW10a+e
GEOLW10a+e
SOILW10a+e
TEMPW10a+e
RAINW10a+e
```

Multi-criteria evaluation files

```
mce x suitw1*w1
mce x suitw4b*w4b
mce x suitw4c*w4c
mce x suitw7a*w7a
mce x suitw7b*w7b
mce x suitw7c*w7c
mce x suitw8e*w8e
mce x suitw9a*w9a
mce x suitw9b*w9b
mce x suitw10a*w10a
mce x suitw10e*w10e
mce x suitw11a*w11a
mce x suitw11b*w11b
mce x suitw14*w14
mce x suitw15c*w15c
mce x suitw17a*w17a
mce x suitw17b*w17b
mce x suitw17c*w17c
mce x suitw17a+b*w17a+b
mce x suitw17a+c*w17a+c
mce x suitw17b+c*w17b+c
mce x suitw17cw4b*w17c+w4b
mce x suitw7b+c*w7b+c
mce x suitw10a+e*w10a+e
```

Approach to forming a single image of all NVC woodland sub-communities

```
crosstab x suitw17a*suitw17b*1*w17aw17b*n
reclass x I*w17aw17b*cr1*2*0*0*2*1*2*3*2*3*4*3*4*5*0*5*7777*-9999
crosstab x cr1*suitw17c*1*c2*n
reclass x I*c2*cr2*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*0*9*7777*-9999
crosstab x cr2*suitw11a*1*c3*n
reclass x I*c3*cr3*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*
10*9*10*11*10*11*12*11*12*13*12*13*14*13*14*15*14*15*16*15*16*17*0*17*7777*-9999
crosstab x cr3*suitw11b*1*c4*n
reclass x I*c4*cr4*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*
10*9*10*11*10*11*12*11*12*13*12*13*14*13*14*15*14*15*16*15*16*17*16*17*18*17*18*19*18*
19*20*19*20*21*20*21*22*21*22*23*22*23*24*23*24*25*24*25*26*0*26*7777*-9999
crosstab x cr4*suitw10a*1*c5*n
reclass x I*c5*cr5*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*10
*9*10*11*10*11*12*11*12*13*12*13*14*13*14*15*14*15*16*15*16*17*16*17*18*17*18*19*18*19
*20*19*20*21*20*21*22*21*22*23*22*23*24*23*24*25*24*25*26*25*26*27*26*27*28*0*28*7777*
-9999
crosstab x cr5*suitw10e*1*c6*n
reclass x I*c6*cr6*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*10*9*10
*11*10*11*12*11*12*13*12*13*14*13*14*15*14*15*16*15*16*17*16*17*18*17*18*19*18*19*20*1
9*20*21*20*21*22*21*22*23*22*23*24*23*24*25*24*25*26*25*26*27*26*27*28*27*28*29*28*29*
```

```
30*29*30*31*30*31*32*31*32*33*32*33*34*33*34*35*34*35*36*35*36*37*36*37*38*37*38*39*38
*39*40*0*40*7777*-9999
crosstab x suitw9a*suitw9b*1*c7*n
reclass x I*c7*cr7*2*0*0*2*1*2*3*2*3*4*0*4*7777*-9999
crosstab x cr7*suitw8e*1*c8*n
reclass x I*c8*cr8*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*0*6*7777*-9999
crosstab x suitw1*suitw4b*1*c9*n
reclass x I*c9*cr9*2*0*0*2*1*2*3*2*3*4*3*4*5*0*5*7777*-9999
crosstab x cr9*suitw4c*1*c10*n
reclass x I*c10*cr10*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*0*6*7777*-9999
crosstab x cr10*suitw7a*1*c11*n
reclass x I*c11*cr11*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*0*9*7777*-9999
crosstab x cr11*suitw7b*1*c12*n
reclass x I*c12*cr12*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*10*9*10
*11*10*11*12*11*12*13*0*13*7777*-9999
crosstab x cr12*suitw7c*1*c13*n
reclass x I*c13*cr13*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*10
*9*10*11*10*11*12*11*12*13*12*13*14*13*14*15*14*15*16*15*16*17*16*17*18*17*18*19*18*19
*20*19*20*21*20*21*22*0*22*7777*-9999
crosstab x suitw14*suitw15c*1*c14*n
reclass x I*c14*cr14*2*0*0*2*1*2*3*2*3*4*3*4*5*0*5*7777*-9999
crosstab x suitw17a+b*suitw17a+c*1*c15*n
reclass x I*c15*cr15*2*0*0*2*1*2*3*2*3*4*3*4*5*0*5*7777*-9999
crosstab x cr15*suitw17b+c*1*c16*n
reclass x I*c16*cr16*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*0*6*7777*-9999
crosstab x cr16*suitw17c+w4b*1*c17*n
reclass x I*c17*cr17*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*0*7*7777*-9999
crosstab x cr17*suitw7b+c*1*c18*n
reclass x I*c18*cr18*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*0*8*7777*-9999
crosstab x cr18*suitw10a+e*1*c19*n
reclass x I*c19*cr19*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*10
*0*10*7777*-9999
```

Forming a single image of NVC woodland communities

```
reclass x I*cr6*nvccom1*2*0*0*1*1*1*8*2*8*9*3*9*16*4*16*17*5*17*20*6*20*21
*7*21*28*6*28*29*7*29*32*6*32*33*7*33*39*0*39*7777*-9999
crosstab x nvccom1*cr8*1*tmp*n
reclass x I*tmp*nvccom2*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8*9*10
*9*10*11*10*11*12*11*12*13*12*13*14*13*14*15*12*15*16*13*16*17*14*17*18*15*18*19*0*19*
7777*-9999
reclass x I*cr13*nvccom3*2*0*0*1*1*1*2*2*2*3*3*3*4*4*4*5*5*5*6*6*6*7*4*7*8*5*8*9
*4*9*10*5*10*11*4*11*12*7*12*13*5*13*14*6*14*15*5*15*16*4*16*18*5*18*19*4*19*20*5*20*2
1*0*21*7777*-9999
crosstab x nvccom2*nvccom3*1*tmp2*n
reclass x I*tmp2*nvccom4*2*0*0*2*1*2*3*2*3*4*5*4*5*3*5*6*6*6*7*4*7*8*7*8*9*8
*9*10*9*10*11*10*11*12*11*12*13*12*13*14*13*14*15*14*15*16*15*16*17*16*17*18*17*18*19*
18*19*20*19*20*21*20*21*22*21*22*23*22*23*24*23*24*25*24*25*26*25*26*27*26*27*28*27*28
*29*28*29*30*29*30*31*32*31*32*33*32*33*30*33*34*31*34*35*0*35*7777*-9999
```

BAP Priority Habitat Types

```
reclass x I*cr8*bap1*2*0*0*1*1*1*5*0*5*7777*-9999
reclass x I*cr6*bap2*2*0*0*1*1*1*39*0*39*7777*-9999
reclass x I*nvccom3*bap3*2*0*0*1*1*1*8*0*8*7777*-9999
reclass x I*cr14*bap4*2*0*0*1*1*1*4*0*4*7777*-9999
```

Forming a single image for all BAP Priority Habitat Types

```
crosstab x bap1*bap2*1*cbap1*n
reclass x I*cbap1*rbap1*2*0*0*2*1*2*3*2*3*4*3*4*5*0*5*7777*-9999
crosstab x rbap1*bap3*1*cbap2*n
reclass x I*cbap2*rbap2*2*0*0*2*1*2*3*2*3*4*3*4*5*4*5*6*5*6*7*0*7*7777*-9999
crosstab x rbap2*bap4*1*cbap3*n
reclass x I*cbap3*bapht*2*0*0*2*2*2*3*1*3*4*3*4*5*4*5*6*5*6*7*6*7*8*7*8*9*8
*9*10*0*10*7777*-9999
```

BAP Priority Habitat Types for presently unwooded land

```
reclass x I*wood80*rwood80*2*0*0*6*1*6*7*0*7*7777*-9999
overlay x 3*rwood80*bapht*bapexp
```

BAP Priority Habitat Types for presently forested land

```
reclass x I*wood80*mwood80*2*0*0*1*1*1*6*0*6*7777*-9999
overlay x 3*mwood80*bapht*bapexist
```

BAP Priority Habitat Types for all suitable sites for woodland creation

```
crosstab x suitsites*bapht*2*none*n
```

BAP Priority Habitat Types for all sites suitable for woodland restoration

