Strategic woodland conservation planning: landscape ecology, landscape assessment and Geographic Information Systems

A case study examining habitat quality modelling and the prediction of Upland Oakwood biodiversity within "clough" landforms of the Dark Peak Natural Area, Peak District National Park, UK

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Part III GIS: Methods and Analysis

The following two chapters detail the methodology involved in the creation of the Dark Peak Woodland GIS from combined digital data and fieldwork, and its initial analysis to examine the occurrence of woodland in "clough" landscape areas.

The Chapters presented are:

Chapter 7: Creation of a "Natural Area" woodland GIS

Chapter 8: Woodland conservation, restoration and creation sites
Identifying Dark Peak woodland landscape character

Chapter 7
Creation of a "Natural Area" Woodland GIS

7.1 Introduction

This chapter details the creation of the Geographic Information System (GIS) used in subsequent results and analysis chapters. The chapter explains the methods used in the compilation and analysis of existing digital data and the woodland fieldwork surveys undertaken to collect additional data within the Dark Peak woodland sites. The outcome of the GIS and fieldwork process was a range of woodland habitat, biodiversity and context data stored within the GIS at two levels of detail: (1) comprehensive data for woodland and semi-woodland habitats, with landscape context information accross the entire Dark Peak, and (2) additional levels of woodland biodiversity survey and mapping information for all identified Ancient Woodland Sites.

The GIS data compilation methodology used builds on that developed by Purdy and Ferris (1999) to integrate several woodland datasets. In order to maintain clarity several technical stages in the creation of the GIS have been summarised, while further detail is included in Appendix 7. The project used the ArcView 3.2 GIS package from ESRI systems, installed on a Pentium based PC with 2GB RAM.

7.2 GIS construction methods

7.2.1 GIS construction overview

The construction of the GIS was based upon a wide range of data sources (Fig. 7.1) (Appendix 7.1) Information on the location and extent of Dark Peak woodland habitats was summarised. The addition of fieldwork results enabled a full classification of Dark Peak woodland into Phase 1 Habitat Survey categories (JNCC, 1993) with woodland classified by canopy composition and naturalness. The methodology involved a number of stages:

- Sourcing GIS data and conversion to a common format
- Assessing the accuracy of source datasets
- Combining digital datasets
- Addition of fieldwork and additional non-digital data
- Addition of supplementary landscape classification digital data
- Assessing the accuracy and resolution of the GIS

Initial investigations of potential GIS data sources and accuracy assessments of each potential source dataset were undertaken (Appendix 7.2). These case studies indicated the nationally available EN AWI data was not sufficiently accurate for GIS creation and planning due to a number of errors, therefore it was updated using a range of map data and fieldwork to give a local, updated, Ancient Woodland Inventory (upAWI) which was used throughout the study (Appendix 7.3). Additionally methods were developed to most efficiently use woodland cover GIS data (Appendix 7.2.3), to which subsequent fieldwork data and aerial photograph interpretation was added.

The initial baseline dataset for the combined woodland GIS was the updated EN Ancient Woodland Inventory (upAWI). Information on the composition and habitat context of these sites was incorporated by including information held on the North Peak Environmentally Sensitive Area (ESA) data which covers some 65% of the Dark Peak and National Inventory of Woodland and Trees (NIWT) datasets which is a national data source. Due to the investigation of the relative quality of the NIWT and ESA data (Appendix 7.2.3), this information was used differently within and outside the ESA boundary. Within the ESA boundary the ESA habitat data was considered more accurate than the NIWT, while two categories of woodland (young woodland and new planting), only occurred within the NIWT dataset. These were therefore used separately to add detail to the GIS. For additional woodland categories the NIWT data was considered more accurate than the ESA data, and for areas beyond the ESA boundary it was the only data available to add woodland context information to the GIS.

During the creation of the GIS a number of operations were often repeated during the addition of data to the broader GIS, or the extraction of individual GIS files. These are summarised rather than detailing their use at each stage in the following methods. At each stage when data were combined using the Geo-processing tools, or were heavily edited, a range of actions were applied to ensure the GIS retained accuracy and error polygons were not present. The Patch Analyst dissolve function was used to dissolve adjacent like classified polygons and to explode multi-part into single polygons (Rempel and Carr, 2003). At most editing stages shapefiles were cleaned using the polycln.ave script and the presence of overlaps was examined using the select overlapping polygons script (Huber, 2004), which were then dissected using the dissect overlaps extension (Huber, 2003). Due to the very large size of the GIS created some process had to be run on sections of the Dark Peak, e.g. N,S,E,W, quarters and were subsequently combined. Occasionally the generalise command was also used to reduce the number of vertices present in shapefiles, to increase processing speed, where this was acceptable within desired positional accuracy limits. The final combined woodland habitat GIS data had a minimum accuracy of 0.1ha, following removal and clarification of sliver polygons (Appendix 7.7).

7.2.2 Creation of a combined Ancient woodland and ESA habitat dataset

The ESA and upAWI datasets were combined using ArcView Geo-processing "union". All upAWI data were included within a 5km buffer around the Dark Peak area to retain contextual information. In order to enable the combined data to be classified, the Phase 1 Habitat Survey reference system was used (JNCC, 1993). The text based habitat descriptions of the ESA data were converted into standard Phase 1 Habitat survey alphanumeric codes (JNCC, 1993). Additional codes were appended to the Phase 1 system to indicate Ancient woodland status; Semi-natural (S) or Replanted (R). This classification indicated the Phase 1 habitat of all polygons and additionally the Semi-natural or Replanted status of Ancient Woodland Sites where relevant. The dataset thus represented all areas of Ancient Woodland within the ESA by the dominant woodland or non-woodland habitat.

7.2.3 Addition of NIWT data to the combined GIS dataset

The use of the NIWT data provided a means of classifying Ancient Woodland outside the ESA. Additionally within the ESA the data was used to examine possible errors within the ESA woodland classification by comparing polygon classification with NIWT data (Table 7.1). Within the ESA the NIWT data was also used to add information on areas of young trees, recent planting and felling operations to areas of open ground or woodland habitat. The NIWT data was clipped and added to the ESA data by union. A field within the GIS was created describing the combined classification of each polygon. It was apparent from the list of habitat classifications where discrepancies occurred. Using the NIWT polygons as the reference dataset each problem site was highlighted and examined against the ESA dataset. Depending on the nature of differences assumptions could be made on the accuracy of the polygon classification. This process highlighted areas requiring later fieldwork survey, or where woods could be fully classified by using digital overlay analysis.

Table 7.1
Relationships between National Inventory of Woodland and Trees (NIWT) data polygon occurrence and Environmentally sensitive Area (ESA) data polygons within the ESA area of the Dark Peak.

Polygon relationship	GIS operations
Correlation	ESA polygon assumed to be accurate, NIWT polygon deleted.
NIWT polygon significantly larger than ESA polygon	NIWT data potentially represented areas of woodland not recorded within the ESA. Polygons retained for verification through surveys.
NIWT polygons classified as "new planting" or "felled" did not have corresponding data within the ESA.	Polygons represented potential for adding information to the ESA dataset. The New planting and felled polygon information were transferred to the combined ESA / AWI dataset.
NIWT "New planting" polygons occurred over existing ESA woodland	Polygon age category field of "Young woods / shrub" added to the ESA woodland polygons.
Young woodland occurred over open ground ESA habitat	New young woodland category was transferred to the underlying ESA polygons to indicate areas of recent planting on open ground.

Following accuracy assessments two GIS datasets were created from the source NIWT file. A GIS theme of young trees and felled areas within the ESA was incorporated directly into the main combined upAWI/ESA dataset. A further theme holding areas of contradictory classifications between the data sources was retained for clarification through survey. The remaining areas of the NIWT data (outside the ESA) were added to the combined ESA/upAWI to create a woodland GIS holding ancient woodland status and habitat data for all the Dark Peak Natural Area, and a surrounding 5km buffer. At this stage the dataset held all available digital information on the woodlands of the Dark Peak, including the extent of Ancient Woodland sites.

Table 7.2
Levels of polygon information recorded within differing habitats during the construction of the GIS.

Habitat group	Inside ESA	Outside ESA
Ancient woodland sites	Classified into broad habitat types with an indication of replanted or semi-natural status	Classified by broad habitat type with an indication of replanted or semi-natural status
Non-ancient woodland sites	Classified into broad habitat type and naturalness categories. (Full Phase 1 habitat survey level classification)	Classified only into broad habitat categories without an indication of naturalness category.
Habitat context	Full coverage of non-woodland habitats	No habitat context information

7.2.4 GIS woodland classification accuracy and woodland survey planning

The aim of the creation of the GIS was to enable the classification of all woodland to Phase 1 habitat survey level. Woodlands within the GIS lacking in full classification were due either to absence of information within the original GIS data or due to data inaccuracies during the data combination process.

Table 7.3
Woodland polygon classifications present within the GIS. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

Polygon Type	Classification code	Code Description
Ancient woodland sites	S + habitat	S indicating ASNW followed by code indicating the habitat
	R + habitat	R indicating PAWS followed by code indicating the habitat
Non-Ancient woods inside the ESA	A111	Woodland, broadleaved, semi-natural
	A112	Woodland, broad-leaved, plantation
	A122	Woodland, coniferous, plantation
	A131	Woodland, mixed, semi-natural
	A132	Woodland, mixed, plantation
Non-Ancient woods outside the ESA	A11	Woodland, broad-leaved
	A12	Woodland, coniferous
	A13	Woodland, mixed
Non-woodland	Habitat	Code indicating the classification of open ground habitats

When the woodlands were automatically classified within the GIS (Table 7.3), a wide range of classification codes occurred, especially within Ancient Woodland Sites. The combination of the two classification systems – the codes for naturalness within Ancient Woodland Sites and the codes for Phase 1 woodland habitat allowed Ancient Woodland Sites to be fully classified from the data. However the codes included combinations that were contradictory e.g. semi-natural coniferous woodland, which indicated a semi-natural woodland polygon classed as coniferous plantation. In such situations without field verification it was unclear whether the Phase 1 woodland category or the Ancient Woodland Site status was accurate. Two data accuracy assessments were undertaken. This involved examining whole "classes" of codes and additionally examining individual problem polygons. Individual problem polygons were examined at a later stage of the project when fieldwork results were available. At this stage the broad classification of categories was examined.

Table 7.4
Classification of woodland polygons and using the GIS to plan structured surveys.

	GIS Habitat Category		Code accuracy		
Site Type	Phase 1 code	Description	Class correct	GIS Category changed to	Field survey
Ancient Woodland	R,S	Replanted or Semi-natural, no woodland present.			✱
	R,S+ Habitat	Replanted or Semi-natural on open ground habitat		✱ : AW + Non-woodland code	
	R +A11	Replanted +Woodland, broadleaved		✱ : R+A112	
	R +A111	Replanted +Woodland, broadleaved, semi-natural			✱
	R +A112	Replanted +Woodland, broadleaved, plantation	✱		
	R +A12	Replanted +Woodland, coniferous		✱ : R+A122	
	R +A122	Replanted +Woodland, coniferous, plantation	✱		
	S +A11	Semi-natural + woodland, broadleaved		✱ : S+A111	
	S +A111	Semi-natural + woodland, broadleaved, semi-natural	✱		
	S +A112	Semi-natural + woodland, broadleaved, plantation			✱
	S +A12	Semi-natural + woodland, coniferous			✱
	S +A122	Semi-natural + woodland, coniferous, plantation			✱
Non ancient	A11	Woodland, broadleaved			✱
	A111	Woodland, broadleaved, semi-natural	✱		
	A112	Woodland, broadleaved, plantation	✱		
	A12	Woodland, coniferous		✱ : A122 (coniferous are plantations)	
	A13	Woodland, mixed		✱ : A132 (mixed are plantations)	

The potential accuracy of each unique "classification" was examined (Table 7.4). Certain classes of AW naturalness and habitat classification were complimentary, for example S A111, "S" indicating Semi-natural Ancient Woodland Site and A111 indicating Woodland, broadleaved, semi-natural habitat. Classes such as SA122, Semi-natural coniferous plantation, cannot represent accurate polygons and represent errors within the dataset. Where the categories of code were complimentary these were used to confirm the full Phase 1 habitat classification of the polygon. This process allowed the majority of the Ancient Woodland polygons to be classified. Where the categories of code were not complementary these sites were marked for field survey. Large areas of non-ancient woodland occurred outside the ESA for which total field survey was not possible. Within the re-classification system several assumptions were made that enabled the areas of land requiring survey work to be reduced considerably. No true areas of semi-natural coniferous woodland occurred in the Dark Peak, therefore all "coniferous woodland" (A12) sites were re-classified to Coniferous plantation woodland (A122). Similarly very few mixed semi-natural woodlands occur and most mixed sites can be considered to be plantations. The GIS Dataset at this stage was compiled, copied and archived for later comparison with the final GIS dataset.

7.2.5 Addition of non-digital data to the GIS

Following the completion of the combined woodland GIS and the designation of categories for field survey a number of additional non-digital datasets were examined prior to undertaking the surveys. Once these were examined the fieldwork surveys were undertaken and the results added to the combined GIS.

7.2.5.1 Addition of non-digital habitat context information

1:50,000 OS Strategi maps To ensure all woodland areas were present within the combined GIS a brief survey was carried out examining woodland coverage within the Dark Peak Woodland GIS against 1:50,000 OS strategi maps. Areas of woodland not recorded within the GIS were digitised and marked for later assessment by Phase 1 maps, aerial photographs or fieldwork.

Reservoir locations Due to the large areas of land covered by reservoirs within the Dark Peak all the major reservoirs were digitised from the OS 1:50,000 maps and added to the project.

PDNPA Phase 1 habitat mapping The information held on existing Phase 1 survey maps at the Peak District National Park Authority was used to further classify the broad-leaved (or mixed) woodland polygons as semi-natural or plantation. Due to the incomplete coverage, consistency and accuracy of the Phase 1 maps many woods could not be sub-divided or classified. Therefore the majority of sites were retained for later survey.

Aerial Photograph Interpretation All areas of woodland, scrub and scattered tree cover not already present within the GIS, but able to be identified from aerial photograph interpretation were digitised. Additionally sites with habitat classifications discrepancies between NIWT and ESA data were examined. Scattered tree cover mapping had not previously been undertaken in the Dark Peak as this habitat was normally omitted from surveys, with preference being given to the mapping of the dominant open ground habitat. Two mapped scattered tree categories were separated on the grounds of canopy density, cover and distance between trees. The method of digitising (Appendix 7.1) essentially involved a prioritization of identifying areas of scattered trees and scrub in cloughs rather than narrow linear occurrences of trees along lowland riparian corridors or within areas enclosed farmland. Within the National Park, digital aerial photography was available within a MapInfo GIS system. Outside the National Park copies of aerial photographs covering the ESA area were obtained from DEFRA while in remaining areas beyond the ESA and the National Park images available within the MultiMap website were used (www.multi-map.com).

7.2.5.2 Addition of Woodland survey results

Ancient Woodland Fieldwork surveys All ancient woodland sites with access permission were surveyed and the surveys digitised. Fieldwork was conducted over 5 seasons (May to September) between 2001 and 2005. Ancient Woodlands were surveyed, similar to mapping under NVC purposes for selection of relatively "homogenous" mapping areas (Rodwell, 1991), these largely corresponded to forestry management compartments where these were present. Recording was carried out across each entire compartment using visual assessment and counts following a similar routine to previous woodland studies (Honnay et al., 1999b, Peterken, 1974, Peterken and Francis, 1999, Kirby, 1988a), where the aim was also an assessment of the entire woodland area, and the features of interest, such as specialised and characteristic woodland flora, were known to be associated with scarce or erratic features such as rock outcrops, variable topography or streams, that would be missed by other sampling methods. The approach therefore attempted a census of the compartment features for many of the recorded variables. The limitations of such methods are acknowledged, but the benefits of this approach in allowing coverage of all sites within a single Natural Area and capable of rapid application by conservation organisations were considered beneficial. Recording of some features such as NVC community and sub-community presence by walk-through visual assessment was occasionally problematical where degraded woods or transitional communities occurred, in such situations it is acknowledged that communities may be difficult to distinguish and transitional sites can occur (Rodwell et al., 2000, Rodwell, 1991). (See Chapter 10 for full discussion of the ancient woodland surveys).

At each site the range of habitats were mapped at 1:5,000 or 1:10,000 scale and classified according to standard Phase 1 methodology (JNCC, 1993). In rare cases during fieldwork errors were observed in the original digital mapping of areas marked as "Cleared" (where woodland was observed with cover and trees the same age as the areas within the ancient wood boundary) in these cases these errors – where they clearly held long-established woodland cover, were also surveyed. Where sites had been recently felled, or sites held young woodland only the woodland type and age was recorded and no detailed survey was undertaken due to the lack of data available in these areas and the difficulty of recording species. During digitisation where a site was enclosed, e.g. by boundary walls, all open ground habitats inside the boundary were retained. However at unenclosed sites all open ground beyond current woodland cover areas were re-classified as non-ancient. According to the original English Nature AWI methodology these areas would be considered to be "cleared". The original EN inventory methodology was followed in retaining small areas of secondary woodland within sites as being ancient woodland. However where large areas of secondary woodland were identified due to recent activity, such as quarrying, then these sites were re-classified as cleared.

Biodiversity indicators were recorded within each surveyed compartment (Table 7.5). A wide range of indicator and surrogate values / species have been suggested and previously used within woodland studies. These can be grouped as biological / taxon indicator species, keystone species, compositional and structural indicators (Lindenmayer et al., 2000, Ferris and

Humphrey, 1999). Ferris and Humphrey (1999) noted the need for indicators "that can be used by forest managers to assess biodiversity at the stand, forest or landscape scale" (Ferris and Humphrey, 1999). They considered that any such indicators must meet several criteria: they must be easily assessable, repeatable and subject to minimum observer bias, cost-effective, and ecologically meaningful (Ferris and Humphrey, 1999).

Although biological / taxon indicators have been recognised as being potentially powerful tools they are not considered adequate at present for widespread use by some authors (Lindenmayer et al., 2000). Biological indicator species suffer from the high cost of research to prove their use in indicating general biodiversity and the difficulty of recording their presence or identification. While in some groups potential suitable indicator species have been identified e.g. woodpeckers for avian woodland diversity (Mikusinski et al., 2001), typically suitable indicators are not available. Therefore other techniques must be found to focus conservation activity. Ferris and Humphrey (1999) note that certain indicators can be used to summarize the composition of woodland patches which in turn affect the species present and levels of ecological interest (Ferris and Humphrey, 1999). Some authors have noted the need for study of potential "keystone complexes" which may be critical in temperate woodland ecosystems where several species are interconnected and rely on keystone species (Ehrlich, 1996), or on keystone structure such as deadwood (Tews et al., 2004). Keystone species such as Birch (*Betula spp.*) and Oak (*Quercus spp.*) have been proposed (Ferris and Humphrey, 1999). Potential indicators can also be taken from features recommended by workers as being known to be associated with higher levels of biodiversity, and therefore recommended for increased provision / creation in woodlands. A past review reported results of factors increasing the potential biodiversity of newly created woods for birds being: extent of open space, extent of dead and decaying wood, tree species richness, tree maturity and retention of very old trees, management type, ride edge structure and vegetation, riparian zones and aquatic habitats and artificial resources such as nest boxes (Spellerberg, 1995). Due to the problems of using biological indicator species, the use of structure based indicators have been recommended. These can be classified as stand complexity, connectivity and heterogeneity (Lindenmayer et al., 2000). These include a variety of patch conditions affecting species occurrence and diversity. Structural indicators summarize habitat structure of woods, which in turn affect the species composition and levels of ecological interest (Ferris and Humphrey, 1999). Other authors have concurred that due to the difficulty of species monitoring that forest management should concentrate on preserving patterns related to the structural and functional attributes of the woodland ecosystem, rather than expend considerable time recording species (Zavala and Oria, 1995). Structural biodiversity indicators relate to stand successional stage and structure, with authors noting that "the total area and both spatial and temporal distribution of broad structural or successional stages may be of use as an indicator of biodiversity at the forest or landscape scale (Ferris and Humphrey, 1999). Both vertical and horizontal patchiness and variation within individual stands were proposed as indicators. Additional structural indicators noted were the levels of dead and decaying wood (Ferris and Humphrey, 1999). Although very detailed methods to measure forest structure heterogeneity have been developed e.g. (Zenner and Hibbs, 2000) the current study utilised a more rapidly assessed method capable of rapid repetition by forest managers and surveyors.