```
crosstab x wrsites*bapht*2*none*n
```

Suitable sites for W9 and W17 communities after excluding altitude

W9

```
RECLASS X I*CSNPSLOP*SLOPW9A*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW9A*2*0*0*3*1*3*10*0*10*11*1*11*12*0*12*17*1*17*18*0*18*777*-
9999
RECLASS X I*SNPSOIL*SOILW9A*2*1*1*2*0*2*3*1*3*4*0*4*5*1*5*6*0*6*9*1*9*10
*0*10*11*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW9A*2*0*0*7*1*7*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW9A*2*0*0*2*1*2*10*0*10*777*-9999
RECLASS X I*CSNPSLOP*SLOPW9B*2*1*1*8*0*8*777*-9999
RECLASS X I*SNPGEOLT*GEOLW9B*2*0*0*3*1*3*4*0*4*7*1*7*8*0*8*777*-9999
RECLASS X I*SNPSOIL*SOILW9B*2*0*0*5*1*5*6*0*6*9*1*9*10*0*10*777*-9999
RECLASS X I*TEMP*TEMPW9B*2*0*0*9*1*9*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW9B*2*0*0*3*1*3*8*0*8*777*-9999

5
0
slopw9a
geolw9a
soilw9a
tempw9a
rainw9a

5
0
slopw9b
geolw9b
soilw9b
tempw9b
rainw9b

mce x suitw9a-2*w9a-2
mce x suitw9b-2*w9b-2

crosstab x suitw9a-2*suitw9b-2*1*suitw9ab*n
reclass x I*suitw9ab*suitw9*2*0*0*1*1*1*3*0*3*7777*-9999
crosstab x suitw9*csnpdem*2*none*n
```

W17

```
RECLASS X I*CSNPSLOP*SLOPW17a*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17a*2*0*0*5*1*5*6*0*6*7*1*7*13*0*13*14*1*14*15
*0*15*16*1*16*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17a*2*1*1*2*0*2*3*1*3*6*0*6*9*1*9*10*0*10*11
*1*11*12*0*12*777*-9999
RECLASS X I*TEMP*TEMPW17a*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RAIN*RAINW17a*2*0*0*4*1*4*10*0*10*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17b*2*0*0*5*1*5*11*0*11*12*1*12*13*0*13*16*1*16*17
*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17b*2*1*1*2*0*2*3*1*3*4*0*4*5*1*5*6*0*6*7*1*7*8
*0*8*9*1*9*10*0*10*11*1*11*12*0*12*777*-9999
RECLASS X I*RAIN*RAINW17b*2*0*0*3*1*3*9*0*9*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17c*2*0*0*5*1*5*13*0*13*15*1*15*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17c*2*1*1*2*0*2*5*1*5*6*0*6*8*1*8*12*0*12*14*1*14*15
*0*15*777*-9999
RECLASS X I*RAIN*RAINW17c*2*0*0*3*1*3*8*0*8*777*-9999

5
0
slopw17a
geolw17a
soilw17a
tempw17a
rainw17a

5
0
```

```
slopw17a
geolw17b
soilw17b
tempw17a
rainw17b

5
0
slopw17a
geolw17c
soilw17c
tempw17a
rainw17c

mce x suitw17a-2*w17a-2
mce x suitw17b-2*w17b-2
mce x suitw17c-2*w17c-2

crosstab x suitw17a-2*suitw17b-2*1*suitw17ab*n
crosstab x suitw17ab*suitw17c-2*1*suitw17abc*n
reclass x I*suitw17abc*suitw17*2*0*0*1*1*1*4*0*4*7777*-9999
crosstab x suitw17*csnpdem*2*none*n
```

Suitable sites for W17 community under scenarios of climate change

2020s Low scenario

```
RECLASS X I*CSNPSLOP*SLOPW17a*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17a*2*0*0*5*1*5*6*0*6*7*1*7*13*0*13*14*1*14*15
*0*15*16*1*16*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17a*2*1*1*2*0*2*3*1*3*6*0*6*9*1*9*10*0*10*11
*1*11*12*0*12*777*-9999
RECLASS X I*TL20S*TEMPW17a*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RL20S2*RAINW17a*2*0*0*4*1*4*10*0*10*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17b*2*0*0*5*1*5*11*0*11*12*1*12*13*0*13*16
*1*16*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17b*2*1*1*2*0*2*3*1*3*4*0*4*5*1*5*6*0*6*7*1*7*8
*0*8*9*1*9*10*0*10*11*1*11*12*0*12*777*-9999
RECLASS X I*RL20S2*RAINW17b*2*0*0*3*1*3*9*0*9*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17c*2*0*0*5*1*5*13*0*13*15*1*15*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17c*2*1*1*2*0*2*5*1*5*6*0*6*8*1*8*12*0*12*14
*1*14*15*0*15*777*-9999
RECLASS X I*RL20S2*RAINW17c*2*0*0*3*1*3*8*0*8*777*-9999

5
0
slopw17a
geolw17a
soilw17a
tempw17a
rainw17a

5
0
slopw17a
geolw17b
soilw17b
tempw17a
rainw17b

5
0
slopw17a
geolw17c
soilw17c
tempw17a
rainw17c

mce x suitw17a-3*w17a-3
mce x suitw17b-3*w17b-3
mce x suitw17c-3*w17c-3

crosstab x suitw17a-3*suitw17b-3*1*suitw17ab-3*n
crosstab x suitw17ab-3*suitw17c-3*1*suitw17abc-3*n
reclass x I*suitw17abc-3*suitw17-3*2*0*0*1*1*1*4*0*4*7777*-9999
crosstab x suitw17-3*csnpdem*2*none*n
```

2020s High scenario

```
RECLASS X I*CSNPSLOP*SLOPW17a*2*1*1*11*0*11*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17a*2*0*0*5*1*5*6*0*6*7*1*7*13*0*13*14*1*14*15
*0*15*16*1*16*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17a*2*1*1*2*0*2*3*1*3*6*0*6*9*1*9*10*0*10*11*1*11*12
*0*12*777*-9999
RECLASS X I*TH20S*TEMPW17a*2*0*0*8*1*8*11*0*11*777*-9999
RECLASS X I*RH20S2*RAINW17a*2*0*0*4*1*4*10*0*10*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17b*2*0*0*5*1*5*11*0*11*12*1*12*13*0*13*16*1*16*17
*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17b*2*1*1*2*0*2*3*1*3*4*0*4*5*1*5*6*0*6*7*1*7*8*0*8*9
*1*9*10*0*10*11*1*11*12*0*12*777*-9999
RECLASS X I*RH20S2*RAINW17b*2*0*0*3*1*3*9*0*9*777*-9999
RECLASS X I*SNPGEOLT*GEOLW17c*2*0*0*5*1*5*13*0*13*15*1*15*17*0*17*777*-9999
RECLASS X I*SNPSOIL*SOILW17c*2*1*1*2*0*2*5*1*5*6*0*6*8*1*8*12*0*12*14*1*14*15
*0*15*777*-9999
RECLASS X I*RH20S2*RAINW17c*2*0*0*3*1*3*8*0*8*777*-9999

5
0
slopw17a
geolw17a
soilw17a
tempw17a
rainw17a

5
0
slopw17a
geolw17b
soilw17b
tempw17a
rainw17b

5
0
slopw17a
geolw17c
soilw17c
tempw17a
rainw17c

mce x suitw17a-4*w17a-4
mce x suitw17b-4*w17b-4
mce x suitw17c-4*w17c-4

crosstab x suitw17a-4*suitw17b-4*1*suitw17ab-4*n
crosstab x suitw17ab-4*suitw17c-4*1*suitw17abc-4*n
reclass x I*suitw17abc-4*suitw17-4*2*0*0*1*1*1*4*0*4*7777*-9999
crosstab x suitw17-4*csnpdem*2*none*n.
```

APPENDIX 4.3. Predicted suitable sites for NVC wet woodland, beech communities, and mosaics.

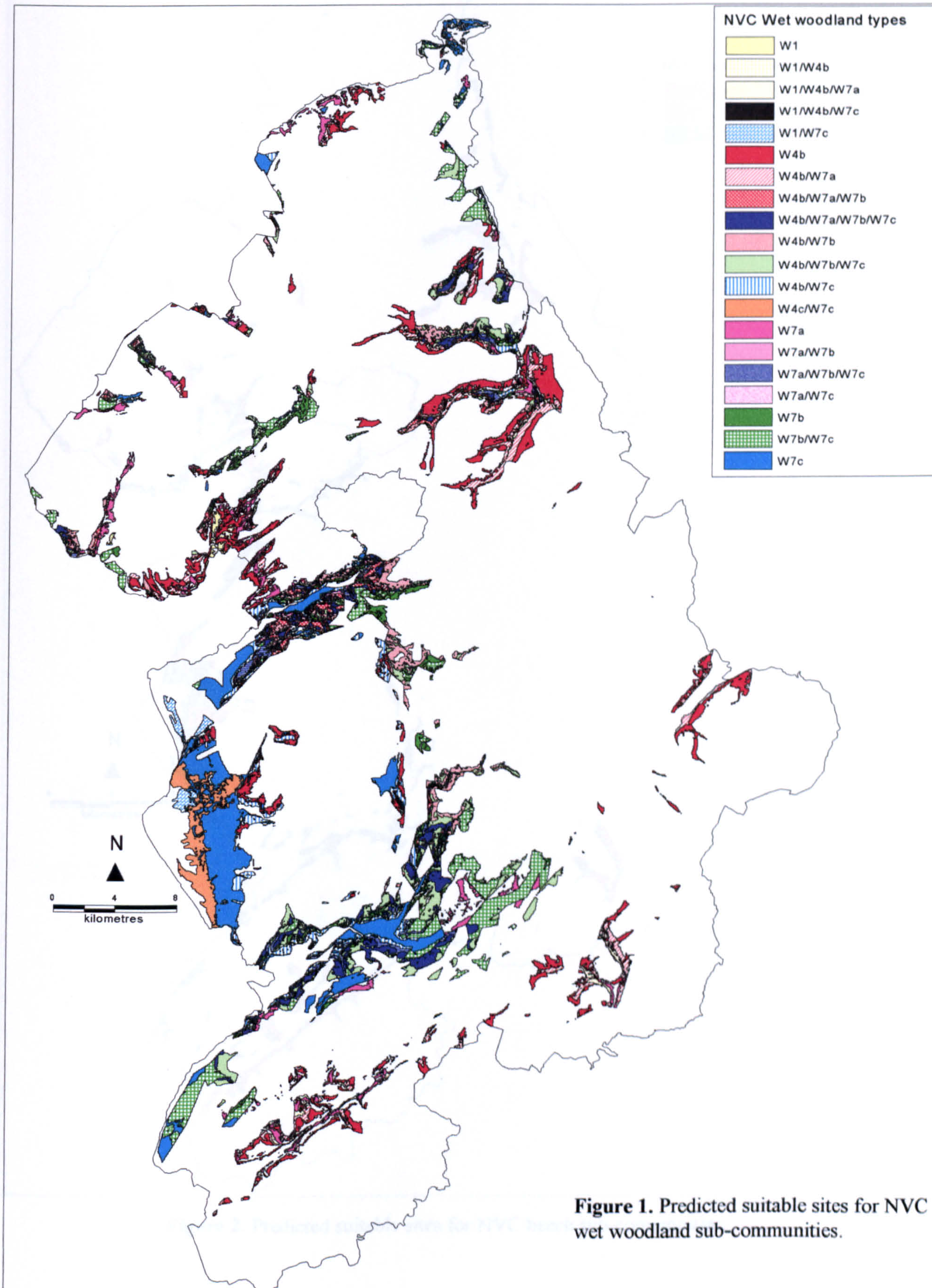


Figure 1. Predicted suitable sites for NVC wet woodland sub-communities.

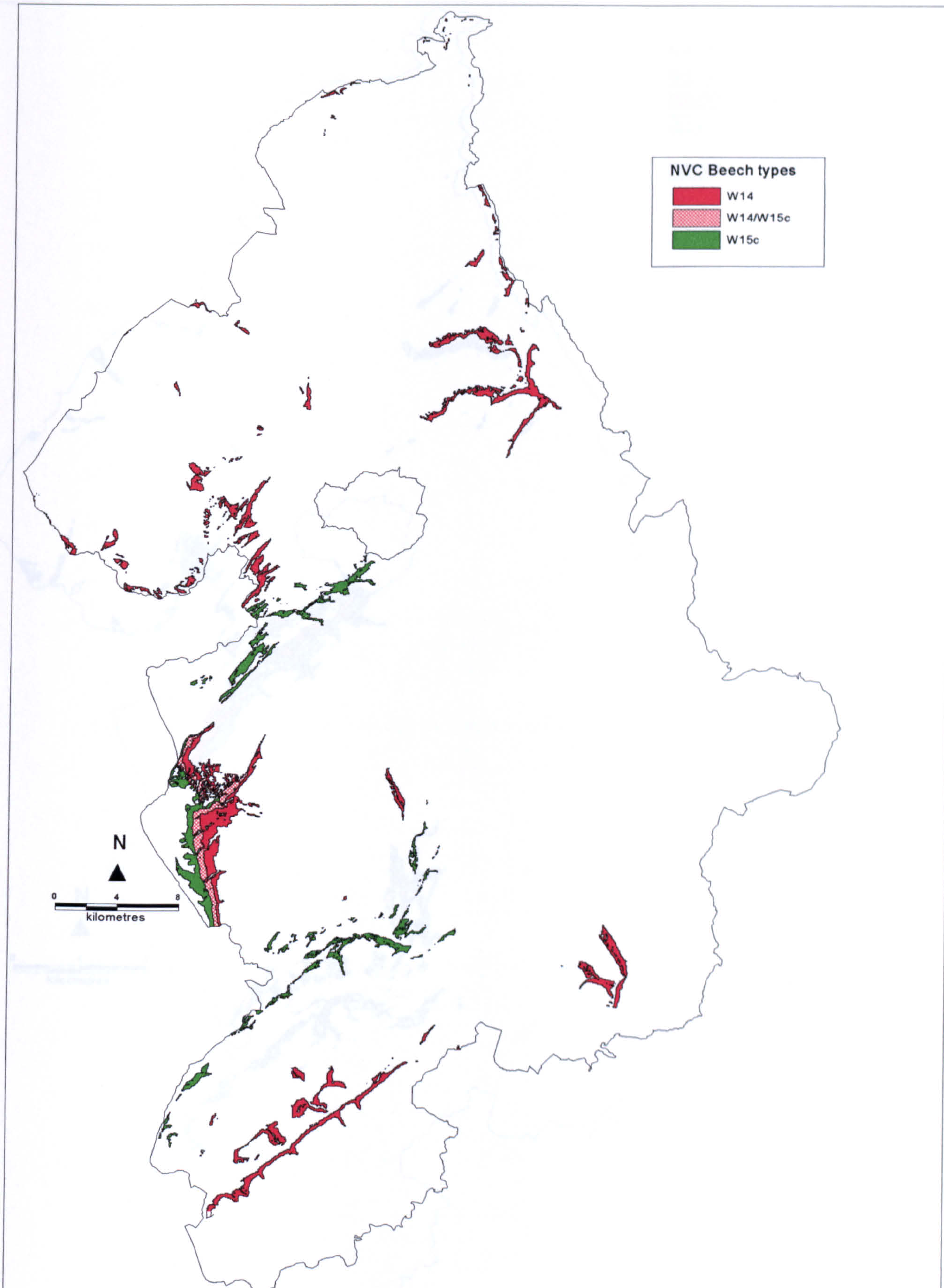


Figure 2. Predicted suitable sites for NVC beech sub-communities.

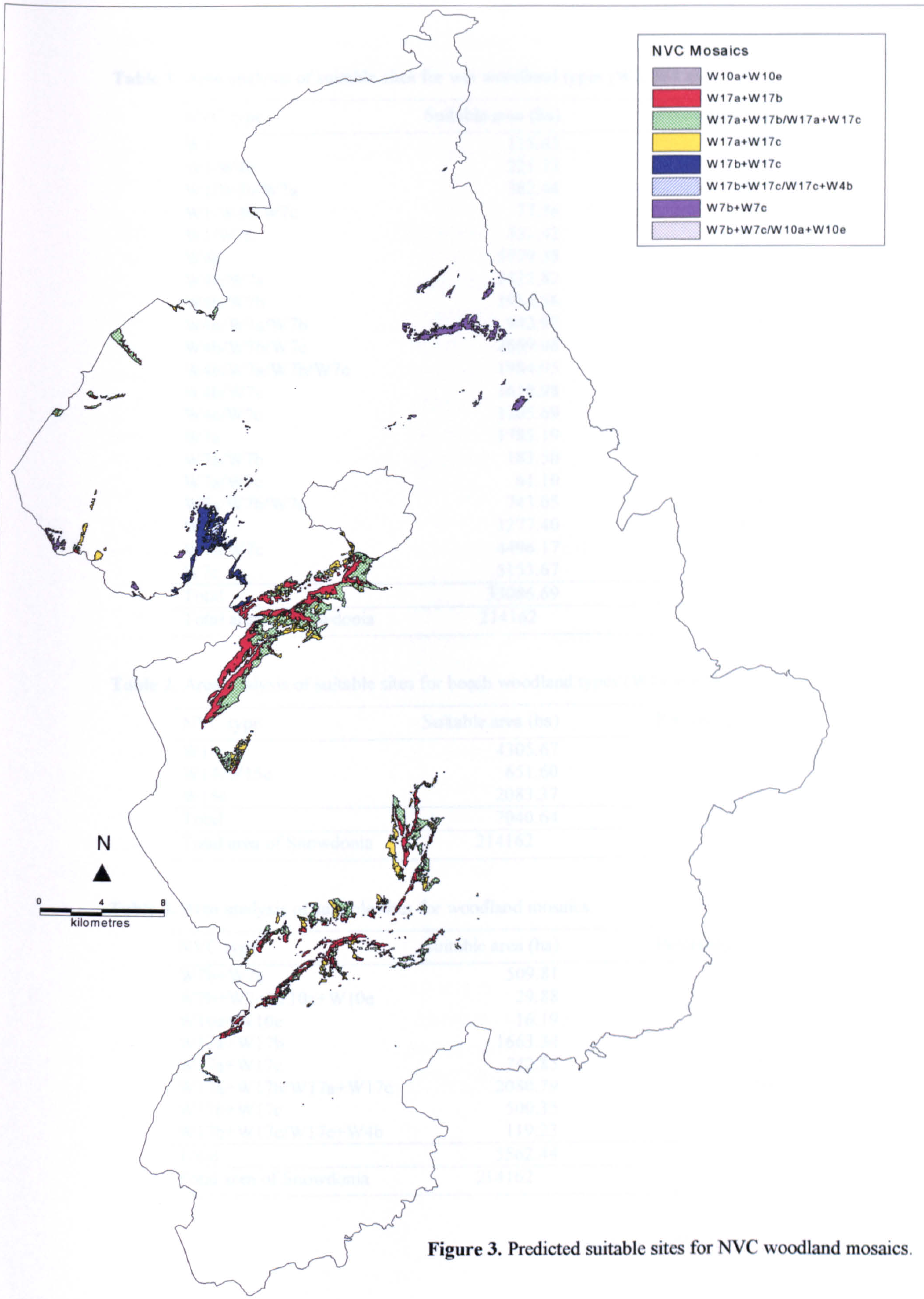


Figure 3. Predicted suitable sites for NVC woodland mosaics.

Table 1. Area analysis of suitable sites for wet woodland types (W1, W4 and W7).

NVC type	Suitable area (ha)	Percentage (%)
W1	115.63	0.05
W1/W4b	221.33	0.10
W1/W4b/W7a	362.44	0.17
W1/W4b/W7c	77.36	0.04
W1/W7c	331.42	0.15
W4b	5779.38	2.70
W4b/W7a	2122.82	0.99
W4b/W7b	1954.56	0.91
W4b/W7a/W7b	942.97	0.44
W4b/W7b/W7c	2669.08	1.25
W4b/W7a/W7b/W7c	1984.95	0.93
W4b/W7c	1618.98	0.76
W4c/W7c	1205.69	0.56
W7a	1785.19	0.83
W7a/W7b	183.50	0.09
W7a/W7c	61.10	0.03
W7a/W7b/W7c	743.05	0.35
W7b	1277.40	0.60
W7b/W7c	4496.17	2.09
W7c	5153.67	2.41
Total	33086.69	15.45
Total area of Snowdonia	214162	

Table 2. Area analysis of suitable sites for beech woodland types (W14 and W15).

NVC type	Suitable area (ha)	Percentage (%)
W14	4305.67	2.01
W14/W15c	651.60	0.31
W15c	2083.37	0.97
Total	7040.64	3.29
Total area of Snowdonia	214162	

Table 3. Area analysis of suitable sites for woodland mosaics.

NVC type	Suitable area (ha)	Percentage (%)
W7b+W7c	509.81	0.24
W7b+W7c/W10a+W10e	29.88	0.01
W10a+W10e	16.19	0.01
W17a+W17b	1663.34	0.77
W17a+W17c	742.85	0.34
W17a+W17b/W17a+W17c	2080.79	0.96
W17b+W17c	500.35	0.22
W17b+W17c/W17c+W4b	119.23	0.05
Total	5562.44	2.60
Total area of Snowdonia	214162	

APPENDIX 4.4. Information on the 53 survey sites in Snowdonia with data on NVC woodland currently present (kindly provided by CCW).

APPENDIX 4.4.1 Information on the 29 survey sites in Snowdonia used for the development of the *NVC Model.*

Name	Grid reference	Date	SSSI	Area estimate
Coed Dolgarrog	SH766670	-	SSSI	
Craig y Benglog	SH807238	9/6/97	SSSI	
Coed y Gofer	SN640967	-	SSSI	y
Fairy Glen Woods	SH809534	8/8/96	SSSI	
Coed Merchllyn	SH764734	-	SSSI	
Coed Aber Artro	SH601270	7/6/97	SSSI	
Coed Llechwedd	SH596321	8/6/97	SSSI	
Coed Lletywalter	SH598276	1988	SSSI	
Arthog Hall Woods	SH647144	16/8/97	SSSI	
Coedydd Maentwrog	SH673417	-	SSSI	
Rhinog	SH640300	20&21/8/97	SSSI	
Coed Graig Uchaf	SH644264	7/6/97	SSSI	
Coed Bryn Brethynau	SH737574	/1998		y
Cadair Idris	SH720130	18&19/8/97	SSSI	
Coed Ganllwyd	SH723243	-	SSSI	
Coed Gorswen	SH755708	-	SSSI	
Torrent Walk	SH758183	18/8/97	SSSI	
Cwm Crafnant	SH737603	5/8/96	SSSI	
Ceunant Dulyn	SH755683	6+7/8/96	SSSI	
Ceunant Cynfal	SH700413	13/6/97	SSSI	
Ceunant Llennyrch	SH667385	12/6/97	SSSI	
Coed Camlyn	SH661399	-	SSSI	
Coed Cymerau NNR	SH685423	-	SSSI	
Coed Cymerau Isaf	SH692427	-		
Coedydd Abergwynant	SH682165	11/6/97	SSSI	
Coed y Rhygen	SH681370	-	SSSI	
Y Wyddfa	SH625540	13/9, 1 & 26/10/96	SSSI	
Hafod Garregog	SH601444	Summer 1997	SSSI	
Coedydd Aber	SH665705	1989	SSSI	

APPENDIX 4.4.2 Information on the 24 survey sites in Snowdonia used as validation sites to evaluate the performance of the *NVC Model.*

Name	Grid reference	Date	SSSI	Area estimate
Coed Erbyn Betws-y-coed	SH793561	-		y
Coed Felin Blwm	SH790611	/1998		
Coed Graienyn	SH924341	/1998		
Aberdovey	SN593970	1995	SSSI	
Coed Hafod	SH808578	/1998		
Coedmor Wood	SH760774	1980s		y
Coed Soflen	SH820579	1980s		y
Coed Garthmyn	SH811561	1980s		y
Morfa Dyffryn	SH555250	1995	SSSI	
Coed Hafod y Bryn	SH587264	/1998		
Coed Bryn Engan	SH732570	1980s		y
Coed Felinrhyd	SH654393	-		