Ultimately Ferris and Humphrey (1999) recommended a range of indictors be utilised, including stand structure (vertical, horizontal patchiness, deadwood), 2-3 key compositional indicators (that can be shown to be linked functionally to a broad range of other species, e.g. extent and species composition of broad-leaved component in conifer forests) and 2-3 key structural indicators which act as surrogates for general species richness/diversity (e.g. the quantity and quality of deadwood). In particular the authors noted key indicators as Oak species, Birch species, ancient woodland indicator species, and for structural indicators measures of stand vertical and horizontal structure and levels of deadwood (Ferris and Humphrey, 1999). The value of such recording of multiple indicators to assess potential species effects has been noted by other authors rather than concentrating on single measures with species effects (Tews et al., 2004). From this examination of the literature a range of compositional and structural indicators were selected to be recorded within the surveyed Ancient woodland (**Table 7.5**), and subsequently used to analyse the association between site quality and abiotic predicted quality (**Chapter 10**). The selected indicators closely follow the recommendations of the reviews (Lindenmayer et al., 2000, Ferris and Humphrey, 1999, Spellerberg, 1995, Noss, 1999). Ultimately these indicator values attempt to find a suitable trade-off between speed and ease of application and incorporation of a sufficient level of biological realism and correlation with ecological value. These measures capture "shorthand" a range of information or features that are surrogates for broader woodland diversity or species richness. Use of internal patch indicators can avoid the over-simplification of studies assuming woodland patches of the same broad category or size hold similar internal patch characteristics. Using range of these indicators allows fragmentation studies to quantify the relative ecological habitat "quality" of individual patches such that these internal patch characteristics may be considered in addition to the physical, patch characteristics of size, shape and context. The inclusion of such indicators however represents an additional cost within these studies in terms of time and resources for their collection. Therefore the indicators selected must be efficient and any correlates between remote sensed / abiotic characteristics and detailed field-based assessment are of considerable use to conservation planning in minimising the need for expensive fieldwork.

Table 7.5
Variables recorded during project fieldwork within each Ancient woodland compartments

Indicator group	Surveyed variable / record	Indicative of:
Conservation interest	Occurrence / Number of National BAP species	Rarity value
	Occurrence / Number of Regional LBAP species	Rarity value
	Occurrence / Number of Regional Notable species	Rarity value
	Occurrence / number of Ancient Woodland Indicator species	Naturalness / typicalness
Compositional	Oak and Birch species presence	Keystone species
	Number of NVC communities	Biodiversity
Structural	Extent of semi-natural tree and shrub cover	Biodiversity
	Canopy structure, age	Biodiversity potential
	Presence of veteran trees	Biodiversity
	Ground flora extent	Biodiversity
	Presence of dead wood	Biodiversity
Restoration potential	Management	Biodiversity
	Invasive species	Threat

Table 7.6
Summary of Ancient Woodland Site polygon classifications within the GIS following the field survey results

Pre-fix	Classification
S	Semi-Natural (Woodland or Scrub habitats)
R	Replanted (Woodland or Scrub habitats)
AW	Open ground (non-woodland) habitat (including scattered trees) In an enclosed AW site this may represent areas of natural open ground, glades or woodland fringe, alternatively these may represent areas that were temporarily cleared and are now re-growing.
CL	Cleared areas no longer capable of supporting woodland or areas that would not be capable of developing ancient woodland flora if woodland cover were to re-develop. These areas include recently cleared areas for roads, quarries, gardens or fields identified from the ground survey. This also included large areas of obviously secondary wood occurring on substrates that had obviously altered – for example larger quarries within ancient woodland sites.
Pre-fix deleted	The Prefix was deleted from sites within the GIS where it was apparent from the field survey that the polygon area could never have been considered to be an AW site

During the initial project methodology analysis aimed to collate existing species records from a range of species from National interest (NBAP), Regional interest (LBAP), and species that were considered to be locally notable or that were used within regional recording programs as provisional Ancient Woodland Indicator Species (AWIS). These initial lists, formulated prior to survey, detailed a range of invertebrate, avian and botanical species records, but proved impractical due to the poor scale of resolution of the data. Therefore field collected biodiversity indicator data was used exclusively.

Non-ancient woodland Phase 1 Habitat survey Maps were produced from the GIS at 1:15,000 or 1:20,000 detailing polygons requiring habitat classification data. These included sites with discrepancies between the NIWT and ESA polygons, sites with a discrepancy in classification between the pdAWI and PDNPA Semi-natural woods file, and the small number of large sites that spanned the Dark Peak boundary requiring Dark Peak woodland status clarification. Sites were visited or viewed using public rights of way and were surveyed to a rapid Phase 1 Habitat classification methodology to identify the main habitat class (JNCC, 1993). Due to the extensive areas of habitat, frequently sites were classified from vantage points using binoculars, such that broads assessment have been made or individual woods, but mapping or subdivision of sites into separate polygons was not always possible. Minimum mapping identifying separate canopy dominance areas was approx 0.5ha. This fieldwork was carried out between April-September 2001-2003. Where one of the datasets (ESA or NIWT) was verified as accurate the digital files were retained and later added to the main GIS woodland file using the ArcView Geo-processing Union command. Smaller sites of more complex areas where new features had been observed by the field survey were digitised into the GIS. Following the completion of this survey work all non-ancient woodland polygons were classified by woodland habitat and naturalness.

7.2.6 Addition of further digital data to the GIS

Following the creation of the woodland habitat GIS and the classification of all woods by digital data and fieldwork results a further range of data was used to classify the landscape, and increase the accuracy of the woodland estimates.

7.2.6.1 Buildings, transport network and urban areas

Analysis was used to create a theme representing the urban areas and transport network within the Dark Peak from OS Landline data (Appendix 7.6). This was then added to the GIS to provide habitat context data. The final urban network file was added by union to the main combined woodland GIS dataset. All occurrences of urban network were classified as Phase 1 habitat survey "urban" habitat (code J3). This addition resulted in changes to the classifications of the woodland network polygons. Many polygons were split into separate areas by roads or areas of housing while other areas occurred completely within areas classified as urban. All areas where woodland occurred within urban areas were re-classified to urban, removing the woodland presence in these areas. It was likely that these occurrences represented errors in mapping or simply concentrations of trees within these urban areas rather than dense woodland conditions. This processing added to the accuracy of the GIS by removing mapped areas of woodland in urban areas and correctly mapping woodland boundaries by roads. The method was based on assigning standard width to different roads, based on their potential negative influence. This method therefore assumed different significance for larger main roads compared to unsurfaced tracks, an extension and clarification of an earlier approach in the literature (Peterken, 2002a).

7.2.6.2 Habitat context data

In order to complete the GIS two final sources of data were compiled. The moorland line dataset holds approximate data on the occurrence of marginal land and heathland, classed as moorland. The data was derived from Ordnance Survey mapping and was not applicable at the small scale. However it was of use in identifying large areas of moorland which were not covered by current information within the GIS. All areas that occurred within this combined Dark Peak / Moorland Line data which were lacking in GIS information were selected and subsequently added to the main GIS dataset using the union command. The areas representing the Moorland Line data were classified as Phase 1 category "heathland" (D) to denote their heathland status but uncertain level of classification. The remaining unclassified areas within the Dark Peak were classified as improved or semi-improved farmland (B4/Bx2). It was however recognised this was a vast simplification of the range of habitats occurring in these areas. The digitised reservoir areas were then added to the GIS for all areas of reservoir visible on the 1:50,000 scale raster map. At this stage the GIS contained full coverage of classified woodland habitat data and a full coverage of classified landscape matrix.

7.2.7 Classifying "Dark Peak" woodlands

The final woodland GIS data contained full habitat context / landscape matrix data within the Dark Peak boundary and woodland data up to a 5km buffer around the Natural Area. A method was required to define "Dark Peak" woodlands which would allow these to be identified while retaining the woods adjacent to the Dark Peak in the dataset. To retain a functional approach a method was chosen based upon whole polygons, not using the simple clip command which cuts polygon boundaries. Woodland boundaries were considered to be accurate, especially after woodland coverage had been altered by the use of the urban data: removing overlaps with towns and splitting woodland extent by roads. All woods that contained an ancient woodland polygon as part of a large continuous block were treated as single functioning woodlands. Initially all woodlands that occurred within, and were intersected by, the Dark Peak Natural Area were classified as "Dark Peak Woodlands". However, a large number of polygons spanned the boundary. Therefore only woods that held more than 50% of their area within the Dark Peak were considered as "Dark Peak Woodland" and were therefore included in subsequent analysis and data reporting or fieldwork.

7.3 GIS analysis

Although the main aim of the methods was to produce a single GIS dataset detailing the classification of the Dark Peak woodland resource, several datasets were produced, enabling different analysis of the results. The main GIS dataset contained a full Phase 1 habitat description of all woods classified as Dark Peak woodland including Ancient Woodland site status. Additionally a dataset was produced detailing only the Phase 1 habitat classification of each woodland, irrespective of Ancient woodland status. Finally a GIS dataset solely of the Ancient Woodland resource was extracted allowing analysis of these woods in isolation from other habitats.

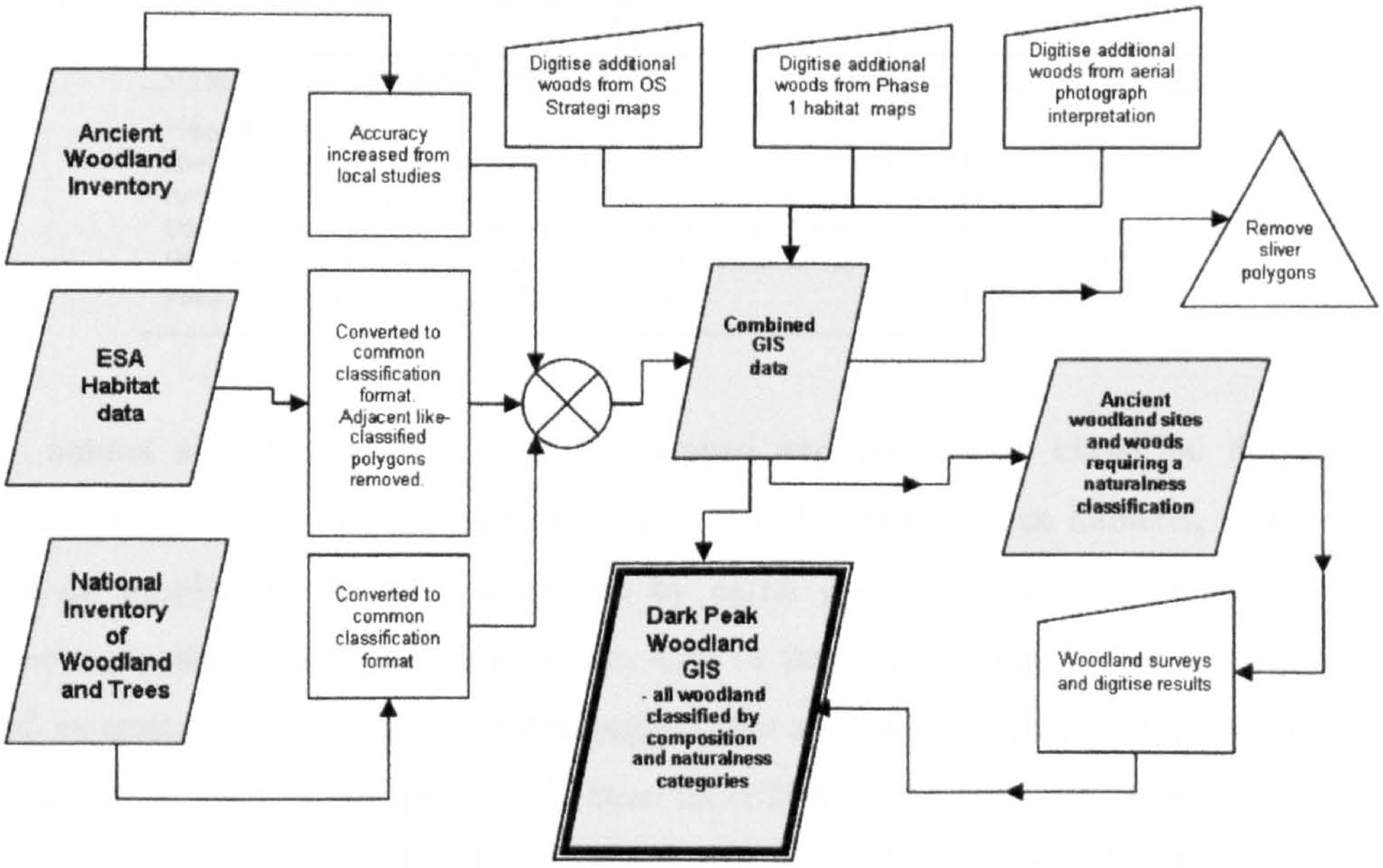


Figure 7.1
Summary of GIS construction methods

7.4 GIS results

A woodland GIS was created by incorporating a range of existing digital habitat information with the results of aerial photograph analysis and ecological surveys (Fig 7.1, Fig 7.2). When all data were compiled within the GIS the majority of the area of woodland habitats, including Ancient Woodland Sites were located and mapped from the main digital source datasets (Table 7.7). Data derived from the NIWT identified 5,437 ha and 49% of the final woodland GIS cover. ESA data identified 2,437 ha and 22% of the area of the final woodland GIS. However a sizeable area of woodland type habitat cover was added through digitising information into the project. 1,800 ha in 842 sites of woodland and associated woodland habitats were identified through the survey elements of the project forming 16% of the final total woodland GIS cover. Of the new sites added to the project as a result of the survey the majority were identified and fully classified to Phase 1 habitat through the use of aerial photographs 1,100ha (61% of digitised area 54% of digitised sites) (Table 7.8). The majority of the remaining digitised sites, 680ha, were identified and mapped through the use of aerial photographs, followed by the use of Phase 1 habitat surveys to clarify dominant habitat types (38% of digitised area, 44% of digitised sites). A small minority of sites were also identified on the ground while undertaking the Phase 1 surveys on sites originally identified through aerial photograph analysis work.

Table 7.7
Source of woodland patch location information for woodland patches present within the GIS

Data source	Patches	Area (ha)
Digitised by the project surveys	844	1,800
Digital data, combined EN AWI boundaries and digital woodland data (ESA or NIWT)	500	1,342
Digital source data (ESA and NIWT)	2096	7,874

Table 7.8
Classification to full Phase 1 Habitat survey standard by project methods

Classification of woodland patches	Count	Area (ha)
Phase 1 Habitat survey	16	21
Aerial photograph analysis followed by Phase 1 habitat survey	369	679
Aerial photograph analysis	457	1099
Digital source polygon classified by Aerial photograph analysis	62	184
Digital source polygon classified by Phase 1 habitat survey	867	3123
Fully classified by existing digital source data	1669	5901

Of the habitat sites that were identified, mapped and completely classified through aerial photograph analysis 78% of the area of these sites held scattered tree habitats, with only 12% mapped as woods. Of the sites identified by aerial photograph analysis and subsequently surveyed under the Phase 1 survey program, 42% of the area was mapped as woods, with 36% mapped as scattered trees. These figures suggest that although the project did identify areas of mature woodland that had not previously been identified within other digital surveys in the area that the majority of woodland had been mapped and most additional woodland habitats mapped by the project were scattered trees habitat. Only 5.5% of the established woodland cover present within the final combined GIS was new woodland cover added entirely as a result of the project surveys, never-the-less this comprises 433 ha in 313 sites.

Of the sites that were initially mapped and added to the project through the use of the ESA and NIWT datasets, the majority remained unchanged following the aerial photograph and field surveys. However 3,123 ha (867 compartments), 35% of the area and 33% of the frequency of digital sites were amended by the Phase 1 survey program. These were principally the unclassified "broadleaved" sites from the NIWT datasets but also included other sites that were identified during the course of the project methodology as requiring verification. 184 ha (62 compartments) of existing digital compartments were fully classified to Phase 1 habitat level solely from the use of aerial photography surveys (2% of the area and 2% of the frequency of the digital mapped sites).

In summary 1,283 ha of woodland and associated woodland habitats were verified by aerial photograph analysis within the project while 3,824 ha of woodland were classified following the Phase 1 habitat surveys. The final combined Dark Peak woodland GIS detailed the location of almost 2,800 woodland patches occupying over 9,200 ha. The composition of this woodland network and its potential prioritisation for conservation, conversion or expansion is addressed in later Chapters.

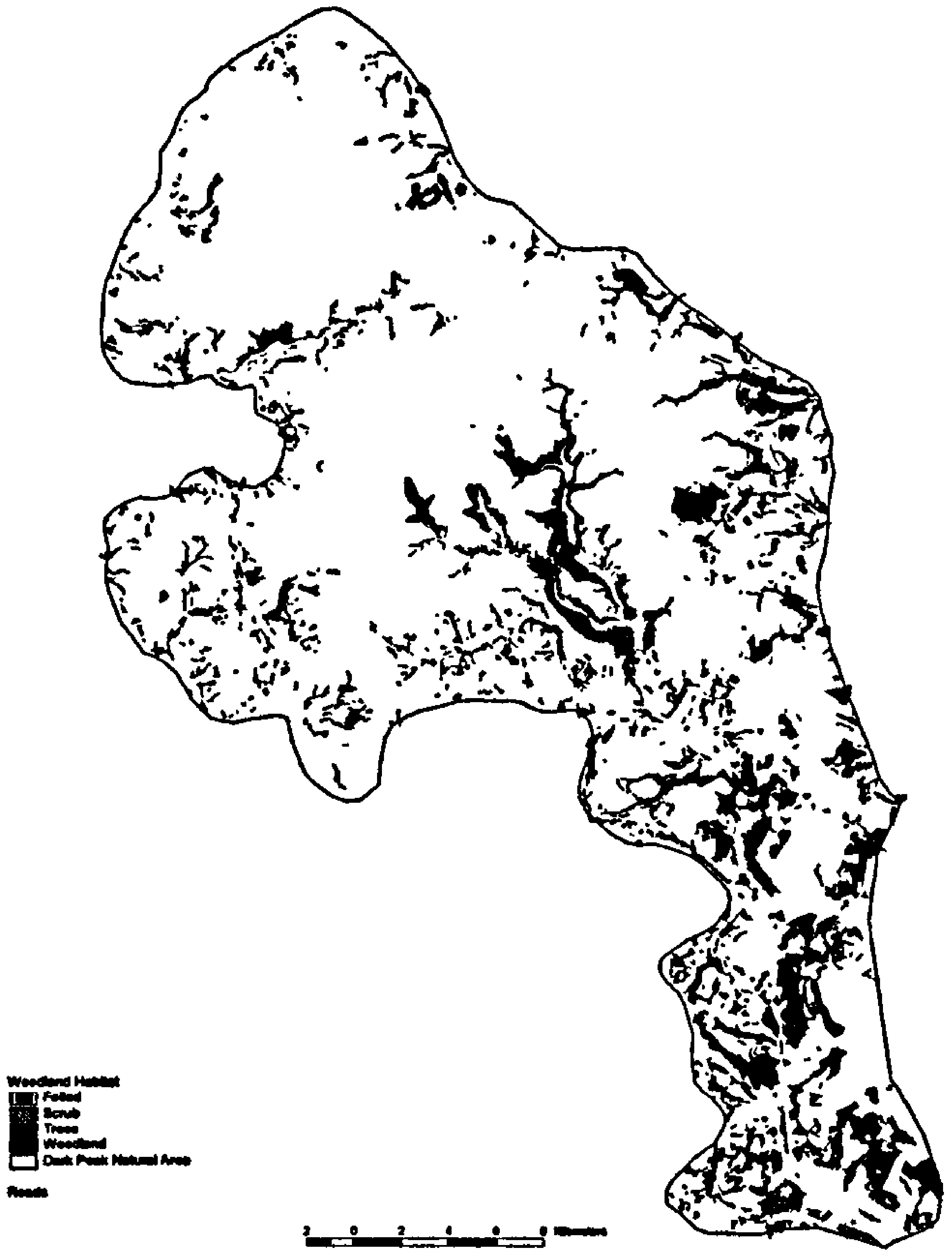


Figure 7.2
The woodland network of the Dark Peak

7.5 Chapter Summary

- A variety of data sources were assessed for their potential use in a Natural Area scale woodland GIS
- The Ancient Woodland Inventory data was not found to be a reliable assessment of woodland habitat cover at the Natural Area scale
- Limited accuracy improvements to the Ancient Woodland Inventory were possible by use of complimentary woodland data (NIWT), however full accuracy improvements required survey fieldwork
- GIS based classification of Ancient Woodland sites by NIWT may hold potential for conservation planning at the broad regional scale
- Compilation of several digital woodland datasets was an effective method of compiling woodland cover data at the Natural Area scale
- GIS classification methods were useful in limiting the number of woodland polygons requiring field survey
- Rapid Phase 1 survey was required to incorporate full naturalness classification to all woodland polygons, at the Natural area scale

Chapter 8
Woodland conservation, restoration and creation sites
Identifying Dark Peak woodland landscape character

8.1 Introduction

This chapter details the methods used to define areas of Dark Peak landscape considered suitable for the conservation, restoration or creation of semi-natural native woodland cover. Initial consideration revealed several potential methods including basing decisions on the current distribution of habitats, classified by suitability for conversion to woodland cover, or basing planning on a "landscape character assessment" of the Dark Peak. Methods based on current habitat cover can utilise information within the woodland GIS. Options for considering the landscape character of woodland included examining the range of physical and topographic positions on which current native woodland cover occurred, and extrapolating these across the Dark Peak. Alternatives included examining existing landscape character assessments and the creation of new "landform" assessments, based on GIS topography data.