Farchynys	SH735574	/1998		
Y Winllan	SH668407	/1998		
Morfa Harlech	SH566342	1995	SSSI	
Crymlyn Oaks	SH643716	1980s		y
Coed Victoria	SH589591	1980s		y
Llyn Nantlle Uchaf	SH520526	1980s		y
Coed Tan y Gareg	SH547567	1980s		y
Hafod y Rhisgl	SH659525	1980s		y
Garth Dinas-hendre	SH603458	1980s		y
Nant Ceunant Mawr	SH660535	1980s		y
Coed Bwlch Derw	SH620493	1980s		y
Coed Aber Dunant complex	SH583417	1980s		y

APPENDIX 4.5. Cross-tabulation results of predicted suitable sites for each NVC woodland sub-community with the NVC woodland sub-communities present in Snowdonia.

Green colour indicates the cells that where not predicted correctly and those predicted correctly accordingly for each NVC category

W1

Cross-tabulation of SUITW1 (columns) against SNP-NVC (rows)

	0	1	Total
0	15107445	27240	15134685
1	1	59	60
2	132	131	263
3	66	0	66
4	306	12	318
5	306	0	306
6	520	0	520
7	429	27	456
8	1141	0	1141
9	238	0	238
10	92	9	101
11	2304	54	2358
12	2821	37	2858
13	624	0	624
14	56	0	56
15	175	4	179
16	76	0	76
17	4210	22	4232
18	6993	164	7157
19	3659	139	3798
20	85	0	85
21	92	0	92
22	164	89	253
23	8	17	25
24	24	0	24
25	15	0	15
26	334	0	334
Total	15132316	28004	15160320

Chi Square = 96027.18750
df = 26
Cramer's V = 0.0796
Overall Kappa 0.0145

W4b

Cross-tabulation of SUITW4B (columns) against SNP-NVC (rows)

	0	1	Total
0	14694262	440423	15134685
1	31	29	60
2	4	259	263
3	66	0	66
4	257	61	318
5	303	3	306
6	480	40	520
7	426	30	456
8	1107	34	1141
9	157	81	238
10	31	70	101
11	2223	135	2358
12	2052	806	2858
13	533	91	624
14	56	0	56
15	163	16	179
16	71	5	76
17	2944	1288	4232
18	4585	2572	7157
19	2049	1749	3798
20	57	28	85
21	62	30	92

22	6	247	253
23	0	25	25
24	0	24	24
25	4	11	15
26	253	81	334
Total	14712182	448138	15160320

Chi Square = 92068.28906
df = 26
Cramer's V = 0.0779
Overall Kappa 0.0148

W4c

Cross-tabulation of SUITW4C (columns) against SNP-NVC (rows)

	0	1	Total
0	15104901	29784	15134685
1	60	0	60
2	263	0	263
3	0	66	66
4	318	0	318
5	306	0	306
6	520	0	520
7	456	0	456
8	1114	27	1141
9	238	0	238
10	101	0	101
11	2358	0	2358
12	2841	17	2858
13	624	0	624
14	56	0	56
15	176	3	179
16	59	17	76
17	4228	4	4232
18	6607	550	7157
19	3798	0	3798
20	85	0	85
21	92	0	92
22	253	0	253
23	25	0	25
24	24	0	24
25	15	0	15
26	334	0	334
Total	15129852	30468	15160320

Chi Square = 54965.71094
df = 26
Cramer's V = 0.0602
Overall Kappa 0.0113

W7a

Cross-tabulation of SUITW7A (columns) against SNP-NVC (rows)

	0	1	Total
0	14932539	202146	15134685
1	31	29	60
2	256	7	263
3	66	0	66
4	1	317	318
5	293	13	306
6	484	36	520
7	456	0	456
8	1036	105	1141
9	75	163	238
10	55	46	101
11	2220	138	2358
12	1967	891	2858
13	560	64	624
14	56	0	56
15	111	68	179
16	71	5	76
17	3760	472	4232

18	5930	1227	7157
19	2816	982	3798
20	64	21	85
21	63	29	92
22	253	0	253
23	25	0	25
24	15	9	24
25	15	0	15
26	240	94	334
Total	14953458	206862	15160320

Chi Square = 91573.79688
df = 26
Cramer's V = 0.0777
Overall Kappa 0.0189

W7b

Cross-tabulation of SUITW7B (columns) against SNP-NVC (rows)

	0	1	Total
0	14784293	350392	15134685
1	60	0	60
2	231	32	263
3	66	0	66
4	306	12	318
5	43	263	306
6	89	431	520
7	456	0	456
8	676	465	1141
9	37	201	238
10	69	32	101
11	1833	525	2358
12	1670	1188	2858
13	140	484	624
14	56	0	56
15	88	91	179
16	68	8	76
17	3108	1124	4232
18	4134	3023	7157
19	2200	1598	3798
20	46	39	85
21	62	30	92
22	253	0	253
23	25	0	25
24	0	24	24
25	0	15	15
26	169	165	334
Total	14800178	360142	15160320

Chi Square = 170018.34375
df = 26
Cramer's V = 0.1059
Overall Kappa 0.0237

W7c

Cross-tabulation of SUITW7C (columns) against SNP-NVC (rows)

	0	1	Total
0	14680638	454047	15134685
1	30	30	60
2	245	18	263
3	0	66	66
4	308	10	318
5	65	241	306
6	42	478	520
7	370	86	456
8	546	595	1141
9	57	181	238
10	85	16	101
11	1772	586	2358
12	1690	1168	2858
13	202	422	624

	0	1	Total
14	56	0	56
15	100	79	179
16	10	66	76
17	2859	1373	4232
18	4471	2686	7157
19	2635	1163	3798
20	43	42	85
21	57	35	92
22	253	0	253
23	25	0	25
24	16	8	24
25	9	6	15
26	244	90	334
Total	14696828	463492	15160320

```
    Chi Square =  118205.32812
            df =        26
    Cramer's V =       0.0883
 Overall Kappa         0.0178
```

W8e

Cross-tabulation of SUITW8E (columns) against SNP-NVC (rows)

	0	1	Total
0	15099188	35497	15134685
1	30	30	60
2	257	6	263
3	66	0	66
4	318	0	318
5	306	0	306
6	519	1	520
7	0	456	456
8	1141	0	1141
9	238	0	238
10	101	0	101
11	1727	631	2358
12	2858	0	2858
13	624	0	624
14	56	0	56
15	179	0	179
16	76	0	76
17	3308	924	4232
18	7083	74	7157
19	3513	285	3798
20	78	7	85
21	70	22	92
22	253	0	253
23	25	0	25
24	24	0	24
25	15	0	15
26	334	0	334
Total	15122387	37933	15160320

```
    Chi Square =  343795.87500
            df =        26
    Cramer's V =       0.1506
 Overall Kappa         0.0378
```

W9a

Cross-tabulation of SUITW9A (columns) against SNP-NVC (rows)

	0	1	Total
0	13101012	2033673	15134685
1	0	60	60
2	0	263	263
3	0	66	66
4	0	318	318
5	0	306	306
6	51	469	520
7	85	371	456
8	82	1059	1141
9	14	224	238

10	0	101	101
11	818	1540	2358
12	170	2688	2858
13	0	624	624
14	56	0	56
15	0	179	179
16	3	73	76
17	765	3467	4232
18	1162	5995	7157
19	717	3081	3798
20	20	65	85
21	62	30	92
22	0	253	253
23	0	25	25
24	0	24	24
25	0	15	15
26	30	304	334
Total	13105047	2055273	15160320

Chi Square = 111701.39063
df = 26
Cramer's V = 0.0858
Overall Kappa 0.0087

W9b

Cross-tabulation of SUITW9B (columns) against SNP-NVC (rows)

	0	1	Total
0	14885903	248782	15134685
1	60	0	60
2	252	11	263
3	66	0	66
4	310	8	318
5	293	13	306
6	472	48	520
7	456	0	456
8	1060	81	1141
9	14	224	238
10	101	0	101
11	2150	208	2358
12	1959	899	2858
13	457	167	624
14	56	0	56
15	179	0	179
16	63	13	76
17	3511	721	4232
18	3964	3193	7157
19	2691	1107	3798
20	20	65	85
21	62	30	92
22	253	0	253
23	25	0	25
24	24	0	24
25	15	0	15
26	290	44	334
Total	14904706	255614	15160320

Chi Square = 137856.42188
df = 26
Cramer's V = 0.0954
Overall Kappa 0.0228

W10a

Cross-tabulation of SUITW10A (columns) against SNP-NVC (rows)

	0	1	Total
0	15048736	85949	15134685
1	31	29	60
2	263	0	263
3	66	0	66
4	286	32	318
5	306	0	306

6	512	8	520
7	456	0	456
8	1128	13	1141
9	238	0	238
10	2	99	101
11	2089	269	2358
12	2755	103	2858
13	624	0	624
14	56	0	56
15	62	117	179
16	76	0	76
17	4074	158	4232
18	7098	59	7157
19	3466	332	3798
20	85	0	85
21	92	0	92
22	253	0	253
23	25	0	25
24	16	8	24
25	15	0	15
26	248	86	334
Total	15073058	87262	15160320

Chi Square = 47435.22656
df = 26
Cramer's V = 0.0559
Overall Kappa 0.0106

W10e

Cross-tabulation of SUITW10E (columns) against SNP-NVC (rows)

	0	1	Total
0	13672740	1461945	15134685
1	1	59	60
2	2	261	263
3	0	66	66
4	228	90	318
5	42	264	306
6	59	461	520
7	0	456	456
8	246	895	1141
9	13	225	238
10	0	101	101
11	144	2214	2358
12	924	1934	2858
13	37	587	624
14	56	0	56
15	36	143	179
16	3	73	76
17	1122	3110	4232
18	1302	5855	7157
19	753	3045	3798
20	0	85	85
21	22	70	92
22	0	253	253
23	0	25	25
24	0	24	24
25	0	15	15
26	35	299	334
Total	13677765	1482555	15160320

Chi Square = 148661.23438
df = 26
Cramer's V = 0.0990
Overall Kappa 0.0121

W11a

Cross-tabulation of SUITW11A (columns) against SNP-NVC (rows)

	0	1	Total
0	12945774	2188911	15134685
1	0	60	60

2	2	261	263
3	0	66	66
4	0	318	318
5	105	201	306
6	156	364	520
7	85	371	456
8	490	651	1141
9	1	237	238
10	0	101	101
11	931	1427	2358
12	1	2857	2858
13	201	423	624
14	56	0	56
15	36	143	179
16	3	73	76
17	950	3282	4232
18	785	6372	7157
19	780	3018	3798
20	20	65	85
21	43	49	92
22	0	253	253
23	0	25	25
24	0	24	24
25	0	15	15
26	65	269	334
Total	12950484	2209836	15160320