Given the aims of the project, in considering potential future landscapes, and the mixed influences that have resulted in historical woodland loss across the Dark Peak, the current distribution of habitats was considered suitable only for identifying a suite of habitats that may represent broad opportunities or constraints to woodland development. Current habitat type was not considered solely sufficient for planning as some conversion between habitats may be appropriate in priority areas, depending on landscape context. In contrast to Good et al (1997) the exact existing distribution of woodland, or native woodland cover was not considered an accurate predictor of potential woodland expansion areas due to past management influences such as the conversion of native woodland to plantation woodland types, broad scale woodland planting in the uplands or woodland clearance. Therefore an analysis of current woodland cover was used to inform woodland planning, but was not considered totally prescriptive. It was however useful in extracting and defining features influencing woodland occurrence and classification (Chapters 9, 10).

Due to the strong influence of topography on natural processes (such as soil development), habitat type and land-use, high priority was given to the identification of suitable landform types for woodland development, supplemented by information from the examination of existing woodland occurrence and habitat distributions.

A number of research areas were combined in order to select potential woodland conservation sites. The methodology initially involved an examination of existing landscape classifications relating to physiography, landcover, cultural pattern, geology and soils. Subsequently an examination of methods for the classification of landform character was followed by analysis of the current topographic characteristics of native woodland cover, to approximate a broad "landscape character assessment" of native woodland cover. Particular attention was paid to the identification of the moorland plateau and clough landscape zones. Finally the compiled habitat information and landscape classification were combined to examine habitats representing opportunities or constraints to woodland creation. The final output of the chapter was a spatial database of locations considered to be suitable for woodland conservation, restoration and creation based on landscape composition, location and current habitat cover.

8.2 Dark Peak Woodland Landscape Character

Landscape Character Assessment provides a broad range of tools for analysing the landscape and is traditionally associated with visual landscape assessment for land-use planning. Recent progress in the UK has resulted in national guidelines (Swanick and Land Use Consultants, 2002). Landscape Character mapping combines many factors relating to the landscape (Fig 8.1), and have been used in a variety of situations such as the identification of supplementary planning guidance for rural planning and forestry (Anon, 2005) and analysing the distribution and characteristics of woodland cover at a national level (Griffiths et al 2004).

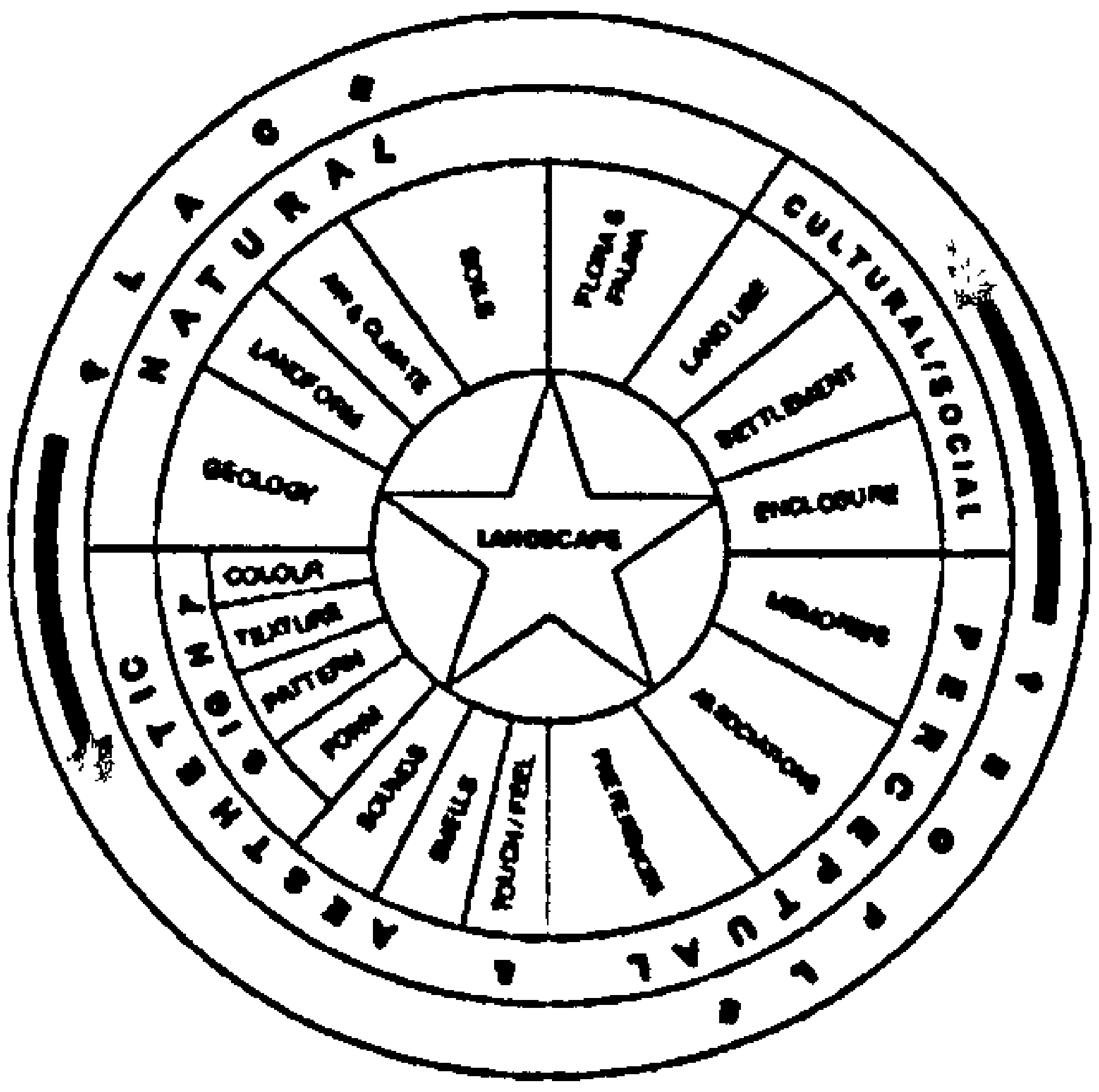


Figure 8.1
The range of factors within the broad definition of "landscape" (Reproduced from Swanick and Land Use Consultants, 2002).

8.2.1 Existing landscape classifications

The GIS methodology used in the identification of the national 159 Character Areas / 120 Natural Areas (Countryside Agency, 2005: English Nature, 2005) initially involved the mapping of landscape features at finer scales. Landscape Descriptive Units (LDU's) were mapped, which could be combined to identify Landscape Character Types (LCT's), which were subsequently combined to form Natural Areas. These were mapped by reference to key features: physiography, ground cover (ecology), settlement pattern and land-use. This methodology and its potential for further use in detailed local assessment are outlined in Fig 8.2. There are 33 unique combinations of the principal features used to generate LDU's in the Dark Peak (Fig 8.4), while there are eight Landscape Character Types in the vicinity (Fig 8.3). The identification of these areas was not intended for direct management planning as Natural Areas were, but the areas were considered suitable blocks on which to base more detailed landscape character assessment.

Table 8.1
Landscape Character Types (LCT) present in the Dark Peak, summarised into broad interpreted landscape zones (Fig 9.4).

	Interpreted Zone	Physiography	Landcover	Cultural pattern
1	Moorland	High hills	Heath&Moor	Unsettled / Openland
2	Moorland fringe	Low hills	Heath&Moor	Waste/unwooded
3	Moorland fringe	Intermediate	Other heavy land	Wooded-ancient woods
4	Moorland fringe	Upland valleys	Other heavy land	Coalfields
5	Enclosed fringes	Upland valleys	Other heavy land	Wooded-ancient woods
6	Enclosed fringes	Low hills	Other heavy land	Wooded-ancient woods
7	White Peak fringe	High hills	Limestone	Nucleated, unwooded
8	White Peak fringe	Upland valleys	Limestone	Wooded-ancient woods

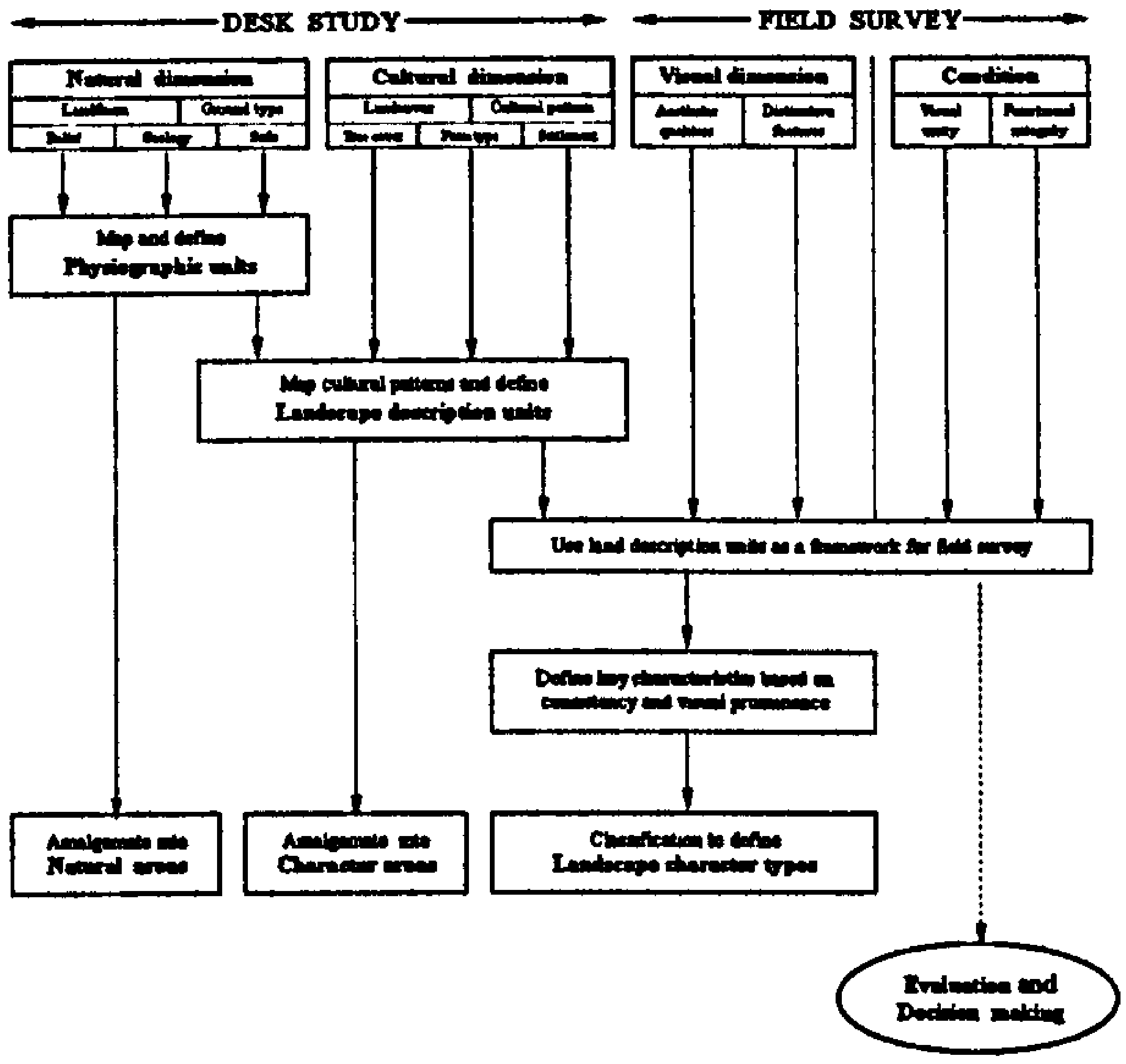


Figure 8.2
The interrelationship between landscape classification and the intended use of the system at a local scale. (Reproduced from (Countryside Agency, 2003)).

The LDU and LCT maps (Fig 8.3-8.5) highlight the influence of elevation on local landscape character, and the dominance of the moorland core with its characteristic features of moorland habitats, low settlement patterns and extensive land-use. The maps detail various landscape divisions highlighting the characteristics of the moorland fringe and lowland areas where steep slopes, floodplains and various forms of land-use or settlement locally affect landscape character. The principal features of landform topography – plateaus, slopes, valleys and elevation effectively divide the landscape into many component areas, which may be utilised for further landscape scale planning. Following consideration of the potential of these existing classifications for woodland planning the level of mapping was considered too coarse to assign suitability for woodland creation to individual zones: the boundaries of the zones being imprecise, and the size of the separate zones being too large. Further classification and division of these zones following additional fieldwork was therefore considered but rejected and instead further research was undertaken to determine if available geology, soils and digital landform data could be used to create similar but more accurate and detailed landscape classifications to enable land-use planning to be undertaken at a scale approaching 1:10,000.

Table 8.2
Definition of the principal physiographic zones within the Landscape Character Types identified in the Dark Peak. Physiography is defined as the underlying structure and physical form of the land surface. The classifications were derived from interpretation of the relationship between geological and contour data. (Reproduced from information supplied by the Countryside Agency through the Magic.gov.uk website).

High hills	High land, mainly over 1000 ft, associated with Palaeozoic (Permian, Carboniferous, Devonian, Ordovician, Silurian & Cambrian) and earlier Pre-Cambrian rocks of sedimentary or igneous origin.
Low hills	Upstanding areas, mainly below 1000 ft - associated with Palaeozoic (Permian, Carboniferous, Devonian, Ordovician, Silurian & Cambrian) and Mesozoic rocks (mainly sandstones and limestones) of sedimentary origin.
Upland valleys	Low-lying areas - associated mainly with Palaeozoic (Permian, Carboniferous, Devonian, Ordovician, Silurian & Cambrian) and earlier Pre-Cambrian rocks of sedimentary origin.
Intermediate	Rolling/undulating areas, below 1000 ft - associated mainly with Mesozoic (Cretaceous, Jurassic, Triassic & Permian) or Tertiary rocks of sedimentary origin and glacial till.

Table 8.3
Definition of the principal landcover zones within the Landscape Character Types identified in the Dark Peak. Landcover is defined as the nature of the ground in which terrestrial plants (natural and cultivated) grow. The classifications were derived from interpretation of geological, soils and agricultural census data. (Reproduced from information supplied by the Countryside Agency through the Magic.gov.uk website).

Heath & Moorland	Land associated with nutrient-poor mineral and/or peaty soils supporting dwarf shrub heath, acidic grassland and bog habitats, or relic heathy/moorland vegetation (bracken, gorse, etc.). This ground type is normally associated with sandstone, or sandy drift in the lowlands, but it is widespread on mixed sedimentary and igneous rocks in upland/hard rock areas. Often marginal in agricultural terms.
Chalk & Limestone	Light land associated with shallow, free-draining soils developed directly on chalk; or limestone bedrock - typically distinguished by stoney soils with relic calcareous grassland on steeper slopes in soft rock areas and rock outcrops/limestone pavement with dry species-rich pasture/hay meadow in hard rock areas.
Other Heavy Land	Heavy land typically associated with base-poor, clayey and loamy soils developed on slowly permeable rocks (mudstones & shales) and mixed till/plateau drift. Seasonal waterlogging is the main constraint to agricultural production and this ground type is mainly under permanent grassland – patches of wet heath are the characteristic associated habitat, grading into wet moorland at higher elevations in the north and west.

Table 8.4
Definition of the principal cultural pattern zones identified within the Landscape Character Types identified within the Dark Peak. Cultural pattern is defined as the structural component of the cultural landscape as expressed through the historic pattern of settlement and land-use. (Reproduced from information supplied by the Countryside Agency through the Magic.gov.uk website).

Wooded – ancient woods	Settled agricultural landscapes (dispersed or nucleated settlement) characterised by an assarted pattern of ancient woodlands which pre-date the surrounding enclosure pattern - in places associated with densely scattered hedgerow trees (typically oak).
Nucleated unwooded	Settled agricultural landscapes characterised by discrete settlement nuclei (villages and/or hamlets) associated with a low to moderate scattering of farms and outlying dwellings. Tree cover is usually fairly sparse and restricted to thinly scattered trees and/or small coverts/tree groups.
Waste unwooded	Open, sparsely settled agricultural landscapes characterised by a surveyor enclosed pattern of large rectilinear fields and isolated farmsteads. Tree cover is usually restricted to watercourses, or groups of trees around buildings.
Unsettled / open land	Extensive areas of uncultivated, mainly unenclosed land (including moorland, heath and coastal grazing marsh) characterised by the virtual absence of human habitation.
Coalfields	Semi-rural areas (e.g. the coalfields of Derbyshire) that have been significantly altered by large-scale industrial activity.

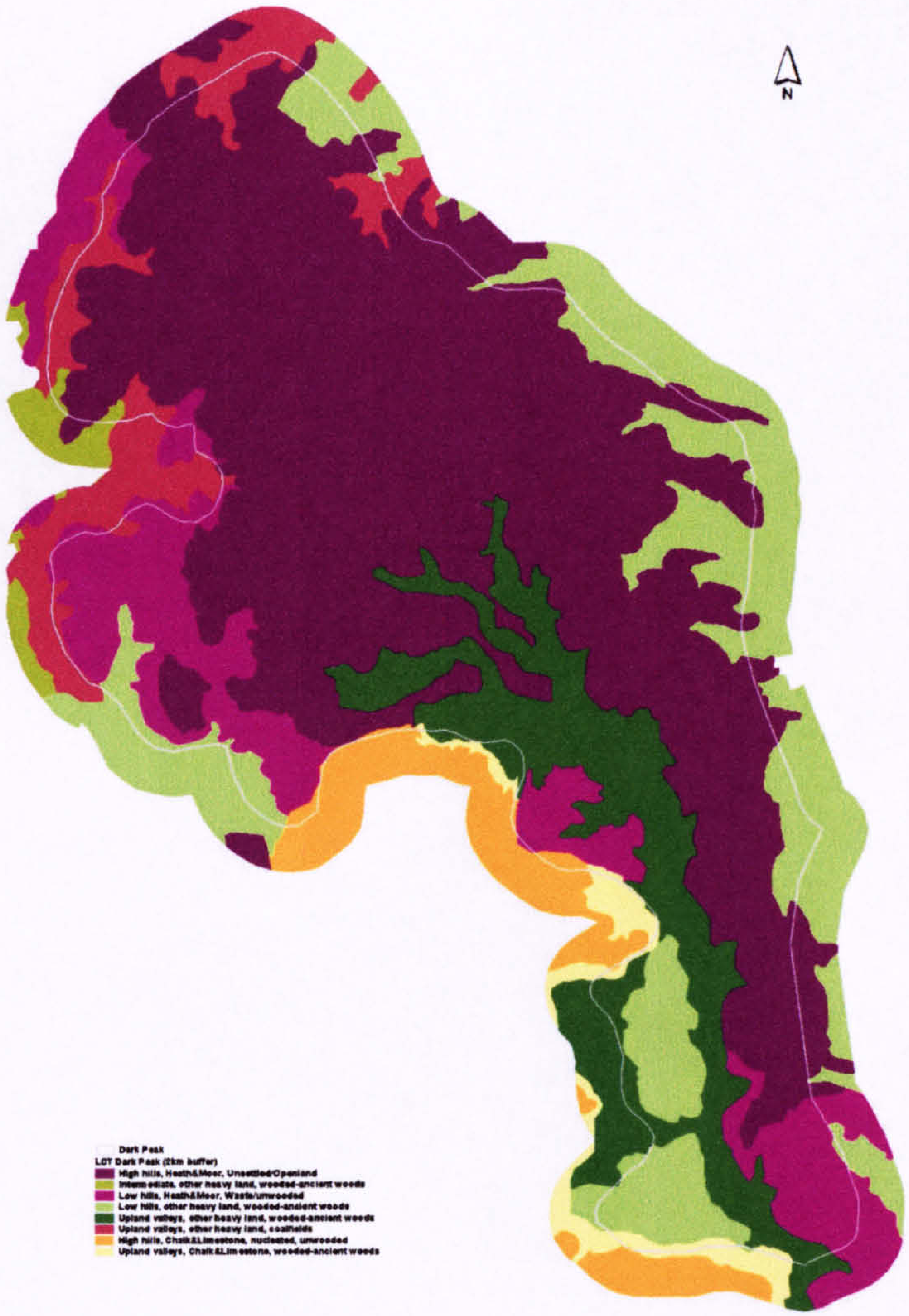


Figure 8.3
Landscape Character Types (LCT) within the Dark Peak and surrounding 2km buffer.