```
   Chi Square =    96217.74219
           df =             26
   Cramer's V =         0.0797
Overall Kappa           0.0077
```

W11b

Cross-tabulation of SUITW11B (columns) against SNP-NVC (rows)

	0	1	Total
0	14734147	400538	15134685
1	60	0	60
2	231	32	263
3	66	0	66
4	309	9	318
5	87	219	306
6	313	207	520
7	456	0	456
8	658	483	1141
9	94	144	238
10	72	29	101
11	2111	247	2358
12	1745	1113	2858
13	5	619	624
14	56	0	56
15	84	95	179
16	68	8	76
17	3193	1039	4232
18	4718	2439	7157
19	2542	1256	3798
20	62	23	85
21	62	30	92
22	253	0	253
23	25	0	25
24	0	24	24
25	0	15	15
26	212	122	334
Total	14751629	408691	15160320

```
   Chi Square =   108715.28125
           df =             26
   Cramer's V =         0.0847
Overall Kappa           0.0172
```

W14

Cross-tabulation of SUITW14 (columns) against SNP-NVC (rows)

	0	1	Total
0	15012080	122605	15134685
1	31	29	60
2	257	6	263
3	18	48	66
4	286	32	318
5	306	0	306
6	517	3	520
7	240	216	456
8	1126	15	1141
9	238	0	238
10	39	62	101
11	1973	385	2358
12	2770	88	2858
13	618	6	624
14	56	0	56
15	36	143	179
16	25	51	76
17	3500	732	4232
18	6707	450	7157
19	3501	297	3798
20	85	0	85
21	92	0	92
22	253	0	253
23	25	0	25
24	21	3	24
25	15	0	15
26	234	100	334
Total	15035049	125271	15160320

```
     Chi Square =    69983.39063
             df =           26
     Cramer's V =        0.0679
  Overall Kappa          0.0165
```

W15c

Cross-tabulation of SUITW15C (columns) against SNP-NVC (rows)

	0	1	Total
0	15067698	66987	15134685
1	60	0	60
2	263	0	263
3	14	52	66
4	318	0	318
5	296	10	306
6	490	30	520
7	364	92	456
8	1115	26	1141
9	131	107	238
10	101	0	101
11	2297	61	2358
12	2641	217	2858
13	617	7	624
14	56	0	56
15	163	16	179
16	0	76	76
17	3893	339	4232
18	6179	978	7157
19	3739	59	3798
20	46	39	85
21	92	0	92
22	253	0	253
23	25	0	25
24	24	0	24
25	15	0	15
26	317	17	334
Total	15091207	69113	15160320

```
     Chi Square =    81034.98438
             df =           26
     Cramer's V =        0.0731
  Overall Kappa          0.0212
```

W17a

Cross-tabulation of SUITW17A (columns) against SNP-NVC (rows)

	0	1	Total
0	13733447	1401238	15134685
1	0	60	60
2	2	261	263
3	0	66	66
4	249	69	318
5	42	264	306
6	43	477	520
7	0	456	456
8	506	635	1141
9	12	226	238
10	0	101	101
11	624	1734	2358
12	1059	1799	2858
13	84	540	624
14	56	0	56
15	36	143	179
16	0	76	76
17	64	4168	4232
18	771	6386	7157
19	395	3403	3798
20	0	85	85
21	3	89	92
22	0	253	253
23	0	25	25
24	0	24	24
25	0	15	15
26	61	273	334
Total	13737454	1422866	15160320

Chi Square = 176483.25000
df = 26
Cramer's V = 0.1079
Overall Kappa 0.0133

W17b

Cross-tabulation of SUITW17B (columns) against SNP-NVC (rows)

	0	1	Total
0	13766417	1368268	15134685
1	0	60	60
2	2	261	263
3	0	66	66
4	0	318	318
5	255	51	306
6	388	132	520
7	0	456	456
8	804	337	1141
9	10	228	238
10	0	101	101
11	816	1542	2358
12	842	2016	2858
13	516	108	624
14	56	0	56
15	36	143	179
16	3	73	76
17	703	3529	4232
18	330	6827	7157
19	329	3469	3798
20	0	85	85
21	3	89	92
22	0	253	253
23	0	25	25
24	0	24	24
25	0	15	15
26	133	201	334
Total	13771643	1388677	15160320

Chi Square =	168055.89063
df =	26
Cramer's V =	0.1053
Overall Kappa	0.0128

W17c

Cross-tabulation of SUITW17C (columns) against SNP-NVC (rows)

	0	1	Total
0	13222732	1911953	15134685
1	0	60	60
2	2	261	263
3	66	0	66
4	0	318	318
5	106	200	306
6	157	363	520
7	0	456	456
8	708	433	1141
9	10	228	238
10	0	101	101
11	637	1721	2358
12	386	2472	2858
13	285	339	624
14	56	0	56
15	54	125	179
16	63	13	76
17	489	3743	4232
18	1371	5786	7157
19	155	3643	3798
20	0	85	85
21	0	92	92
22	0	253	253
23	0	25	25
24	0	24	24
25	0	15	15
26	61	273	334
Total	13227338	1932982	15160320

Chi Square =	115990.48438
df =	26
Cramer's V =	0.0875
Overall Kappa	0.0091

W17a+W17b mosaic

Cross-tabulation of SUITW17A+B (columns) against SNP-NVC (rows)

	0	1	Total
0	15044753	89932	15134685
1	60	0	60
2	260	3	263
3	66	0	66
4	310	8	318
5	300	6	306
6	510	10	520
7	380	76	456
8	1100	41	1141
9	119	119	238
10	101	0	101
11	1983	375	2358
12	2670	188	2858
13	546	78	624
14	56	0	56
15	179	0	179
16	63	13	76
17	3599	633	4232
18	4918	2239	7157
19	3081	717	3798
20	1	84	85
21	39	53	92
22	253	0	253
23	25	0	25
24	24	0	24
25	15	0	15

	0	1	Total
26	294	40	334
Total	15065705	94615	15160320

```
    Chi Square =  185566.15625
            df =          26
    Cramer's V =        0.1106
 Overall Kappa          0.0377
```

W17a+W17c mosaic

Cross-tabulation of SUITW17A+C (columns) against SNP-NVC (rows)

	0	1	Total
0	15066298	68387	15134685
1	60	0	60
2	260	3	263
3	66	0	66
4	315	3	318
5	305	1	306
6	513	7	520
7	455	1	456
8	1132	9	1141
9	191	47	238
10	101	0	101
11	2161	197	2358
12	2642	216	2858
13	554	70	624
14	56	0	56
15	179	0	179
16	76	0	76
17	3822	410	4232
18	6194	963	7157
19	2888	910	3798
20	72	13	85
21	1	91	92
22	253	0	253
23	25	0	25
24	24	0	24
25	15	0	15
26	308	26	334
Total	15088966	71354	15160320