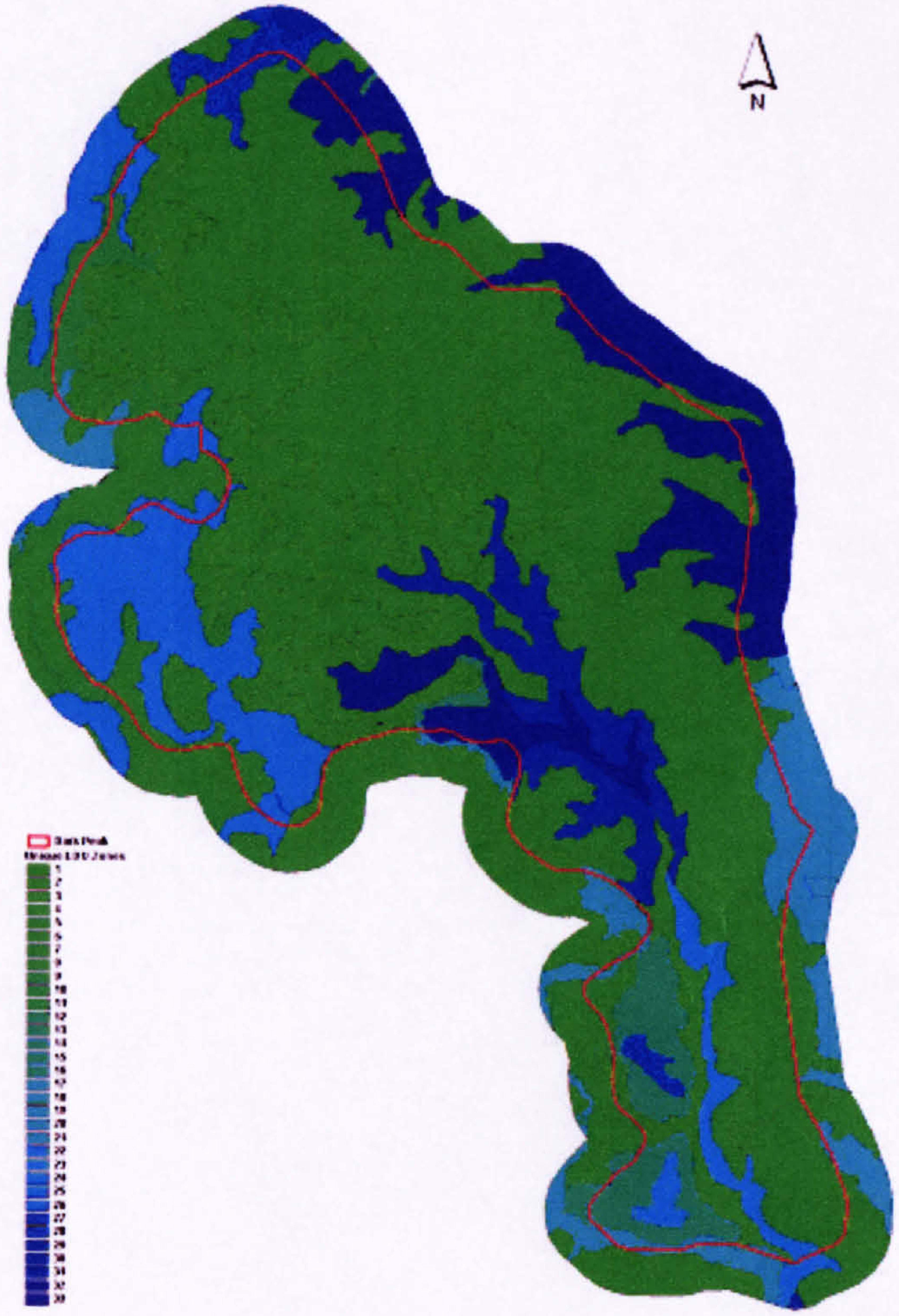


Figure 8.4
Unique mapped Landscape Description Units (LDU) for Dark Peak and surrounding 2km buffer.

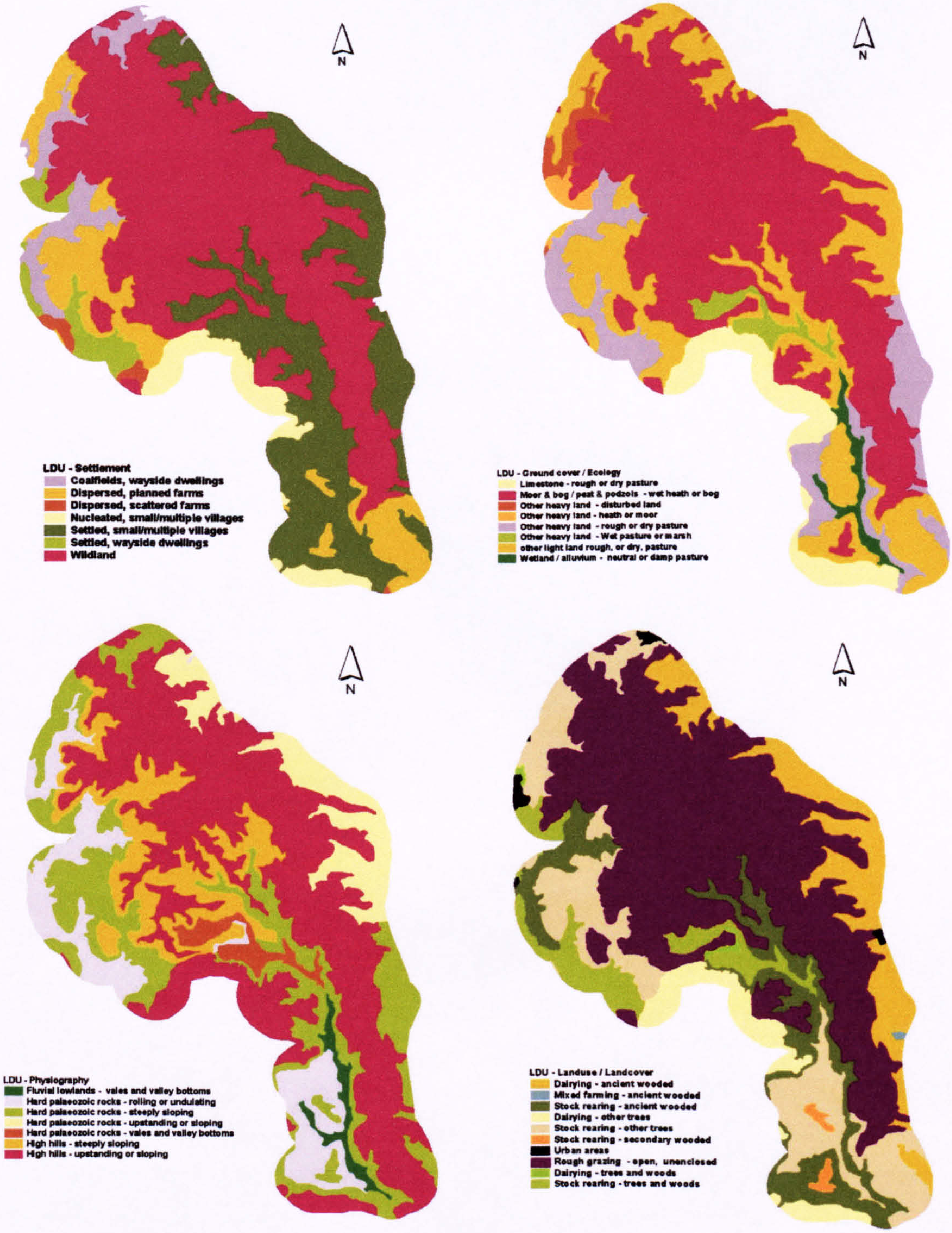


Figure 8.5
Landscape Description Unit (LDU) maps
Settlement, Ground cover (ecology), Physiography and Land-use LDU classifications for the Dark Peak area and surrounding 2km.

8.2.2 The Geology and soils of the Dark Peak

The mapping of the LDU and LCT zones included a broad assessment of geology, however detailed geological information at 1:50,000 scale was available (British Geological Survey, 2002), and was used in place of the broad information contained within these maps. The geology was simplified by merging categories to enable the mapping of geological variation in a reduced number of categories, without excessive loss of accuracy. Finally marginal areas of limestone geology were deleted where they occurred along the fringes of the Dark Peak. The resultant maps of drift and solid geology are reproduced in Fig 8.6. The solid geology was dominated by sandstone finely intermixed with areas of mudstone and siltstone. Large areas also showed the influence of drift geology, most notably the covering of peat across the central moorland areas, but additionally substantial areas of glacial till, alluvium, fluvio-glacial and head deposits. Significant areas occurred where there had been sizeable landslips leading to areas of mixed geology, principally comprising clays.

Geology data provides a further clarification of the landscape character of the Dark Peak, and in particular determines the nature of the soils found in different areas. The sourcing of digital soils data was considered, however the scale of availability of the data was an order of magnitude higher than the majority of data available in the research (1:250,000) therefore geology was used to infer soil and habitat associations. Comparison of the geology data in drift, solid and mass movement against available soils maps provided insight into the major associations. A large area of the Dark Peak comprised peat on the higher ground, with the sloping fringes holding very acid loamy upland soils with a wet peaty surface and areas of typical brown earths (Anon, 1983), 1983). Several of the larger river valleys held river terrace deposits and alluvium which tended to form various types of rich freely draining floodplain soils (Anon, 1983). Large areas of landslip also occurred and these held varying soils; humic rankers, cambic stagnogleys and typical brown earths (Anon, 1983).

The occurrence of soils types within was compared against the range of soil types typical of upland oakwoods recorded within the British Plant Community Woodland Volume (Appendix 9.5) (Rodwell, 1991). In considering the range of soils on which upland oakwoods were known to occur it was considered that the drift geology categories of peat, alluvium and river terrace deposits would provide most useful input into the constraints mapping of woodland potential. These areas were considered to be unsuitable for upland oakwood development and were therefore removed from the GIS. The remaining areas of geology formed various types of acidic soils but it was felt the scale of mapping of the geology at 1:50,000 was too coarse to accurately predict the nature of soils from these, as formation would be affected at a fine scale by factors such as slope angle, aspect, and elevation. All such areas were therefore retained as suitable for woodland development.

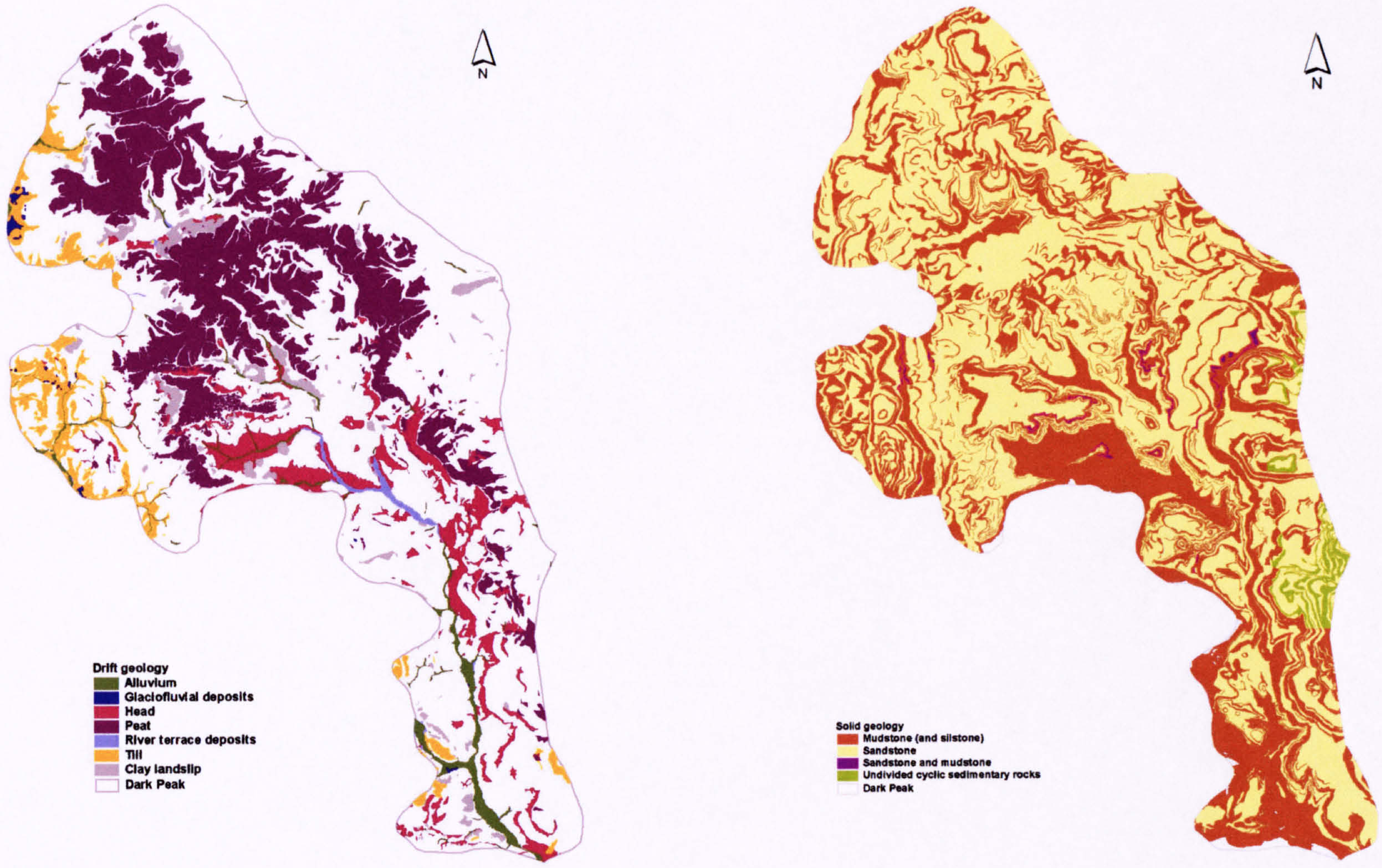


Figure 8.6
Dark Peak solid and drift geology. Reproduced by permission of the British Geological Survey. ©NERC. All rights reserved.

Table 8.5

Comparison of drift and solid geology against existing soils distribution mapping. (Soils survey = (Anon, 1983) : Natmap = (Anon, 2004)). The Natmap GIS soils survey was viewed within the PDNPA GIS.

Drift Geology	Solid Geology	Soils survey	Natmap soils
Peat	Sandstone and Mudstone	Peat	Blanket bog peat soils
Alluvium	Mudstone (and siltstone)	Typical brown alluvial soils (Withnell1)	Freely draining floodplain soils
Alluvium	Sandstone	Typical brown earths	Freely draining slightly acid loamy soils (Freely draining floodplain soils)
River terrace deposits	Mudstone (and siltstone)	Typical brown alluvial soils (Withnell1)	Freely draining floodplain soils
River terrace deposits	Sandstone	Ferric stagnopodzols and ironpan stagnopodzols	Very acid loamy upland soils with a wet peaty surface
Glaciofluvial deposits	Mudstone (and siltstone)	Cambic stagno-gleys and Pelo-stagnogleys soils	Slowly permeable seasonally wet acid loamy and clayey soils
Glaciofluvial deposits	Sandstone	Cambic stagno-gleys and Pelo-stagnogleys soils	Slowly permeable seasonally wet acid loamy and clayey soils
Head	Sandstone	Typical brown earths	Freely draining slightly acid loamy soils
Head	Mudstone (and siltstone)	Cambic stagno-gleys and Pelo-stagnogleys soils	Slowly permeable seasonally wet acid loamy and clayey soils (Very acid loamy upland soils with a wet peaty surface)
Head	Sandstone and mudstone	Ferric stagnopodzols and ironpan stagnopodzols	Very acid loamy upland soils with a wet peaty surface
Till	Mudstone (and siltstone)	Cambic stagno-gleys and Pelo-stagnogleys soils	Slowly permeable seasonally wet acid loamy and clayey soils
Till	Sandstone	Cambic stagno-gleys and Pelo-stagnogleys soils	Slowly permeable seasonally wet acid loamy and clayey soils
No drift geology	Mudstone (and siltstone)	Ferric stagnopodzols and ironpan stagnopodzols	Very acid loamy upland soils with a wet peaty surface
No drift geology	Sandstone	Typical brown earths	Freely draining slightly acid loamy soils (Very acid loamy upland soils with a wet peaty surface)
No drift geology	Sandstone and mudstone	Ferric stagnopodzols and ironpan stagnopodzols	Very acid loamy upland soils with a wet peaty surface

8.2.3 Landform assessment

Following an examination of the LDU, LCT and geology data it was considered that although informative in mapping areas of constraints to woodland conservation the level of detail captured was inadequate to enable an accurate examination of the wooded landscape. Methods were therefore investigated to more accurately characterise areas. Methods for the classification of landscape features were applied utilising the Topographic Position Index (TPI) (Jenness, 2005b). Subsequently more detailed analysis was undertaken that was more specifically related to the Dark Peak, based upon an examination of the key landscape elements of importance to woodland development and occurrence. These were elevation, slope and distance to watercourses.

8.2.3.1 Mapping landform using the Topographic Position Index

TPI analysis was used to classify slope position and landform. TPI was calculated on an examination of elevation values within an analysis neighbourhood around target grid cells. Central grid cells were classified by their relationship to the average elevation in the surrounding neighbourhood. By examining the TPI value in different cells information was gained on the relative position of cells above or below surrounding cells. TPI values can be calculated at different neighbourhood distances. A set neighbourhood size can be used to identify slope position. By calculating TPI values at two neighbourhood sizes the landscape can be classified into landform categories based on the relationship between classified slope position in each of the TPI grids (**Fig 8.7**). The ArcView TPI extension was used to calculate the values (Jenness, 2005b).

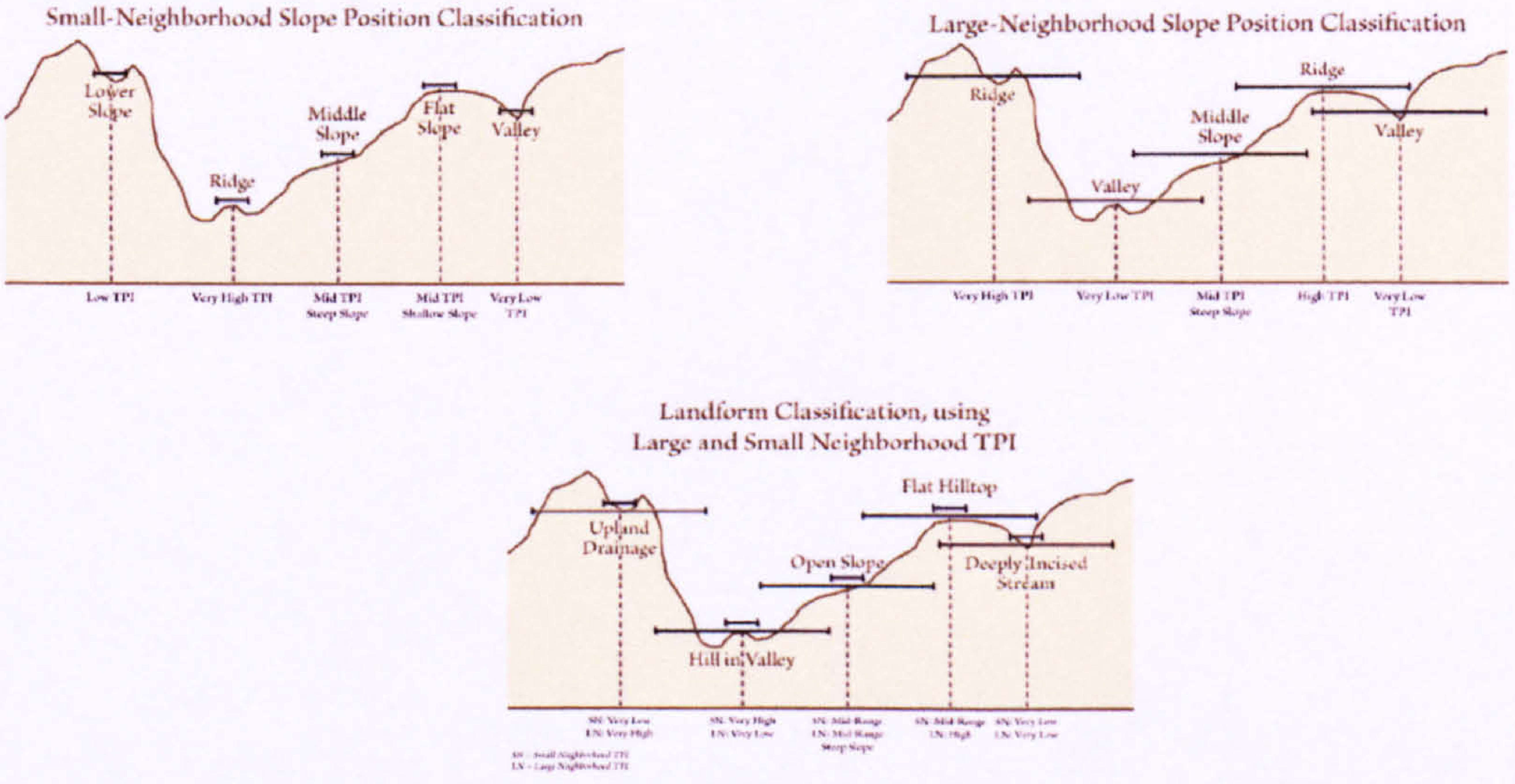


Figure 8.7
The classification of landform utilising two slope position Topographic Position Index (TPI) grids calculated at two cell neighbourhood sizes (reproduced from (Jenness, 2005b)).

Examinations were undertaken in a 6x6km case study area within the Upper Derwent valley in order to determine values for the two neighbourhoods. This area held examples of clough woodland and contained a range of topographic features typical of the Dark Peak. Analysis utilised a test area rather than calculating comparisons across the entire Dark Peak due to the extremely long calculation run times of the TPI slope position and landform analysis. Case study analysis runs were 30min for each neighbourhood size, while Dark Peak analysis took over 24 hours on a Pentium 3, 3 GHz, 2GB RAM. Slope position was calculated at neighbourhood sizes from 50m to 2km. The results of each analysis were compared against known topographic features and were used to determine two scales, one classifying minor moorland fringe and farmland stream cloughs and one enabling classification of the broad features occurring across the moors, characterised by upland plateaus, gritstone edges and wide rolling valleys. The neighbourhood scales selected were 150m and 1250m. These were subsequently used to create the Dark Peak landform classifications of the (**Fig 8.8, 8.9**).

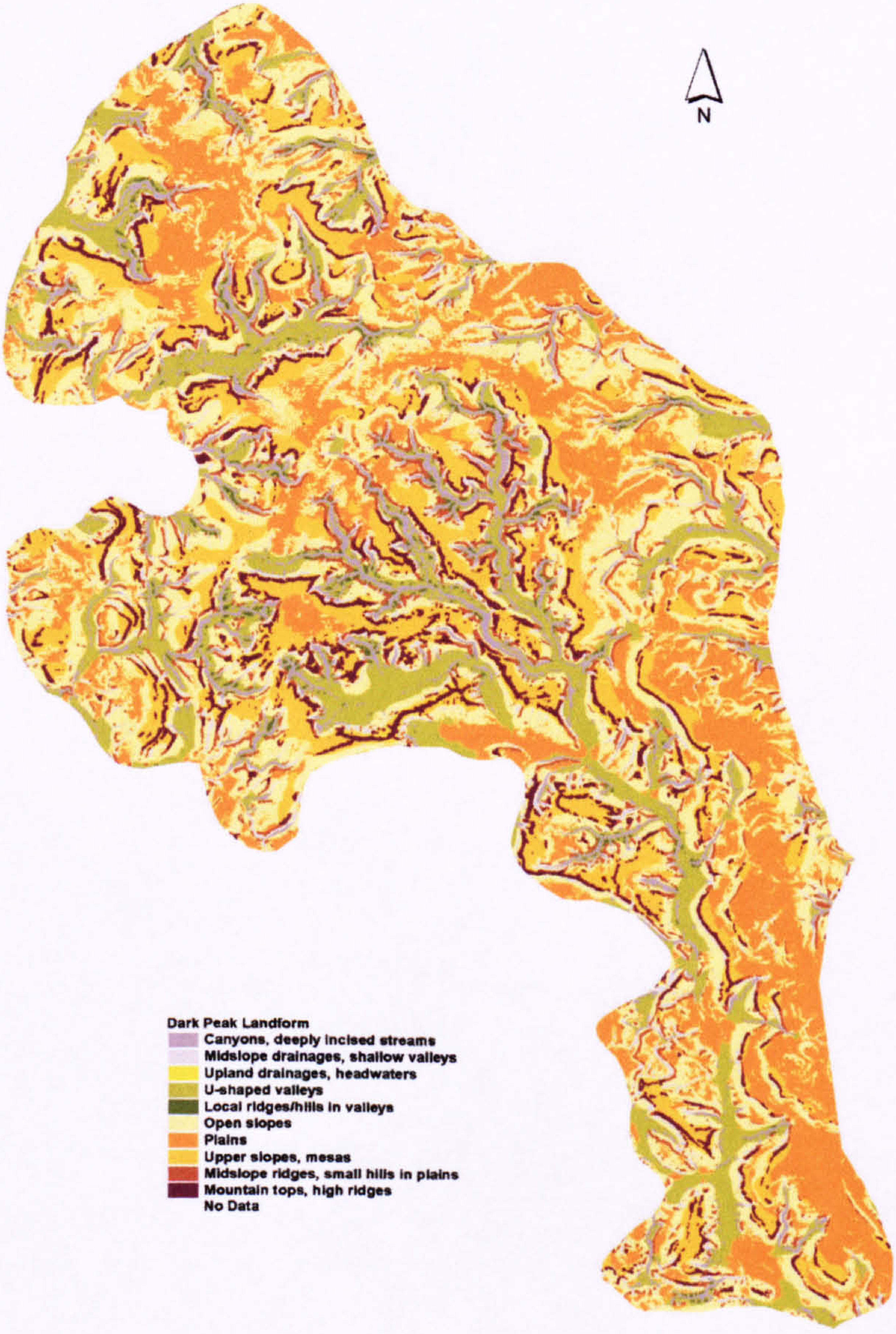


Figure 8.8
Landform classification of the Dark Peak based on TPI grids at 150m and 1250m.

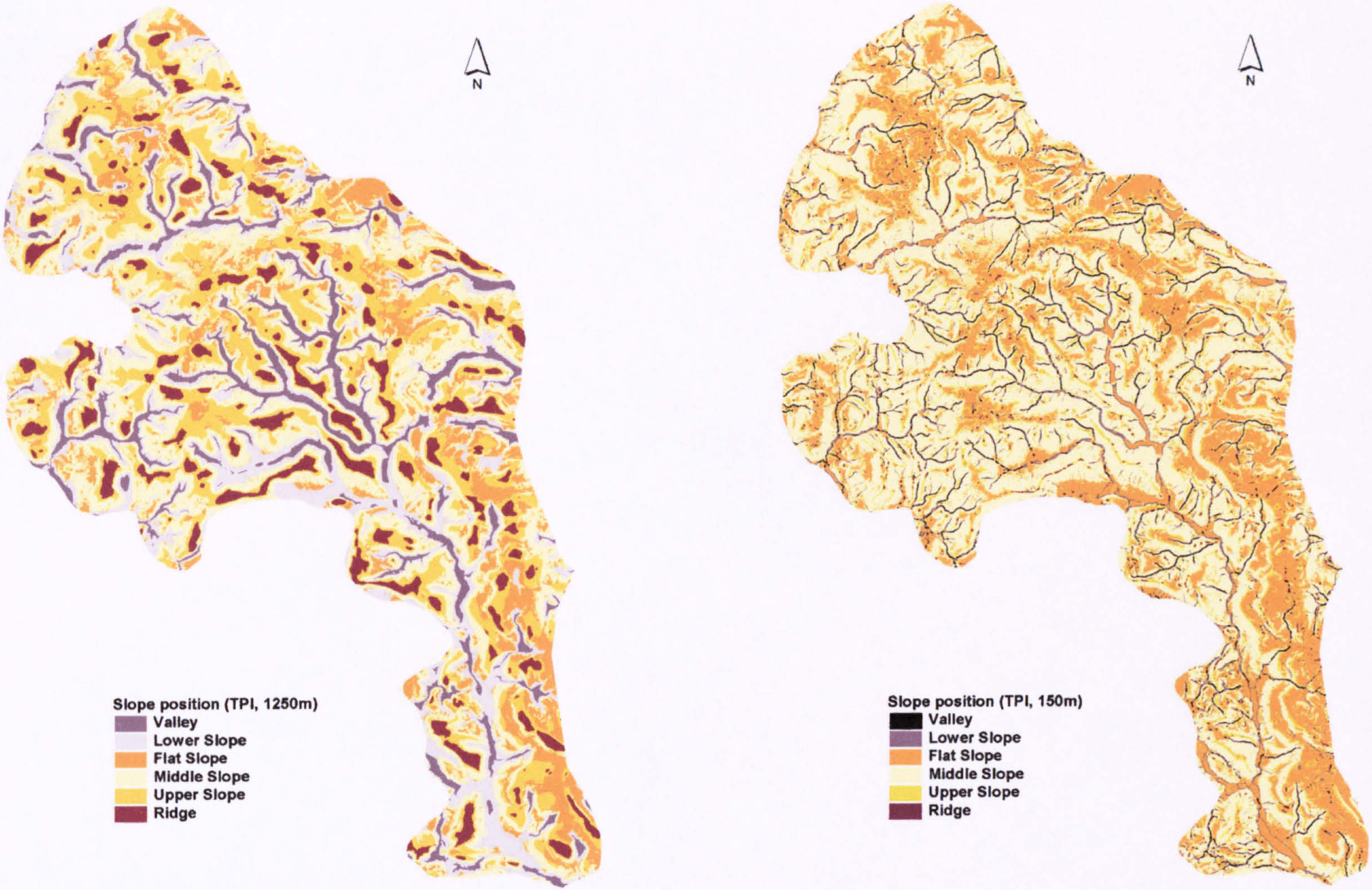


Figure 8.9
Slope position classifications of the Dark Peak based on Topographic Position Index (TPI) grids at 150m and 1250m.

8.2.3.2 "Clough" landform mapping

Following the examination of the landform identified by TPI analysis it was observed that while some broad zones e.g. the upland moorland plateau and broad valleys / cloughs were usefully and accurately classified, more distinction was required in the zones occurring immediately around valley / clough landscape features. Further analysis was undertaken to define landform positions around stream cloughs / steep slopes where woodland cover may be favourably encouraged. The landscape was examined in relation to the primary factors affecting woodland and clough topography occurrence: elevation, slope angle and distance to watercourses. The construction of these zones was based on two main data sources, a digital terrain model (DTM) and a stream network for the Dark Peak. By analysing the various combinations of data a number of well defined landscape elements were mapped.

Table 8.6
Classes used in the identification of landscape zones within the Dark Peak.

Altitude (m)		Slopes (degrees)		Distance to Watercourses (m)	
Very high uplands	> 550m	Very steep	25+	Streamside	0 – 50m
High uplands	400 – 550m	Steep	15 - 25	Close	50 –150m
Uplands	300 – 400m	Moderate	10 - 15	Far	150 – 300m
Upland fringe	200 – 300m	Gentle	5 -10	Ridges, slopes, plateaus	300+
Lowland	< 200m	Flat	0 - 5		

Landscape categories were defined to divide the landscape into zones, such as the 300m limit for uplands, the slope steepness classes of Bibby (1991) (defined by physical limitations to agriculture) and by examination of the relationship between current clough features and the stream network (Section 8.3.2). This created a classification system with 100 potential combinations, although not all combinations existed in the Dark Peak.

Initial processing using the Spatial Analyst Extension of ArcView GIS created a grid theme representing slopes. Although stream data was available within the OS Landline dataset initial analysis suggested a raster based representation of the stream network would be more useful than the vector based OS landline network. Options for utilising a raster stream network included the simple conversion of the vector data to raster format, or the creation of a new stream network dataset from the DTM using hydrological analysis (Hydrologic modelling v1.1). Although similar to the OS stream data already available in the GIS the creation of a stream network using hydrologic modelling held several advantages. The data were in grid format, which increased analysis speed and importantly did not include ponds, drains and minor moorland streams that may be misleading in later analysis. The raster stream network was created by landform modelling of water accumulation and flow across slopes and therefore tended to map valleys and cloughs that in reality may be dry. This was considered an advantage as this analysis allowed a variety of potential stream networks to be modelled and analysed separately.

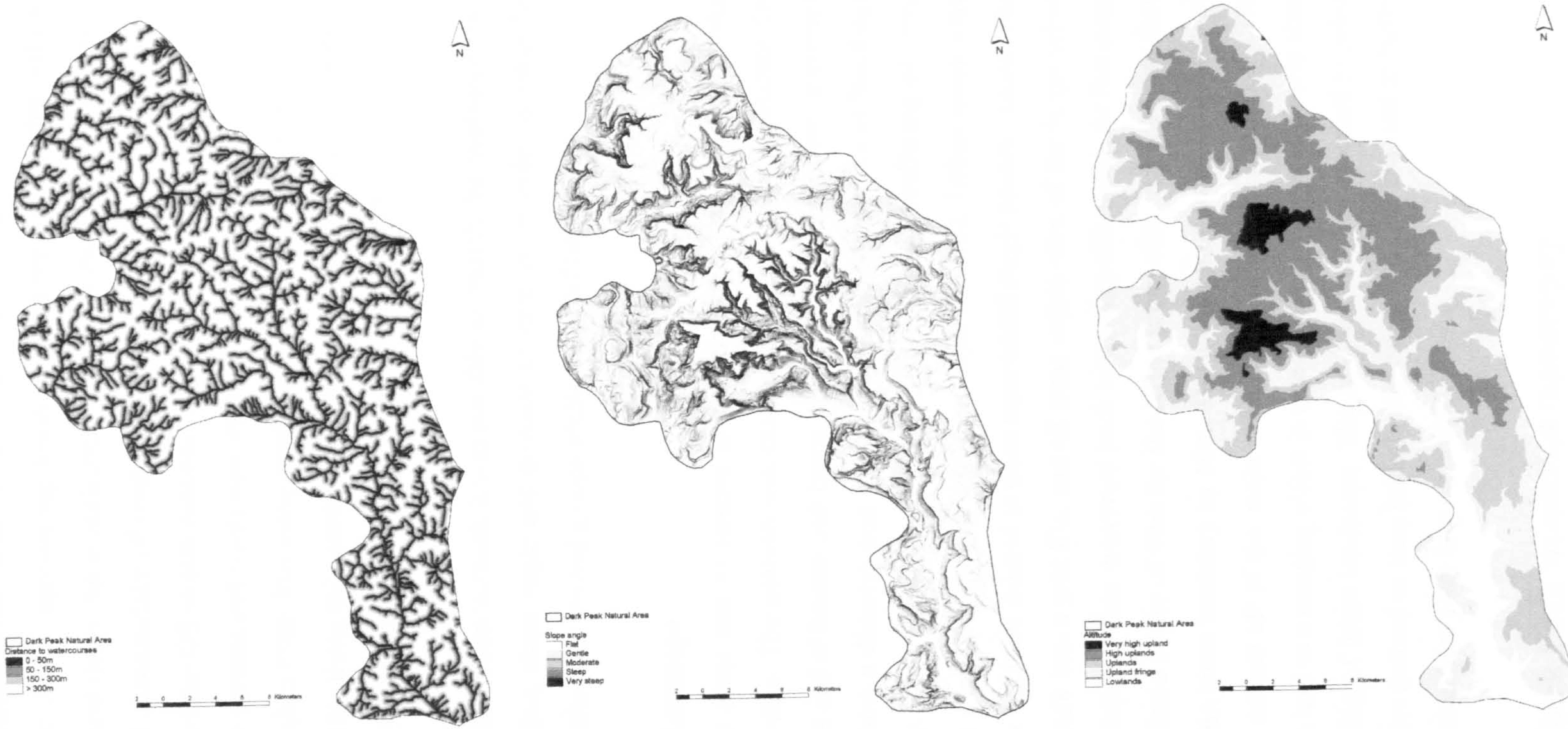


Figure 8.10
The three principal factors analysed in relation to woodland potential: Distance to watercourses, slope angle and elevation.

In order to create the raster stream network the Hydrology Modelling Extension of Spatial Analyst (Hydrologic modelling v1.1) was used to create a DTM without "sinks" following which flow direction and flow accumulation were calculated. The modelling produced a map of predicted Flow Accumulation. Stream networks can be defined by identifying a minimum flow accumulation rate, with smaller values representing lower order streams and higher values indicating higher order streams and rivers. An investigation of the Flow Accumulation map was carried out to determine a level characteristic of Dark Peak clough streams. Categories were compared within the GIS against the OS stream network to identify a level that corresponded closely, but where only the main streams and rivers were mapped within the larger cloughs. The value selected was cells greater than 1500. The many smaller drainage streams occurring on the moorland plateau were omitted by using this selection process. A distance data grid was then created which contained values representing the distance to this stream network.

Following the creation of the new stream network it was possible to classify the landscape into separate zones based on elevation, slope angle and distance to streams. In order to simplify analysis these values were classified into several groups within the GIS (Table 8.6).

8.2.4 The Dark Peak Urban Landscape

The aim of creating the urban areas was to remove larger areas of urban land from being classified as potential creation sites. The analysis was carried out in two stages to account for the identification of urban areas and of houses and farms. OS building features were converted to a raster grid (10m), from which a distance grid was created. Areas within 50m of buildings were selected and converted to a vector shapefile. This editing resulted in buffering of sites, such that adjacent urban areas / building merged and gaps were removed. Urban areas were analysed and areas smaller than 2ha were deleted as these represented single houses / farms. The shapefile was then converted back into a grid file, and all areas within 40m of the larger urban areas were selected. This selection was then converted back into a shapefile again. At this stage the urban areas had an accumulated buffer of 90m for the larger urban sites. A buffer was then created on the inside of the urban areas boundary by 60m. The overlapping areas were removed leaving a final buffer of 30m around all of the main urban areas within the Dark Peak. The effect of this processing was to lead to a merging effect in urban areas and between closely sited houses to create a broad mapping of urban landscape. The analysis was then repeated to select all the single and isolated houses defined as sites initially classified as below 2ha, and to buffer these by 20m. The two urban areas files were then combined.

8.3 Characterising Dark Peak woodland topography

Following the identification of zones mapping the Dark Peak, analysis was undertaken to examine "clough woodland" topography and identify areas suitable for woodland expansion and creation. Two areas were examined, a case study of known high quality clough woodland sites and potential restoration sites and a detailed analysis of the topographic features of the native woodland network.

8.3.1 Clough woodland case study sites

A case study was undertaken to examine the topographical position of high quality clough woodland sites. 11 semi-natural clough woodland sites were chosen within which to measure landscape characteristics. Although the term "clough" woodland was used to define the primary native woodland topography, several typical topographic locations of semi-natural woodland were identified within the Dark Peak. These locations were the Gritstone edges (slopes below broad landscape ridge features), Valleysides (extensive areas of valley slopes, one sided) and Cloughs (enclosed, steep and narrow two sided streamside valleys). Although all three types were common within the Environmentally Sensitive Area (ESA), outside the ESA simple clough and valleyside sites were the main potential woodland creation types.

To select case study sites the GIS data was used to select semi-natural woodlands were along with the cover of moorland habitats. The GIS was then used to select a range of sites that were either within / adjacent to moorland or distant from moorland. These were then termed upland and lowland cloughs. Features within the OS background mapping such as field boundaries were used to aid in this distinction. High quality examples of woodland in typical clough situations in each of these zones were selected by reference to the Ancient Woodland Inventory, SSSI or SBI.

GIS measurements were recorded at each site. These included mean, minimum, and maximum elevation of the upper and lower slopes, mean slope angle of upper mid and lower slopes, and the distance to the nearest stream from both upper and lower slopes. Measurements were made across the site if it was a valleyside site or a one sided clough, alternatively if the site spread across a whole clough / valley then measurements were always made from the central stream (if present) to the edges of the woodland on both sides. Distances were recorded perpendicular to the stream.

Table 8.7
Summary of clough woodland location case study measurements.

Measure	Upland clough		Lowland clough	
	Mean	Range	Mean	Range
Upper slope elevation / m	270	243-380	205	130-299
Lower slope elevation / m	218	148 - 377	194	121 – 252
Upper slope / degrees	23	9 – 40	17	1 - 33
Lower slope / degrees	9	6 - 15	9	1 - 20
Midslope / degrees	20	9 - 35	18	10 - 38
Upper slopes – distance to stream / m	282	48 - 925	114	23 - 227
Lower slopes – distance to stream / m	69	4 - 476	0	0

The case study clough sites generally occurred below 300m and exclusively below 400m in elevation. The sites occurred on generally relatively steep slopes (15 / 20 degrees) although the lower slopes of the woodland did extend onto more gentle slopes of below 10 degrees. The woodland occurred in relatively close proximity to watercourses, although a wide range of values was observed, especially in the upland sites. The distance to the upper limit of a wood from the central clough stream was generally less than 300m in upland sites and less than 120m in lowland sites.

8.3.2 Clough landscape zone woodland topography analysis

Following the Case Study examination the GIS was used to examine the topography on which all woodland cover existed within the Dark Peak by summarising grid values. The results are summarised in **Tables 8.8-8.14** and **Fig 8.11-8.12** under the class headings identified in **Table 8.6**. These results were produced from an analysis of 10m grid cell distribution of woodland in each zone, and reflect the actual areas of woodland occurring in each zone, not the distribution of whole woodland compartments or woodland sites. Examination of the semi-natural broadleaved woodland and all combined woodland cover among the landscape zones of elevation, slope angle and distance to watercourses revealed a number of trends (**Fig 8.11**). The majority of woodland cover exists in the 200m to 300m elevation zone with almost no native woodland occurring over 400m. A high percentage of semi-natural woodland occurred within 50m of the nearest watercourse and the majority within 150m. Areas of woodland cover are distributed among a range of slope angles, although rather less common on the extremely shallow and extremely steep slopes.