```
    Chi Square =  107734.46875
            df =          26
    Cramer's V =        0.0843
 Overall Kappa          0.0294
```

W17b+W17c mosaic

Cross-tabulation of SUITW17B+C (columns) against SNP-NVC (rows)

	0	1	Total
0	15120633	14052	15134685
1	60	0	60
2	40	223	263
3	66	0	66
4	318	0	318
5	306	0	306
6	520	0	520
7	456	0	456
8	1141	0	1141
9	238	0	238
10	101	0	101
11	2358	0	2358
12	2858	0	2858
13	624	0	624
14	56	0	56
15	179	0	179
16	76	0	76
17	4232	0	4232
18	6299	858	7157
19	3551	247	3798
20	85	0	85

	0	1	Total
21	92	0	92
22	1	252	253
23	0	25	25
24	24	0	24
25	15	0	15
26	334	0	334
Total	15144663	15657	15160320

```
Chi Square = 563041.43750
        df =     26
Cramer's V =      0.1927
Overall Kappa     0.0383
```

W17c+W4b mosaic

Cross-tabulation of SUITW17C+W4B (columns) against SNP-NVC (rows)

	0	1	Total
0	15132156	2529	15134685
1	60	0	60
2	140	123	263
3	66	0	66
4	318	0	318
5	306	0	306
6	520	0	520
7	456	0	456
8	1141	0	1141
9	238	0	238
10	101	0	101
11	2358	0	2358
12	2858	0	2858
13	624	0	624
14	56	0	56
15	179	0	179
16	76	0	76
17	4232	0	4232
18	7005	152	7157
19	3702	96	3798
20	85	0	85
21	92	0	92
22	163	90	253
23	2	23	25
24	24	0	24
25	15	0	15
26	334	0	334
Total	15157307	3013	15160320

```
Chi Square = 584686.75000
        df =     26
Cramer's V =      0.1964
Overall Kappa     0.0167
```

W7b+W7c mosaic

Cross-tabulation of SUITW7B+C (columns) against SNP-NVC (rows)

	0	1	Total
0	15121398	13287	15134685
1	60	0	60
2	261	2	263
3	66	0	66
4	317	1	318
5	306	0	306
6	520	0	520
7	456	0	456
8	1136	5	1141
9	238	0	238
10	98	3	101
11	2358	0	2358
12	2783	75	2858
13	624	0	624

APPENDIX 4.6. Statistical analysis of the data used in validation procedure.

Overall model

A 2x2 contingency table

True classification	Predicted classification: Absent	Predicted classification: Present	Total
Absent	184	132	316
Present	13	31	44
Total	197	163	360

The expected number for any cell is given by dividing the product of the two corresponding marginal totals by the grand total (Bailey, 1995). For example, the expected count with absent predicted classification and absent true classification is 197 x 316 ÷ 360 = 172.92.

```
Chi-Square Test (result from MINITAB rel.13.1): 1, 2
Expected counts are printed below observed counts

             1         2     Total
    1      184       132       316
        172.92    143.08

    2       13        31        44
         24.08     19.92

Total      197       163       360

Chi-Sq =  0.710 +  0.858 +
          5.097 +  6.160 = 12.824
DF = 1, P-Value = 0.000
```

NVC woodland communities

W1

```
Expected counts are printed below observed counts

             1         2     Total
    1       19         2        21
         18.38      2.63

    2        2         1         3
          2.63      0.38

Total       21         3        24
```

W4c

```
Expected counts are printed below observed counts

             1         2     Total
    1       21         1        22
         21.08      0.92