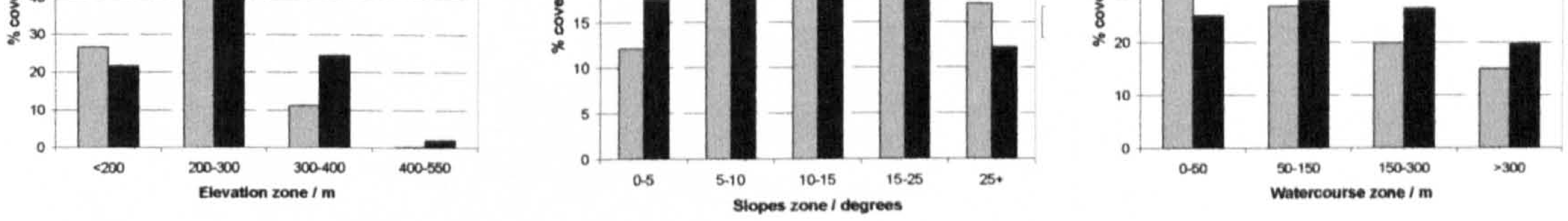


Figure 8.11
Area of semi-natural (grey) and all woodland (black) cover occurring within the mapped landscape zones.

When the mean values for the areas of woodland in each zone are compared against the other two landscape zones several trends emerge. The semi-natural woods tend to occur on steeper slopes as elevation increases. This effect is more pronounced for semi-natural woods than woodland as a whole. Within the first three elevation classes there appears to be a trend to increased distances from watercourses as elevation increases. For all the elevation zones the mean distance to watercourses is less than approx 200m. When woodland cover is examined within the distance to watercourses zones there appears to be little change between typical slope angles, except a slight reduction in slope of woods very distant from streams. The woods occurring in the zones more distant from streams tend to occur at higher elevations. When slope angle zones are examined the more extremely sloping areas of woods tend to occur at higher elevations, while the distance to watercourses from different slopes angles zones appears similar.

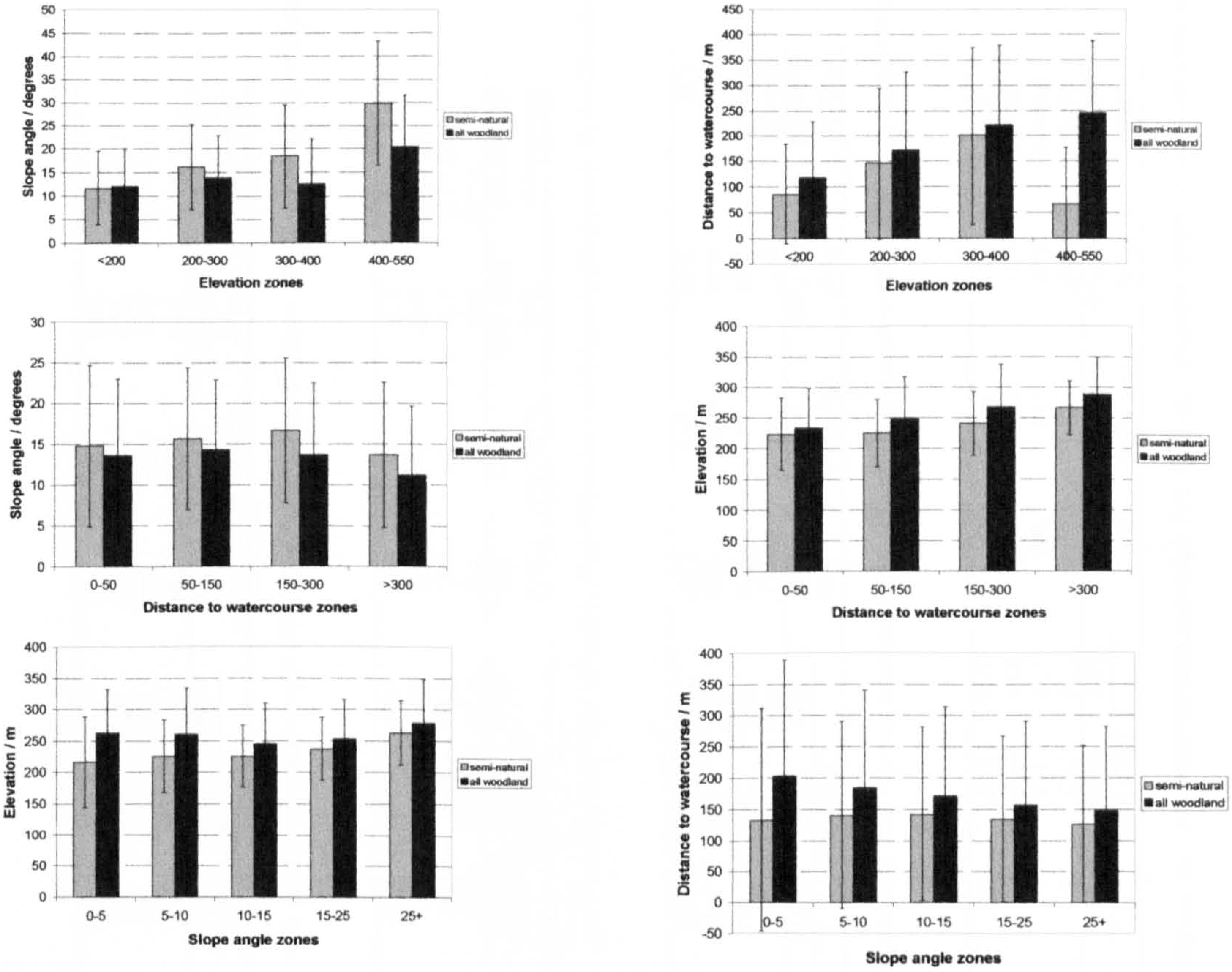


Figure 8.12
Cross comparison of the mean areas (+_ st dev) of woods occurring within the different landscape zones classes. Semi-natural (grey) and all woodland (black).

Table 8.8
Summarised characteristics for semi-natural woodland sites occurring within each main elevation zone. (No woodlands were recorded in the elevation zone above 550m).

Altitude	% of	% of wood	Area	Slope (deg)			Elevation (m)			Distance to watercourse (m)		
Zone (m)	Dark Peak	cover	(ha)	Max	Mean	St dev	Max	Mean	St dev	Max	Mean	St dev
400-550	0.005	0.2	4	57.6	29.9	13.4	494	444.8	27.6	396	68	109
300-400	0.24	11.3	208	57.3	18.5	11.1	399	321.1	20.0	742	201	174
200-300	1.31	61.8	1139	53.4	16.2	9.1	299	249.4	27.5	772	146	148
<200	0.57	26.7	493	57.2	11.7	7.8	199	161.6	27.6	534	87	97

Table 8.9
Summarised characteristics for all established woodland sites occurring within each main elevation zone. (No woodlands were recorded in the elevation zone above 550m).

Altitude	% of	% of wood	Area	Slope (deg)			Elevation (m)			Distance to watercourse (m)		
Zone (m)	Dark Peak	cover	(ha)	Max	Mean	St dev	Max	Mean	St dev	Max	Mean	St dev
400-550	0.17	2.0	144	57.6	20.4	11.2	507	425.9	22.7	751	246	142
300-400	2.08	24.5	1798	57.3	12.7	9.4	400	337.4	27.3	804	222	158
200-300	4.39	51.8	3804	53.4	13.9	8.9	300	253.9	28.5	847	172	155
<200	1.84	21.7	1597	57.2	12.2	7.8	200	164.4	26.1	583	118	111

Table 8.10
Summarised characteristics for semi-natural woodland sites occurring within each main watercourse distance zone.

Watercourse	% of	% of wood	Area	Slope (deg)			Elevation (m)			Distance to watercourse (m)		
distance (m)	Dark Peak	cover	(ha)	Max	Mean	St dev	Max	Mean	St dev	Max	Mean	St dev
0 - 50	0.83	39	716	57.6	14.8	9.9	494	224	59	49	19	15
50 - 150	0.57	27	492	52.5	15.7	8.7	488	226	55	150	93	29
150 - 300	0.42	20	365	57.3	16.7	8.9	470	241	52	300	216	43
> 300	0.31	15	270	53.6	13.7	8.9	420	267	44	772	417	85

Table 8.11
Summarised characteristics for all established woodland sites occurring within each main watercourse distance zone.

Watercourse	% of	% of wood	Area	Slope (deg)			Elevation (m)			Distance to watercourse (m)		
distance (m)	Dark Peak	cover	(ha)	Max	Mean	St dev	Max	Mean	St dev	Max	Mean	St dev
0 - 50	2.15	25.2	1859	57.6	13.6	9.4	494	234.0	64.8	50	21	15
50 - 150	2.41	28.3	2084	53.9	14.3	8.6	488	250.1	67.1	150	96	29
150 - 300	2.26	26.6	1956	57.3	13.7	8.8	506	267.6	70.1	300	218	43
> 300	1.69	19.9	1464	53.6	11.2	8.4	507	287.9	61.8	847	421	100

Table 8.12

Distance to watercourse values for broadleaved semi-natural woodland sites within 7 distance classes.

Watercourse distance (m)	Area (ha)	% of Dark Peak	% of wood cover	Cumulative % wood cover	Mean	Std
0 - 50	716.5	0.83	38.9	38.9	18.6	14.5
50 - 100	298.0	0.34	16.2	55.0	73.1	14.6
100 - 200	346.3	0.40	18.8	73.8	145.9	28.7
200 - 300	212.9	0.25	11.5	85.4	246.4	28.6
300 - 400	132.7	0.15	7.2	92.6	346.7	28.7
400 - 500	86.9	0.10	4.7	97.3	446.1	28.3
500 - 1000	50.4	0.06	2.7	100.0	554.5	44.6

Table 8.13
Summarised characteristics for semi-natural woodland sites occurring within each main slope class zone.

Slope class	% of	% of wood	Area	Slope (deg)			Elevation (m)			Distance to watercourse (m)		
(deg)	Dark Peak	cover	(ha)	Max	Mean	St dev	Max	Mean	St dev	Max	Mean	St dev
0 - 5	0.26	12.1	222.7	4.5	2.4	1.5	419	216.3	72.2	731.5	133.0	178.5
5 - 10	0.45	21.2	390.6	9.9	7.4	1.5	491	225.8	57.7	724.7	140.6	149.5
10 - 15	0.45	21.2	390.7	15.0	12.4	1.5	493	225.7	49.2	703.7	142.5	139.0
15 - 25	0.61	28.4	524.0	24.9	19.6	2.9	494	237.6	49.7	770.0	135.0	133.0
25+	0.36	17.1	315.8	57.6	30.6	4.5	493	263.4	51.1	771.6	126.3	125.9

Table 8.14
Summarised characteristics for all established woodland sites occurring within each main slope class zone.

Slope class	% of	% of wood	Area	Slope (deg)			Elevation (m)			Distance to watercourse (m)		
(deg)	Dark Peak	cover	(ha)	Max	Mean	St dev	Max	Mean	St dev	Max	Mean	St dev
0 - 5	1.49	17.6	1293.1	4.5	2.4	1.5	480	262.7	70.6	846.6	203.8	185.4
5 - 10	2.09	24.6	1808.9	9.9	7.2	1.5	501	260.6	73.7	828.1	184.8	155.7
10 - 15	1.69	19.9	1462.9	15.0	12.4	1.5	506	245.4	65.0	770.0	171.8	142.1
15 - 25	2.19	25.7	1894.0	24.9	19.5	2.8	507	253.1	62.6	770.0	156.9	133.4
25+	1.04	12.3	904.0	57.6	30.0	4.1	502	278.5	70.7	771.6	149.9	131.7

8.4 Identifying suitable locations for woodland conservation, restoration or creation

Following the analysis of topographic features typical of native woodlands, the Dark Peak landscape was considered in relation to areas representing opportunities or constraints for woodland conservation. In particular the depiction of clough and moorland plateau landform features were examined. The areas of land representing these features were considered against known examples of such landforms before the final areas suitable for woodland conservation were mapped.

8.4.1 Classifying Dark Peak landforms by woodland conservation potential

Each of the ten landform classes derived from the TPI analysis (Section 8.2.3.1) was examined in four test areas, in order to determine the potential for woodland restoration or creation. Two test areas were located in upland situations to the north of the Dark Peak (Kinder/Hayfield, Longdendale valley) and two in more lowland fringe situations to the south (Two Dales, Clough woods SSSI). Each category was classified from an examination of the current distribution of clough woodland in each area, and an assessment of the accuracy of the landform classification by comparison to existing OS background feature mapping (Table 8.15). The principal features examined were the classification of the moorland plateau and clough landscape zones. Broad landform categories characteristic of the upland moorland plateau areas were considered to be unfavourable for woodland conservation and development, while areas of steeply sloping cloughs were considered favourable.

Table 8.15
Analysis of the woodland development potential of the Dark Peak landscape classified into 10 landform categories.

Landform category	Woodland potential	Area (ha)	% of Dark Peak
Canyons, deeply incised streams	Opportunity	5,329	6
Upper slopes, mesas	Constraint	12,009	14
Mountain tops, high ridges	Constraint	3,637	4
Plains	Constraint	19,811	23
Midslope drainages, shallow valleys	Mixed	3,330	4
Midslope ridges, small hills in plains	Mixed	4,868	6
Upland drainages, headwaters	Mixed	233	0.3
Local ridges/hills in valleys	Mixed	678	0.8
U-shaped valleys	Mixed	10,336	12
Open slopes	Mixed	26,372	30

The classification revealed one landform category representing suitable positions for woodland development and three categories characteristic of the upper moorland plateau and upper "edges" of the Dark Peak, representing constraints to woodland cover. However several landform classes were considered to hold mixed potential or constraints to woodland development (Table 8.15). These areas included slopes or minor valleys near to cloughs where woodland may currently, or could potentially occur. Therefore it was considered that further analysis was required of these detailed zones.

8.4.2 Identifying clough woodland landscape position

The information gained within the cloughs case study (Section 8.3.1) and the analysis of native woodland topography (Section 8.3.2) was combined to examine the potential range of landscape zones identified in Table 8.6 and consider the potential within each zone for promoting woodland creation or expansion. Altitude was considered in relation to both historic and current limitations of woodland cover. Degree of slope was considered in relation to case study sites, existing limits and characteristics of woodland cover and the limitation that slopes place on potential for conversion of sites to agriculture. The Land Capability Classification for agriculture noted 15 degrees represented the limit of activity for 2 wheel drive tractors with fully mounted equipment, while 25 degrees was considered steeply sloping and the limit of activity for 4 wheel drive tractors with trailed equipment (Bibby et al., 1991). These values indicate land likely to have been agriculturally improved or cultivated in the past. Areas steeper than these slope categories were unlikely to have been improved and therefore to hold unimproved habitats such as unimproved grassland, bracken, heathland, woodland or scrub habitats. Altitude zones were the main initial consideration for woodland conservation / creation suitability. For each of the 5 altitude classes consideration was given to the likely location of suitable positions for woodland conservation. Within each altitude zone an assessment was made of landscape character and likely positions in which woodland creation opportunities occurred. This was achieved by examining typical clough locations in the case studies, and by converting these into combinations of landscape features. The altitudinal zones were utilized as the primary classification of the landscape as this factor had a major effect on the general form of the landscape and on the principal land-use. Following this initial assessment each combination of landscape features was examined and used to label each detailed zone as an opportunity or constraint to woodland conservation / creation. The results of this analysis were:

Very high upland (above 550m) This broad altitude zone was characterised by areas of moorland plateau and slopes. The extent of the zone was relatively restricted and these areas occurred beyond even historical limits of woodland within the Dark Peak and were considered unsuitable for woodland.

High uplands (400m to 550m) This zone largely consisted of rolling blanket moor with fringes of unimproved acid grassland. The opportunities for woodland were limited, and only occurred where sites could extend out from woods in the zone below (e.g. along narrow, steep sided cloughs). No large areas of sloping land beyond cloughs were considered opportunities. Many of the more gently sloping sites already held areas of existing conservation interest. Therefore only the main, steeply sloping cloughs were considered suitable for woodland creation.

Uplands (300m to 400m) This zone typically held areas of steeply sloping ground around the fringes of the main moorland plateau but also comprised moorland plateau areas to the south of the natural area. This was a principal altitude zone considered suitable for clough woodland creation or expansion, and currently held low covers of native woodland. In this area the main opportunities occurred along steep-sided cloughs. Areas of steeply sloping land away from streamsides were generally less suitable as they were often part of larger expanses of valleyside or slope, rather than cloughs. However in addition to the main areas of steep slopes in this zone it was considered important to retain areas of gentler slopes that formed part of continuous larger clough valleys. Therefore once the main "core" clough areas had been identified, additional slopes were also selected where these occurred adjacent to the core cloughs, these often formed the lower sequences of the slope transitions. Thus while in the majority of cases slopes less than 15 degrees were not considered suitable for woodland development, these slopes were selected where they occupied part of larger cloughs.

Upland fringe (200m to 300m) This zone comprised areas of steeply sloping land within the main valleys and cloughs around the fringes of the moorland plateau and areas of gentle slopes to the south of the Natural Area. This zone was considered suitable for woodland development. Opportunities occurred in steep sided cloughs, but also along slopes further away from streams, such as along gritstone "edges", where rock outcrops occurred, especially where bracken beds were present. In contrast to higher altitudes, these were considered opportunities. These areas were selected by locating gentle slopes that occurred close to steep slopes. In other areas where gentle slopes occurred away from streams or areas of steep slopes, these were not considered suitable for woodland cover. In this more lowland landscape such areas were likely to be farmland, heath, unimproved acid grassland or be prominent in the landscape, and therefore were not prioritised. Opportunities more than 300m from streams were considered to be limited.

Lowlands (less than 200m) This zone was largely agricultural, most gently sloping being improved, including areas along floodplains. The main opportunities for wood creation lay within the narrower, steeply sloping cloughs and streamsides. Opportunities also occurred in areas of more steeply sloping ground away from stream edges, although the steepness of slope required to have avoided historical agricultural improvement within this zone was considered to be greater than higher elevation zones due to the intensity of land-use here. The potential conflict with areas of remaining conservation interest preventing woodland expansion is likely to be higher in this zone due to the scarcer covers of semi-natural habitats, and the higher local importance of the remaining areas.

These assessments, were used to guide the classification of the 100 detailed zones. In practice zones were selected and classified in groups, but where further clarification was required a zone was observed within the GIS and the distribution compared against known woodland sites, and known potential woodland sites. Using this classification system large areas of land were easily classified, such as lowland floodplains and moorland plateau. However several zones were problematical in their consideration for woodland potential. Therefore three final classes of landscape position were defined by suitability for woodland cover:

- "Core" clough areas: steeply sloping cloughs (>15 degrees), generally within 150m of the nearest stream (Table 8.16).
- "Additional slopes": considered suitable only where they occurred adjacent to core cloughs, where these formed the upper or lower slopes of broader cloughs. Characterised by more gentle slopes than the core cloughs, extending further from streams (Table 8.17).
- "Bracken / low conservation interest slopes": steep or moderately sloping land at further from streams / watercourses. Holds potential when occurring as part of a continuum from cloughs and, at lower elevations, in situations further away from streams along gritstone edges. Typically only considered suitable where appropriate pre-cursor habitats present comprising low conservation interest grassland, bracken or scrub. These areas avoided choosing inappropriate areas of more gentle slopes that may be mainly isolated from other slope features / cloughs (Table 8.18).

Table 8.16
Core clough zones

Altitude		Slopes		Distance to streams	
High uplands	>400 < 550	Very steep	25+	Streamside	0 – 50
		Very steep	25 +	Close	50 - 150
Uplands	300-400	Very steep	25 +	Streamside	0 – 50
		Very steep	25 +	Close	50 – 150
		Steep	15-25	Streamside	0 - 50
Upland fringe	200–300	Very steep	25+	All distances	All distances
		Steep	15-25	Streamside	0 - 50
		Steep	15-25	Close	50 – 150
Lowland	<200	Very steep	25+	All distances	All distances
		Steep	15-25	Streamside	0 - 50

Table 8.17
Additional slopes zone

Altitude		Slopes		Distance to streams		Core cloughs proximity	
High uplands	400-550	Very steep	25+	All distances	All distances	Moderate	0-150
		Steep	15-25	Close	0-100	Close	0-50
		Moderate	10-15	Streamside	0-50	Close	0-50
Uplands	300-400	Steep	15-25	Close	0-150	Moderate	0-100
		Steep	15-25	Far	150 +	Moderate	0-150
		Moderate	10-15	Streamside	0-50	Moderate	0-100
		Moderate	10-15	Close	50-100	Close	0-50
		Gentle	5-10	Streamside	0-50	Close	0-25
Upland fringe	200-300	Steep	15-25	Far	150 +	Moderate	0-100
		Moderate	10-15	Streamside	0-50	Moderate	0-100
		Moderate	10-15	Close	50-150	Close	0-50
		Gentle	5-10	Close	0-150	Close	0-50
Lowland	<200	Steep	15-25	Close	50-150	Moderate	0-100
		Steep	15-25	Far	150 +	Moderate	0-75
		Moderate	10-15	Streamside	0-50	Moderate	0-100
		Moderate	10-15	Close	50-150	Close	0-50

Table 8.18
Bracken / low conservation interest zone

Altitude		Slopes		Distance to streams
Uplands	300-400	Steep	15-25	All distances
		Moderate	10-15	All distances
Upland fringe	200-300	Steep	15-25	All distances
		Moderate	10-15	All distances
Lowland	<200	Steep	15-25	All distances

From examining the combinations of landscape classes, 14 were considered to form "core cloughs", 18 formed "additional slopes near core cloughs", while five classes formed the additional, low conservation interest slopes. When the final landscape zones had been defined the map calculator function of Spatial Analyst was used to create a grid (10m) representing the final selection of landscape features within the GIS. The combined core clough area and additional adjacent slopes zones occupied almost 5,500 ha and 16% of the Dark Peak (**Table 9.18**).

Table 8.19
Areas identified by the defined landscape zones with potential for woodland cover.

Landscape zone	Area (ha)	% Dark Peak
Core cloughs	5,465	6
Additional slopes near cloughs	8,867	10
Additional slopes if bracken dominated	8,043	9
Total	22,375	25

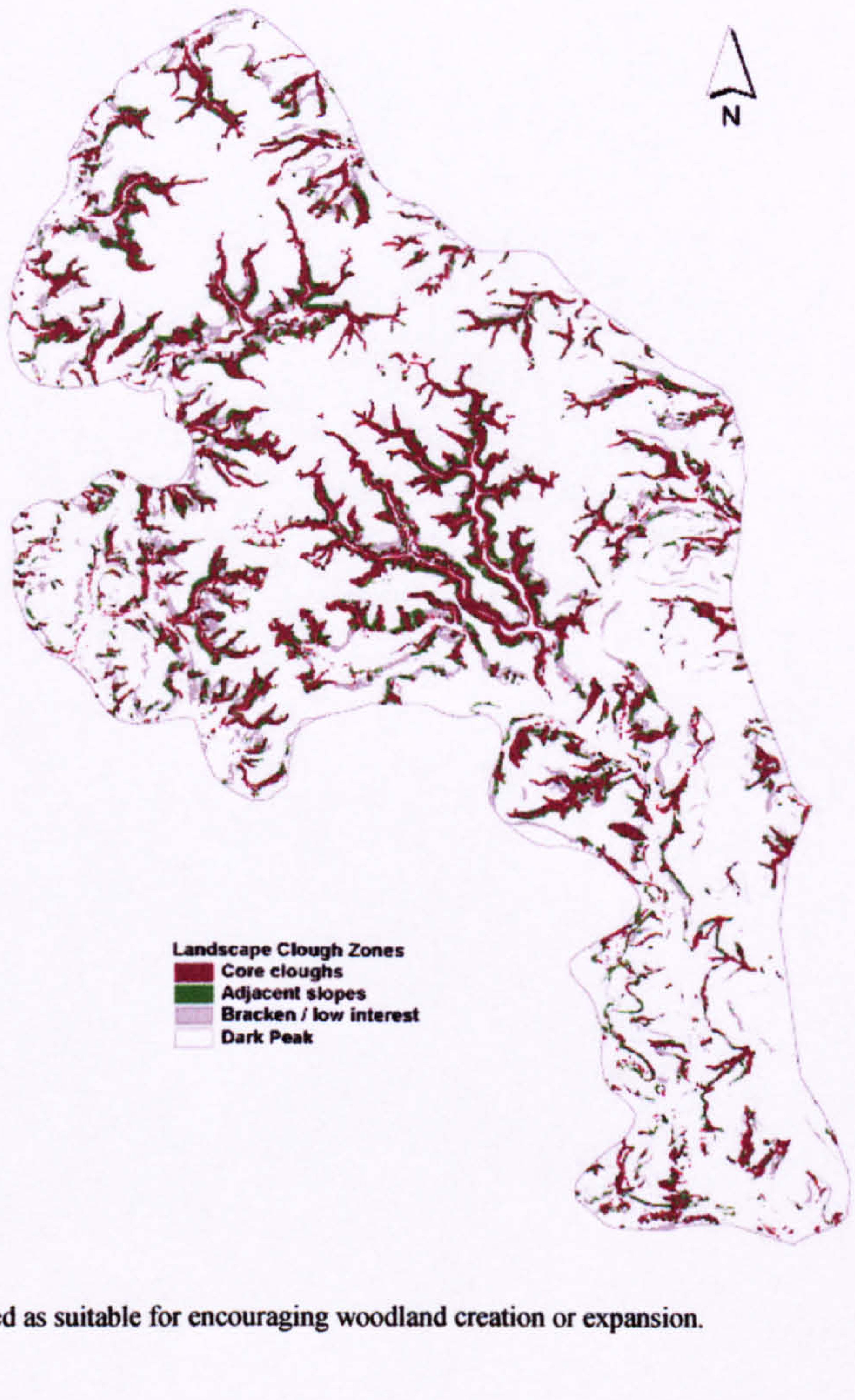


Figure 8.13
Areas provisionally identified as suitable for encouraging woodland creation or expansion.

8.4.3 Combining broad landform and detailed clough opportunity areas

Following the separate analysis in 8.4.1 and 8.4.2 several areas had been identified representing opportunities or constraints to woodland conservation. Analysis was undertaken to combine the mapped areas from these two methods, while work was also undertaken to smooth the resulting file and to remove small gaps resulting from the raster creation methods (Appendix 8.3). This analysis produced a new 3 category cloughs file with core cloughs, adjacent slopes and bracken only areas with all categories having been edited and smoothed, and buffered to create simplified landscape zones. In the final stage of the analysis all areas identified as constraints from the TPI, urban landscape and geology analysis were removed from the classified clough maps. Within this analysis small, sub 0.2ha areas, of TPI constraints were removed. The geology constraints occurred in larger polygon units and were not edited prior to removal. The resultant sites were then converted back to a grid at 4m cell resolution. Once the final suitability grids were created final slivers editing was undertaken to remove small slivers and areas of clough that occurred away from other clough areas. Detached and isolated clough areas less than 0.1ha were removed.

Table 8.20
Clough zone areas following buffering and editing to smooth zone boundaries and remove slivers

Zone	Area (ha)	%
Core cloughs	10,140	12
Additional slopes	4,798	5
Bracken	6,026	7
Total	20,964	24

8.5 Identifying suitable pre-cursor woodland habitats

Following the final classification of the woodland conservation landscape zones the distribution of existing habitats was considered in relation to their suitability for restoration or conversion to native woodland and for woodland creation. The GIS was used to classify habitats for which it was known woodland creation would not be permitted, due to existing ecological interest. During initial consideration however, it was determined there were also habitats which may or may not be suitable for creation / restoration depending on their topographical or landscape position. Therefore the habitats of the Dark Peak were classified into three categories: Opportunity, Constraint and Dependent.

Table 8.21
Classification of Dark Peak habitats by potential for woodland creation

Constraint	Opportunity	Dependent
High value habitats not available for woodland development	Low ecological interest, or habitats with high potential for woodland development	Habitats that may be constraints or opportunities depending on either their level of ecological quality or topographical location

Existing guidelines on woodland creation and restoration, combined with the results of the literature review were used to classify habitats (Table 8.22). The range of features affecting the habitats considered to be classed as "dependent" were then examined (Table 8.23). These were considered to be affected by three factors: topographical location, habitat quality and physical proximity to other habitats. The ability to define these factors within the GIS was then considered. The major factors associated with habitat topography were a distinction between habitats occurring on the moorland plateau and moorland fringe slopes or within valley side cloughs. Major habitat quality considerations were an avoidance of converting existing high quality habitats into woodland where this would lead to an overall loss of ecological interest. The major location considerations were the prioritisation of sites close to existing woodlands or where conversion would lead to linkage or buffering. These areas were then addressed within the GIS methodology. The topography factors were addressed by carrying out a broad landscape character assessment of the Dark Peak to divide the landscape into identifiable zones based on topography and local landform / landscape character. Many of the dependent habitats were considered constraints where they occurred on the open moorland plateau but may be opportunities if occurring on cloughs or steep slopes. These areas were classified from dependant to opportunity where they occurred within "cloughs and valleys". The habitat quality of sites was addressed by an examination within the GIS of the current designation of habitat within SSSI or SBI's. However it was considered that the accuracy and ability of planning within a GIS in relation to current habitat quality rather than location was problematical. It was therefore recognised that additional assessment of the potential quality of proposed restoration or creation sites would have to be considered when final sites were prioritised (Chapter 11). The final factor, position within an ecological landscape, will be addressed during a scoring assessment within the GIS that considers the composition and structure of the habitats around a potential restoration site (Chapter 11).

Table 8.22
Locations and habitats considered by potential for woodland creation, summarised from Peak District National Park Authority Ecology Service guidelines (PDNPA; File A5538) combined with the results of the initial project questionnaire.

Constraints	GIS Considerations
Slopes below gritstone edges with high quality heather/bilberry moorland	Steep slopes near ridges. High quality sites may be identified from designations, but are difficult to determine from within GIS
Species-rich grassland	Semi-improved or unimproved grassland of known ecological interest. Quality may be inferred by site designations
Wetlands / marshes / rush pastures	Wetland and marshy grassland habitats, further identification in areas lacking detailed habitat data may be possible from analysis of soils or hydrologic data

Opportunity	GIS Considerations
Cloughs with scattered trees / shrubs	Scattered trees or scrub habitat occurring on sloping land in close proximity to watercourses
Enclosed farmland of low ecological value e.g. bracken, stream gullies, species poor semi-improved grassland	Land adjacent to streams, Bracken banks in lowland areas, Semi-improved acid grassland and Semi-improved neutral grassland
Improved grassland – only considered to be of real value where buffering or linking existing sites	Improved grassland, within a close distance of existing woodland sites
Sites adjacent to existing semi-natural woodland (especially where linking such sites)	Land within a set distance of semi-natural woodland.
Slopes below gritstone edges with bracken or scattered trees / scrub	Sloping land close to ridge features with bracken or scrub
Rough grazing land on valleysides – only considered suitable if strong benefits would occur e.g. linking cloughs, or comprising part of woodland extending from valley floor to moorland edge	Acid grassland on moderate to steep slopes, more than a set distance from streams but close to existing woodlands or if part of a large area of potential woodland creation
Valley bottom pasture, adjacent to rivers (e.g. for wet woodland)	Grassland on gently sloping land close to streams
Bracken in cloughs or slopes where recently wooded or near semi-natural woodland (not bracken on moorland)	Bracken not occurring on moorland areas
Species-poor grasslands (enclosed or rough grazing, but areas of extensive open grass moor should generally be retained)	Large open moorland edge acid grassland sites not appropriate

Table 8.23
The initial classification of polygons as Opportunity / Constraints / Dependant. C = constraints, O = Opportunity, D = Dependant

Phase 1 code	Phase 1 Habitat classification (or ESA derived class)	Category
A111	Broad leaved semi-natural woodland	C
A112	Broad leaved plantation	O
A122	Coniferous plantation	O
A131	Mixed semi-natural woodland	O
A132	Mixed plantation	O
A2	Scrub	O
A4	Recently felled woodland	O
A3	Scattered trees	O
B11	Unimproved acid grassland	D
B12	Semi-improved acid grassland	D
B21	(Neutral grassland, unimproved)	D
B22	Semi-improved neutral grassland	D
B22 rough	Semi-improved neutral rough pasture	D
B2x/B4	Semi-improved or improved grassland	D
B5	Juncus dominated marshy grassland	D
B5 / E17	Molinia dominated grassland	D
C11	Continuous bracken	D
D11	Dwarf shrub heath	D
D2	Wet dwarf shrub heath	C
D6	(Wet heath / acid grass)	D
E161 / E17	(Wet bog)	C
E18	Dry bog / Cottongrass moorland	C
E21	(Acid flush)	C
E4	(Bare peat) / (Eroding moorland)	C
G	(Open water)	C
I11	(Cliff)	D
I12	(Scree)	D
I21	(Quarry)	D
J11, J12	(Short term ley / Arable), (Amenity grassland)	D
J14	(Introduced shrub)	C
J3	(Urban)	C
J4	(Bare ground)	D

Table 8.24

An examination of the features relevant to classifying dependant habitats as either opportunity or constraint, defined as topography, habitat quality or landscape / location factors.

Habitat Phase 1	Topography factors		Habitat Quality	Landscape Opportunity factors
	Opportunity	Constraint	Constraints	Opportunity
Broadleaved woodland, plantation	Cloughs	Moorland / gentle slopes	None	Adjacent to semi-natural woodland
Coniferous woodland, plantation	Cloughs,	Moorland / gentle slopes.	None	Adjacent to semi-natural woodland
Mixed woodland, plantation	Cloughs,	Moorland / gentle slopes	None	Adjacent to semi-natural woodland
Unimproved acid grassland		Moorland / gentle slopes	Species rich / bird habitat	Adjacent to semi-natural woodland
Neutral grassland	None		Species rich / bird habitat	Adjacent to semi-natural woodland.
Marshy grassland		Moorland / gentle slopes	Species rich / bird habitat	Adjacent to semi-natural woodland.
Improved grassland	None		None	Adjacent to semi-natural woodland or linking sites
Marshy grassland / Wet bog		Moorland / gentle slopes	Species rich / bird habitat	Adjacent to semi-natural woodland.
Bracken, continuous		Moorland plateau	Bird habitat interest	Adjacent to semi-natural woodland.
Dry dwarf shrub heath	Cloughs, steep slopes	Moorland plateau	High quality habitat	Adjacent to semi-natural woodland
Wet heath / acid grassland mosaic	Cloughs, steep slopes	Moorland plateau	High quality habitat	Adjacent to semi-natural woodland.
Cliff		Moorland plateau		Adjacent to semi-natural woodland.
Scree		Moorland plateau		Adjacent to semi-natural woodland., or part of large restoration area
Quarry		Moorland plateau	High current interest, e.g. birds	
Arable / short term ley grassland				Adjacent to semi-natural woodland, part of larger sites or linking woods
Amenity grassland				Adjacent to semi-natural woodland, part of larger sites or linking woods
Bare ground		Moorland plateau		Adjacent to semi-natural woodland, part of larger sites or linking woods

8.6 Classifying potential woodland conservation, restoration and creation zones

Following the analysis of topography in 8.4 and identification of pre-cursor habitats in 8.5 a final analysis of suitable areas classified by habitat and landform was undertaken. The woodland GIS created in Chapter 7 was converted to a 4m cell grid and combined with the classified landform position. Utilising the decision rules identified in 8.5 the habitats were classified according to suitability and landform occurrence (Table 8.24). The range of methods resulted in the identification of suitable landscape positions for woodland conservation action, and also the location of habitats considered suitable for native woodland creation or conversion. The final range of habitats considered to represent opportunities for woodland conservation formed 13,888ha of the Dark Peak (Fig 8.14, 8.15).

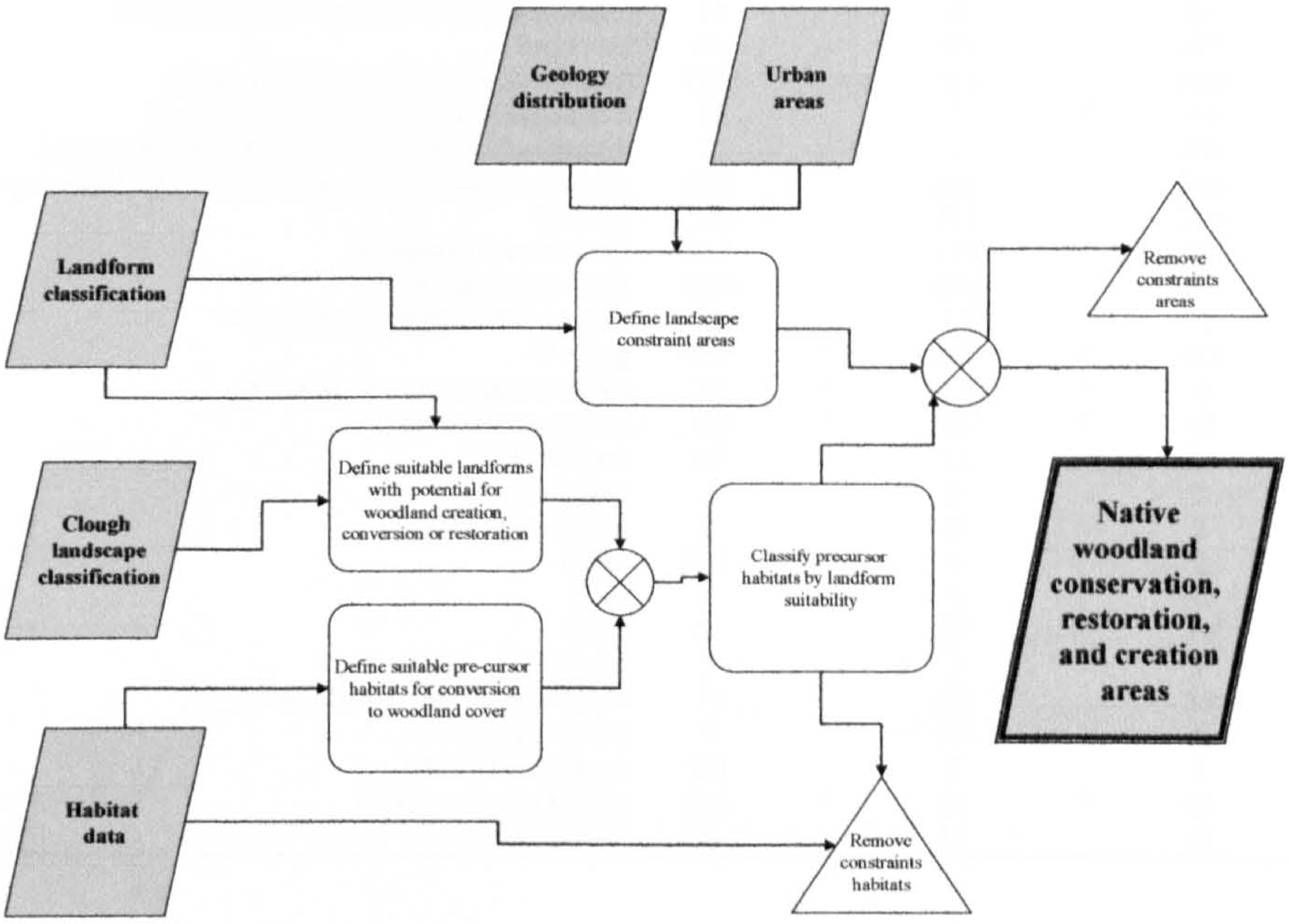


Figure 8.14
The sequence of methodology involved in the identification of suitable landscape and habitat areas for woodland creation and restoration.

Table 8.25

Classifying habitats occurring within the cloughs landscape zone. Dependant habitats are marked as constraint within the relevant landscape zones (Clough = core cloughs zone, Slopes = additional slopes zone, bracken = bracken or low conservation interest zone, Cons = constraint).