    2        2         0         2
          1.92      0.08

Total       23         1        24
```

W7b

```
Expected counts are printed below observed counts
```

	1	2	Total
1	16	6	22
	15.58	6.42	
2	1	1	2
	1.42	0.58	
Total	17	7	24

W7c

Expected counts are printed below observed counts

	1	2	Total
1	12	10	22
	11.00	11.00	
2	0	2	2
	1.00	1.00	
Total	12	12	24

W8e

Expected counts are printed below observed counts

	1	2	Total
1	20	2	22
	20.17	1.83	
2	2	0	2
	1.83	0.17	
Total	22	2	24

W9a

Expected counts are printed below observed counts

	1	2	Total
1	5	18	23
	4.79	18.21	
2	0	1	1
	0.21	0.79	
Total	5	19	24

W9b

Expected counts are printed below observed counts

	1	2	Total
1	18	5	23
	18.21	4.79	
2	1	0	1
	0.79	0.21	
Total	19	5	24

W10a

Expected counts are printed below observed counts

	1	2	Total
1	16	3	19

	14.25	4.75	
2	2	3	5
	3.75	1.25	
Total	18	6	24

W10e

Expected counts are printed below observed counts

	1	2	Total
1	4	16	20
	3.33	16.67	
2	0	4	4
	0.67	3.33	
Total	4	20	24

W11a

Expected counts are printed below observed counts

	1	2	Total
1	4	13	17
	2.83	14.17	
2	0	7	7
	1.17	5.83	
Total	4	20	24

W11b

Expected counts are printed below observed counts

	1	2	Total
1	15	8	23
	15.33	7.67	
2	1	0	1
	0.67	0.33	
Total	16	8	24

W14

Expected counts are printed below observed counts

	1	2	Total
1	17	6	23
	16.29	6.71	
2	0	1	1
	0.71	0.29	
Total	17	7	24

W17a

Expected counts are printed below observed counts

	1	2	Total
1	6	16	22
	5.50	16.50	
2	0	2	2

	0.50	1.50	
Total	6	18	24

W17b

Expected counts are printed below observed counts

	1	2	Total
1	4	13	17
	3.54	13.46	
2	1	6	7
	1.46	5.54	
Total	5	19	24

W17c

Expected counts are printed below observed counts

	1	2	Total
1	7	13	20
	6.67	13.33	
2	1	3	4
	1.33	2.67	
Total	8	16	24

Binary Logistic Regression: Predicted vegetation communities versus Actual size (result from MINITAB rel.13.1)

Link Function: Logit

Response Information

Variable	Value	Count	
Predicted	1	31	(Event)
	0	13	
	Total	44	

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Upper
Constant	0.6158	0.4171	1.48	0.140			
Actual size	0.04864	0.06047	0.80	0.421	1.05	0.93	1.18

Log-Likelihood = -26.036
Test that all slopes are zero: G = 1.340, DF = 1, P-Value = 0.247

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	26.208	31	0.711
Deviance	31.618	31	0.435
Hosmer-Lemeshow	8.214	8	0.413
Brown:			
General Alternative	0.231	2	0.891
Symmetric Alternative	0.032	1	0.859

Table of Observed and Expected Frequencies:
(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

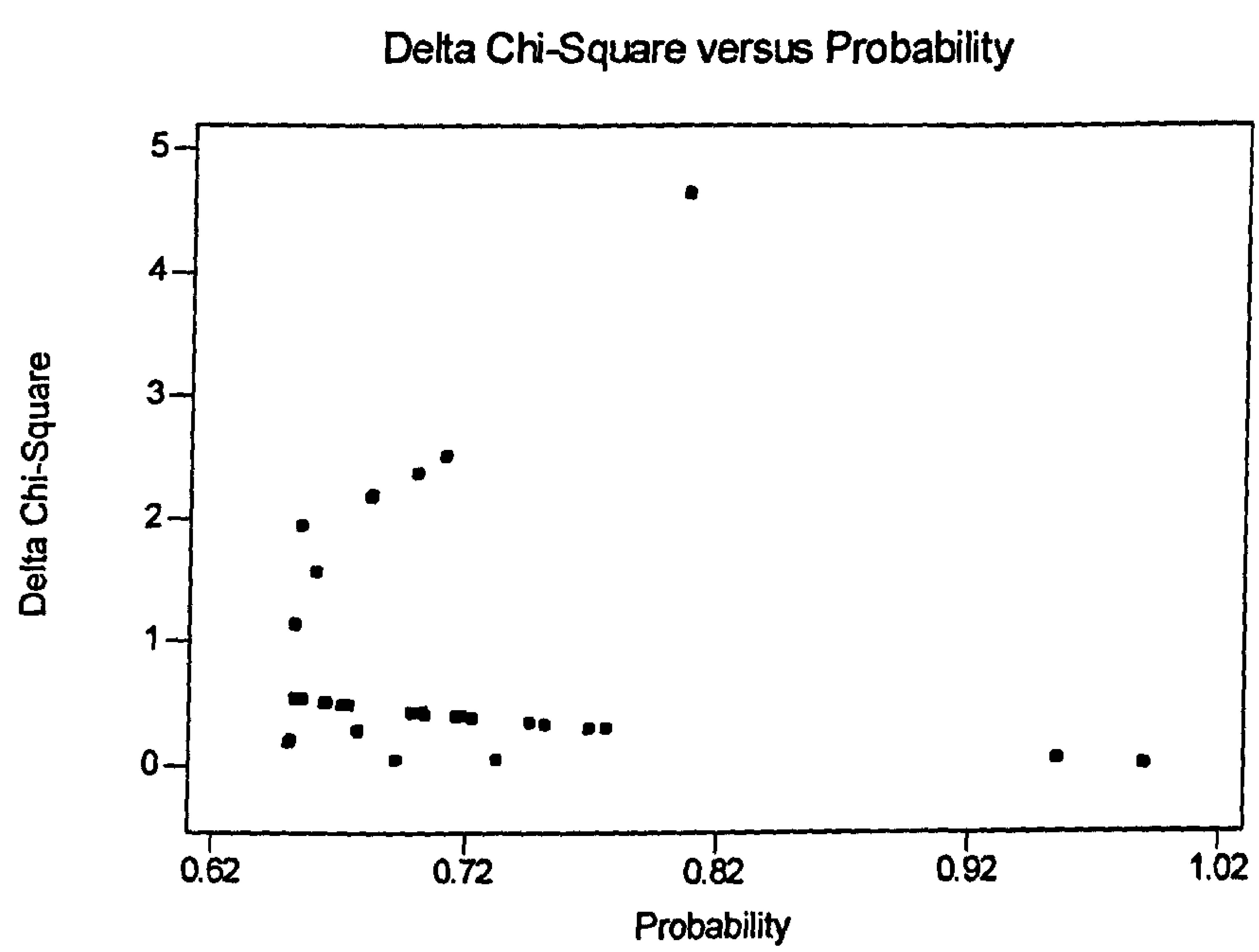
	Group										
Value	1	2	3	4	5	6	7	8	9	10	Total
1											
Obs	2	3	3	4	2	3	3	5	4	2	31
Exp	2.6	2.6	3.3	2.7	3.4	2.8	2.8	5.1	3.0	2.7	
0											
Obs	2	1	2	0	3	1	1	2	0	1	13
Exp	1.4	1.4	1.7	1.3	1.6	1.2	1.2	1.9	1.0	0.3	
Total	4	4	5	4	5	4	4	7	4	3	44

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

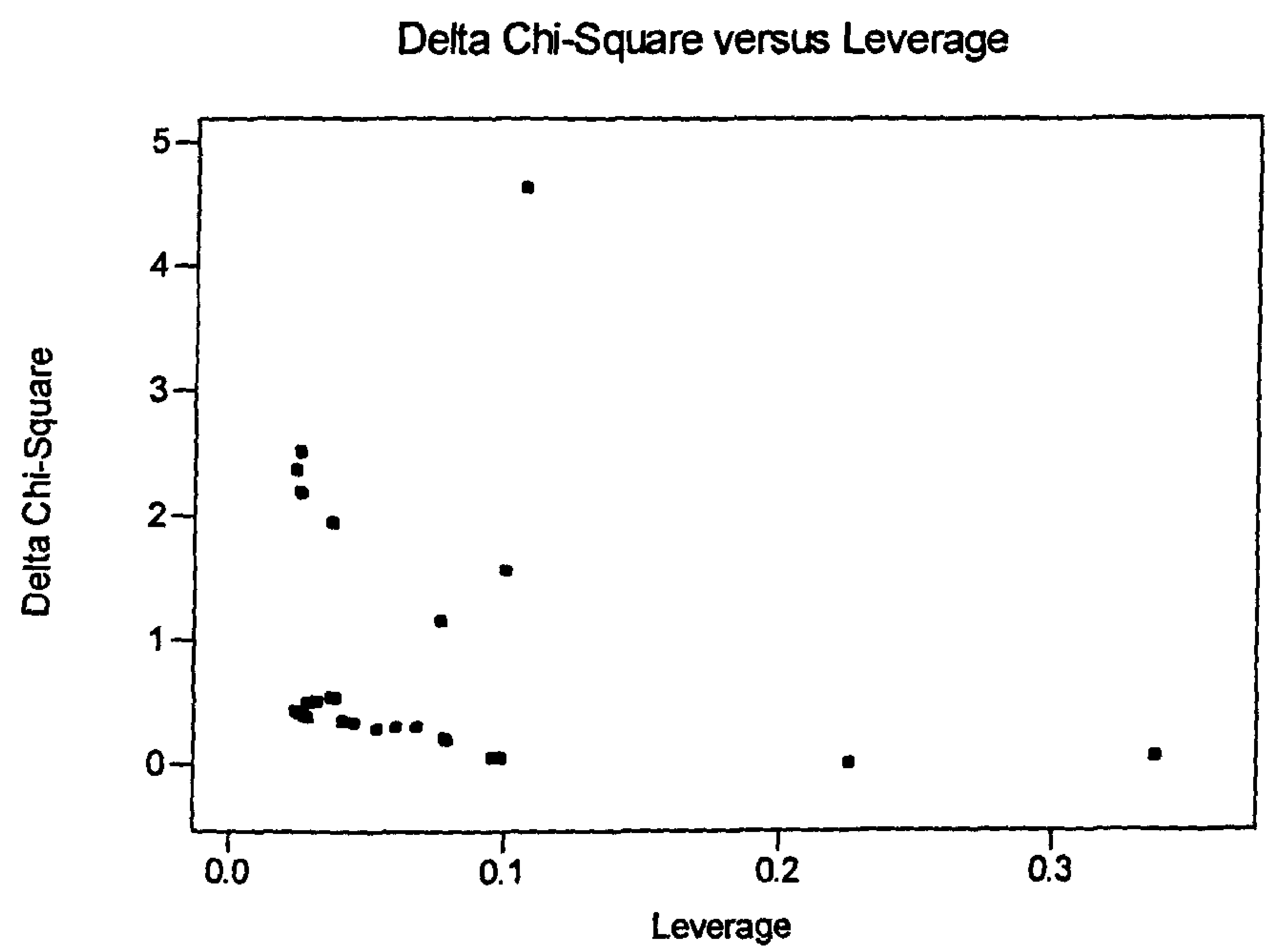
Pairs	Number	Percent	Summary Measures	
Concordant	225	55.8%	Somers' D	0.16
Discordant	160	39.7%	Goodman-Kruskal Gamma	0.17
Ties	18	4.5%	Kendall's Tau-a	0.07
Total	403	100.0%		

Plots

Delta Chi-Square versus Probability



Delta Chi-Square versus Hi



Interpretation of results

Chi-Square value of 12.824> x^2 critical = 10.83 for p = 0.001 suggests a highly significant association between the observed and the predicted classification.

Binary Logistic Regression
Logistic regression Table shows that:

- The actual size parameter has for z = 0.80 p = 0.421>0.05, indicating that there is not sufficient evidence to say the coefficient is not zero using a significance level a = 0.05. The null hypothesis (H_0) is that the value is zero and we accept that unless there is evidence against that hypothesis.
- The odds ratio is very close to 1 (1.05), indicating that a 1ha increase in size minimally effects a community's prediction.

G statistic has a value of 1.340 with a p-value of 0.247, suggesting that there is sufficient evidence that the coefficient associated with the actual size is equal to 0.

Goodness-of-fit Tests with p-values ranging from 0.413 to 0.891 (p-values>0.05), indicate that there is insufficient evidence to claim that the model does not fit the data adequately.

Measures of association (summary measures) show that the measures range from 0.07 to 0.17 which implies a poor predictive ability.

Plots indicate that three observations are not well fit by the model.

Plot of Table 6.15 in section 6.5.5. There is no evidence of any relationship between predicted community and area, however when you look at the graph there is very little chance of it finding any relationship (C.J. Whitaker, pers. comm.). There are very few dots on the graph with a large area, but the ones that have had a predicted community of 1.

Overall result
The conclusion is that there is no relationship between woodland area and the predicted community value.