	Clough		Slopes		Bracken	
Habitat	Area (ha)	Cons	Area (ha)	Cons	Area (ha)	Cons
Young woods	95		34		34	
Broadleaved woodland	4		1		1	
Broadleaved, semi-natural woodland	889	*	195	*	110	*
Broadleaved, plantation woodland	365		145		75	
Coniferous plantation woodland	873		361		291	
Mixed, semi-natural	3	*	2	*	1	*
Mixed, plantation	426		135		100	
Scrub	18		4		3	
Scrub, dense	38		18		8	
Scrub, scattered	63		36		23	
Scattered trees, open	141		44		32	
Scattered trees, close	169		88		80	
Felled	26		8		12	
Acid grassland, unimproved	1133		609		628	*
Acid grassland, semi-improved	206		117		240	*
Acid grassland, semi-improved (Rough)	59		27		98	*
Neutral grassland, semi-improved	347		210		477	*
Neutral grassland, semi-improved (Rough)	23		8		21	*
Improved	56		44		171	*
Improved / Semi-improved (enclosed)	1353		966		1749	*
Marshy grassland (Soft rush dominated)	15		7	*	19	*
Marshy grassland (Purple moor grass dominated)	1		1		0.7	*
Marshy grassland / Wet bog (Purple moor grass dominated)	386		221		308	*
Bracken	540		211		214	
Heathland / unenclosed	217		174		335	*
Dry dwarf shrub heath	1866		846		710	*
Wet heath / acid grassland mosaic	31		17		13	*
Wet bog	0.4	*	0.2	*	0.1	*
Wet bog / Cottongrass moorland	15	*	17	*	9	*
Cottongrass moorland	149	*	104	*	69	*
Acid flush	69		21	*	29	*
Bare peat	3		3		2	*
Eroding moorland	7		8		2	*
Water	244	*	8	*	2	*
Cliff	4		1		0.3	
Scree	31		19		18	
Quarry	3		3		1	
Arable / short term ley grassland	11		10		39	*
Amenity grassland	5		0.8		1	*
Introduced shrub	0.5		2		1	
Urban – roads / houses	226	*	63	*	84	*
Bare ground	26		11		11	*

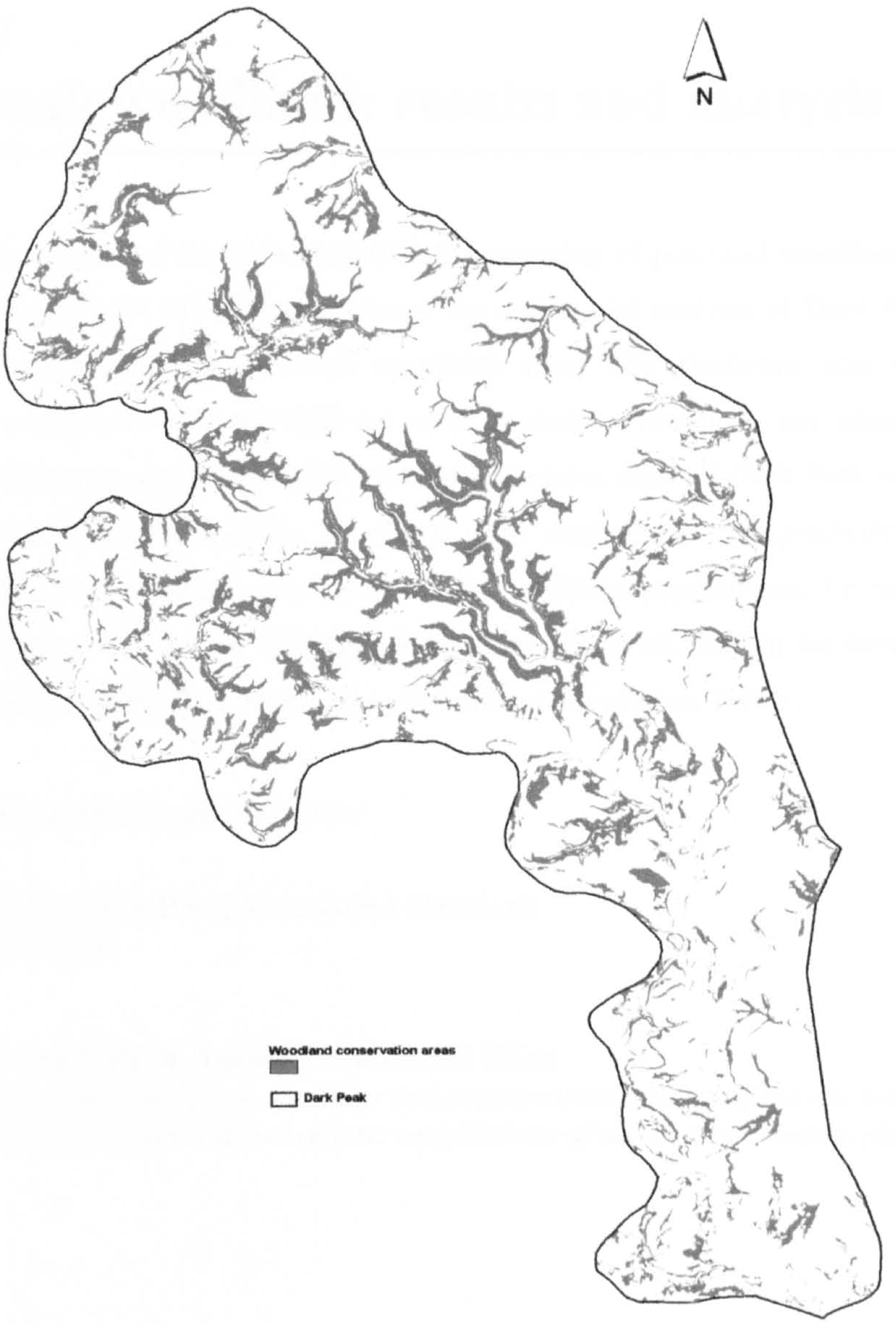


Figure 8.15
The final classified woodland conservation areas resulting from landform and habitat analysis.

8.7 Chapter Summary

- A landscape character assessment was undertaken for the Dark Peak Natural Area
- Clough landscape zones were examined using landscape zone classification and use of the Topographic Position Index
- Features of native and total woodland cover were examined by landscape features
- Clough landscape positions were identified
- The suitability of different identified landscape zones were analysed for woodland conservation potential
- Habitats were classified by their occurrence within different landscape zones for potential conversion to woodland conservation land-use

Part IV
Dark Peak woodland: results and analysis

Following the creation of the woodland GIS and mapping of potential woodland conservation landscape areas, Part IV of the thesis present the results and analysis of Dark Peak woodland characteristics and examines Ancient woodland sites. The fieldwork and GIS collected information, compiled within the GIS are used to analyse woodland site characteristics and woodland habitat type and biodiversity associations across both all Dark Peak woodland sites, and in more detail within Ancient Woodland sites. Exploratory and predictive analysis are undertaken of theory predicted woodland–abiotic condition associations, for potential use in landscape planning. The section extracts relationships ultimately used in the formulation of the woodland strategy for the Dark Peak, presented in the final section, Part V.

This part includes the following chapters:

Chapter 9: The Dark Peak Woodland Network
Habitat survey results

Chapter 10: Dark Peak Ancient Woodland Sites
Assessing the current ecological condition and conservation interest of the Ancient Woodland resource and analysing habitat and abiotic associations of use in conservation planning

Chapter 9
The Dark Peak Woodland Network
Habitat survey results

9.1 Introduction

This chapter presents the results of the woodland fieldwork survey and aerial photograph analysis together with the GIS compilation of data to present the form and structure of the Dark Peak woodland network. The current composition of the woodland resource is detailed, and analysis identifies characteristic or habitat-specific variations in patch size, topology and topography.

9.2 Methods

Habitat data were extracted from the GIS in order to examine the form of the woodland network. Simple abiotic data (area, shape, topography and landscape position) were compiled within the GIS, based upon individual polygons. Additional core area and isolation analysis utilised Patch Analyst (Rempel and Carr, 2003) and the Fragstats package (McGarigal et al., 2002), in addition to a number of GIS scripts and extensions (Jenness, 2004, Jenness, 2003) to derive landscape metrics describing fragmentation.

For the Fragstats analysis the woodland habitat shapefiles were converted to grid themes with a 5m cell size. This was chosen as this was the minimum size that allowed the accuracy of the mapping to be maximized but reduced subsequent analysis file size sufficiently to allow analysis to be carried out with available computing power. The conversion of mapped vector data to raster data leads to a number of errors in the data set. In certain shapes the process and subsequent analysis in Fragstats leads to differences in the total number of polygons. Thin vector polygons / patches may be split into numerous small single celled patches, while in other cases the rasterization leads to the merging of polygons / patches that were previously separate within the shapefile theme. It was considered that due to the high resolution of the original vector data and by using small 5m cells that merging of previously separate patches within the rasterization process would not be a common error, therefore the creation of small error polygon was considered the main issue. To counteract this 8N clumping methodology was used in Fragstats and all patches identified within the results less than 0.07 ha were removed from the files before the analysis of results. General polygon accuracy presented was approx 0.1ha minimum in the original shapefile theme format. Core area calculations were based on "edge effects" of 12m, where woodlands were adjacent to open ground habitats, 8m where woodlands occurred adjacent to shading coniferous plantation woods and 4m when adjacent to dense semi-woodland habitats such as dense scrub and dense scattered trees (Appendix 9.1). A range of

ArcView extensions and scripts were also utilised to calculate additional fragmentation values. These included nearest neighbour isolation distances (Jenness, 2004) for both single classes and all woodland habitats and the number of woodland polygons occurring within set distances around focal woodland patches (Jenness, 2003). Subsequent analysis was conducted in SPSS (14) and PC-Ord 5 (McCune and Jefford, 2006) in addition to ArcView 3.2 (ESRI, 1999) and ArcGIS 9.2 (ESRI, 2006). Following collation, data were examined and where possible variables were transformed to normality or to allow analysis of variance. However the majority of data were not normally distributed and could not be transformed to normality, therefore non-parametric analysis methods were employed. Survey results included small areas of woodland classed as semi-natural mixed plantation and as felled woodland: these are typically omitted from tables and charts due to there rarity, and to improve clarity of presentation.

9.3 Results and Analysis:

Dark Peak Woodland patch and Habitat Network characteristics

9.3.1 Woodland habitat area and frequency

The completion of the GIS allowed a more accurate breakdown of the Dark Peak habitats and woodland cover than was previously available (**Table 9.1**). Woodland habitats (established woods, new planting and recent felling) comprise approx 9% of the Dark Peak landcover (**Table 9.1**). Smaller but significant areas of scattered trees habitat also occur. The majority of the Natural Area however is characterised by moorland or enclosed grassland. Established woodland occupied over 7,300 ha within just over 2,000 patches (**Table 9.3**), dominated by coniferous plantations (forming approx 44% of the total established woodland cover). The second most abundant woodland type comprised semi-natural broadleaved woodland (25% of established woodland). Significant areas were also covered by scattered trees, occupying over 1,000 ha. It was notable that the occurrence of scrub habitat was low, and lower than the occurrence of scattered tree habitats (**Fig 9.1, Table 9.2**).

Table 9.1
Dark Peak landcover by broad habitat group. The data was produced following GIS operations to dissolve all polygons less than 0.1ha, after clipping data to the Dark Peak boundary.

Broad Habitat	Area (%)	Area (ha)
Moors and upland habitats	54	46,805
Enclosed grassland	31	26,872
Woodland habitats	8.9	7,698
Urban areas and roads	2.9	2,472
Rivers and reservoirs	1.4	1,179
Trees	1.3	1,170
Scrub	0.4	312

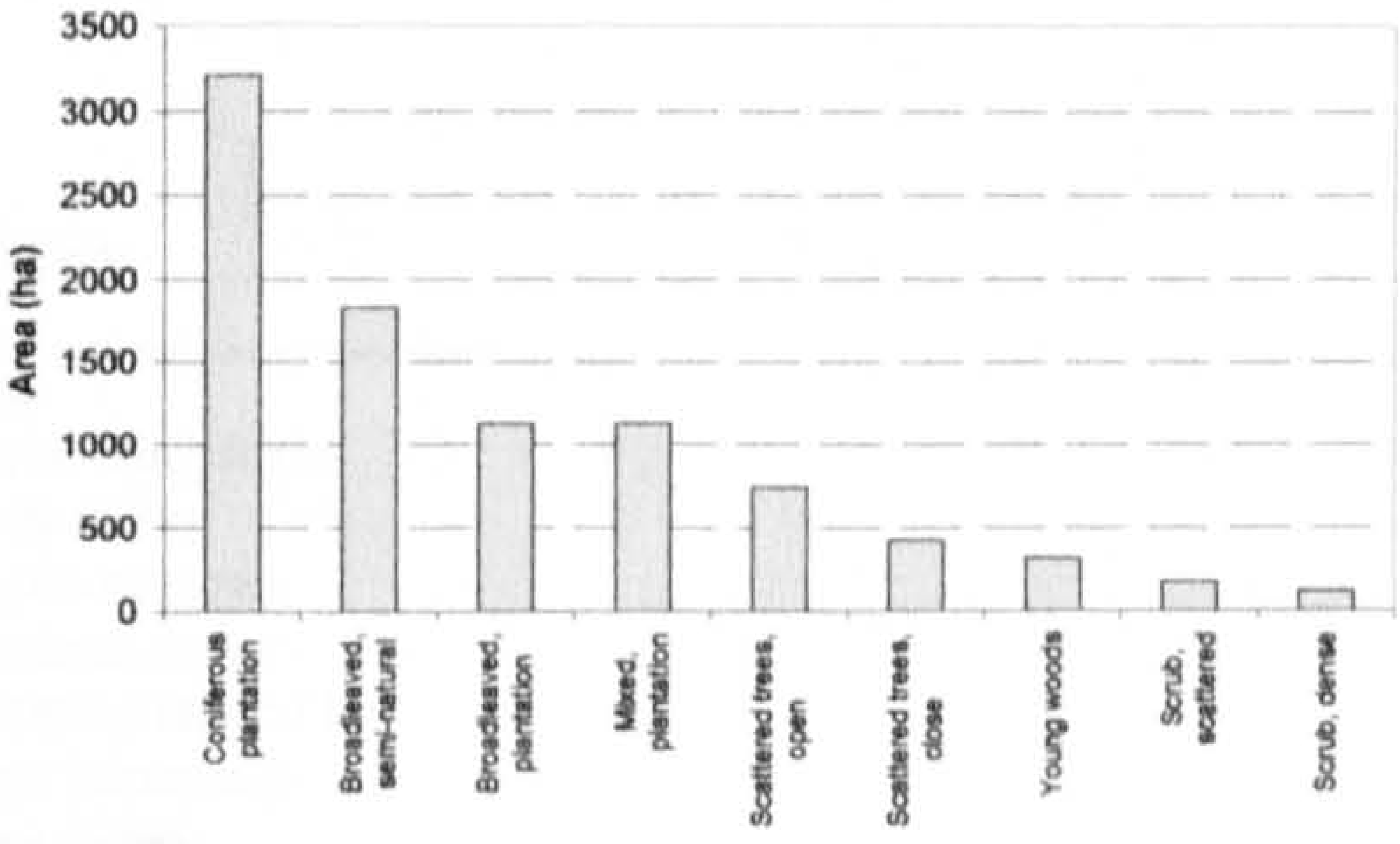


Figure 9.1
Total area of Phase 1 classified woodland habitats occurring within the Dark Peak.

Table 9.2
The area and frequency of woodland and associated habitats classified by Phase 1 Habitat. Although original data compilation methods were derived from vector datasets, the data presented are produced from raster data as this was the main dataset referred to in the remaining section of results. There are minor differences in the number of patches and the total areas of habitats identified by the two methods.

	Patch		%
Habitat	Frequency	Area (ha)	Dark Peak
Broadleaved, semi-natural	612	1832	2.1
Broadleaved, plantation	602	1130	1.3
Coniferous plantation	485	3216	3.7
Mixed plantation	312	1128	1.3
Scrub	60	34	0.04
Scrub, dense	68	119	0.1
Scrub, scattered	68	176	0.2
Scattered trees, close	238	429	0.5
Scattered trees, open	203	740	0.9
Young woods	114	320	0.4
Felled	28	85	0.1
Total woods, trees, scrub	2798	9227	10.7

Table 9.3
The area and frequency of established woodland habitats classified by Phase 1 Habitat category. Although original data compilation methods were derived from vector datasets, the data presented here are produced from raster based data as this was the main dataset referred to in the remaining section of results. There are minor differences in the number of patches and the total areas of habitats identified by the two methods.

	Frequency		Area	
Woodland Habitat	Count	%	ha	%
Broadleaved, semi-natural	612	30.3	1832	25.0
Broadleaved, plantation	602	29.8	1130	15.4
Coniferous, plantation	485	24.0	3216	43.9
Mixed, plantation	312	15.5	1128	15.4
Established woods	2019	100	7325	100

9.3.2 Woodland patch variable selection and data correlations

27 variables describing woodland form were compiled or calculated for each woodland patch (Appendix 9.2). Many of these were highly correlated and therefore initial analysis of bivariate correlations, exploratory multivariate analysis and interpretation of the ecological and statistical significance of each variable was used to eliminate redundant variables, producing a reduced list of 20 key variables (Table 9.4). Where variables were thought to hold high ecological significance or exploratory multivariate analysis indicated retention of correlated variables had little influence on results several correlated variables were retained for study. Correlations between variables are indicated in Table 9.5.

Table 9.4
Key variables used to interpret patch and woodland network characteristics

Patch area:	Area
Patch shape:	Fractal complexity
	Circle index
Patch topography:	Elevation mean
	Elevation range
	Elevation range / ha
	Slope minimum
	Slope mean
	Slope range
	Slope range / ha
	Aspect variability / ha
Fragmentation and Connectivity:	NN, 2ndNN
	Core area index

Table 9.5
Spearman's rho correlations for woodland patch variables for broadleaved semi-natural woodland patches and all established woodland patch habitats combined. Only significant correlations (>.0.05) are shown. Elev = elevation Rng = range, ha = hectare, var = variability. ENN = nearest neighbour distance. Very large correlations are indicated in bold, less than moderate correlation are in greyscale.

		Fractal index	Circle index	Elev mean	Elev range	Elev rng/ha	Slope min.	Slope mean	Slope Range	Slope rng/ha	Aspect var.	Asp var/ha	Core area index	1st ENN
Wood	Estb woods	.11****	.12****		**.74******	-.69****	-.41****	.10****	.60****	**-.85******	.59****	**-.89******	**.80******	
area	*Brd, semi-natural*	.21****	.18****		**.77******	-.62****	-.40****	.15****	.65****	**-.85******	.61****	**-.90******	**.82**	
Fractal	Estb woods		**.86******	-.15****	.14****	-.06**	-.20****		.25****		.22****			-.22****
index	*Brd, semi-natural*		**.86******	-.20****	.15***	-.19****	-.32****	-.11**	.21****	-.14***	.34****			-.23****
Circle	Estb woods			-.14****	.13****	-.06**	-.16****	.10****	.27****		.19****		-.27****	-.20****
index	*Brd, semi-natural*			-.15***	.13**	-.14***	-.27****		.22****	-.10*	.29****		-.23****	-.17****
Elev	Estb woods				.08***	.14****	.14****	.10****			-.10****			.11****
mean	*Brd, semi-natural*				.13***	.28****	.25****	.30****		.14***	-.17****			.31****
Elev	Estb woods					-.09****		.57****	**.73******	-.46****	.29****	**-.74******	.61****	
range	*Brd, semi-natural*							.58****	**.74******	-.51****	.30****	**-.78******	.65****	.11*
Elev	Estb woods						**.65******	.45****	-.14****	**.79******	-.59****	.53****		.12****
rng/ha	*Brd, semi-natural*						**.67******	.45****	-.14***	**.78******	-.60****	.46****		.20****
Slope	Estb woods							.54****	-.25****	.38****	**-.90******	.09****		.09****
min.	*Brd, semi-natural*							.55****	-.26****	.40****	**-.81******	.08*		.14***
Slope	Estb woods								.57****	.22****	-.24****	-.24****	.15****	.07***
mean	*Brd, semi-natural*								.56****	.16****	-.25****	-.31****	.25****	.17****
Slope	Estb woods									-.14****	.48****	-.47****	.41****	
range	*Brd, semi-natural*									-.21****	.52****	-.51****	.47****	
Slope	Estb woods										-.44****	**.81******		.07**
rng/ha	*Brd, semi-natural*										-.46****	**.81******		.09*
Aspect	Estb woods											-.20****	.33****	-.07***
var.	*Brd, semi-natural*											-.24****	.32****	-.12**
Aspect	Estb woods													
Var/ha	*Brd, semi-natural*													
Core	Estb woods													.07***
Area index	*Brd, semi-natural*													.09*
1st	Estb woods													
ENN	*Brd, semi-natural*													

**** Correlation is significant at the .0001 level (2-tailed).
*** Correlation is significant at the .001 level (2-tailed).
** Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

9.3.3 Analysing woodland habitat character: Multivariate analysis

Principal component analysis (PCA) and Discriminant analysis (DA) were used to examine the characteristics that differ most among Dark Peak woodlands and the variables that particularly discriminate between the main woodland types. Prior to multivariate analysis each variable was analysed for normality, homogeneity of variances and appropriate transformations were attempted to meet normality. Tests were examined for all combined data and separately within each woodland class. These analyses, combined with biological interpretation, were used to produce a reduced set suitable for further analysis.

9.3.3.1 Principal Component Analysis

11 patch size, topology and topography variables were retained from a potential 26 variables for PCA analysis following examination of the distribution, correlations and initial PCA exploratory analysis. Data transformations produced good improvement in distributions and normality of histograms, but none proved to be significantly normal. Subsequent use of the transformed variable showed improved results in PCA therefore they were retained over the raw data. A PCA was conducted utilising the correlation matrix, with varimax rotation and this resulted in 3 principal components with eigenvalues greater than 1 representing 79% of the variation in the data. The first 3 components captured 37%, 24% and 18% of variance, respectively.

Component Matrix[a]

	Component		
	1	2	3
area (log10)	-.957		
aspect variability / ha (log10)	.872		
slope range / ha (log10)	.833		
elevation range (log10)	-.724	.611	
elevation range / ha (log10)	.670	.667	
slope range (sq root)	-.635	.521	
mean slope (sq root)		.956	
slope minimum (sq root)	.443	.620	
fractal index (log10)			.893
circle index			.879
mean elevation			

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Rotated Component Matrix[a]

	Component		
	1	2	3
elevation range (log10)	.953		
slope range (sq root)	.800		
aspect variability / ha (log10)	-.789	.462	
mean slope (sq root)	.710	.649	
area (log10)	.706	-.656	
elevation range / ha (log10)		.941	
slope range / ha (log10)	-.411	.835	
slope minimum (sq root)		.729	
fractal index (log10)			.910
circle index			.898
mean elevation			

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Figure 9.2
PCA component matrix showing component loading correlations to input variables. Correlations lower than 0.4 are omitted for clarity.

A plot of the PCA data points labelled by woodland habitat shows the spread of component scores within and between the main habitat classes (Fig 9.3). Differences were found in the PCA scores between the habitats. Post hoc Man-Whitney U tests (Monte Carlo) revealed the pair-wise differences (Table 9.6).

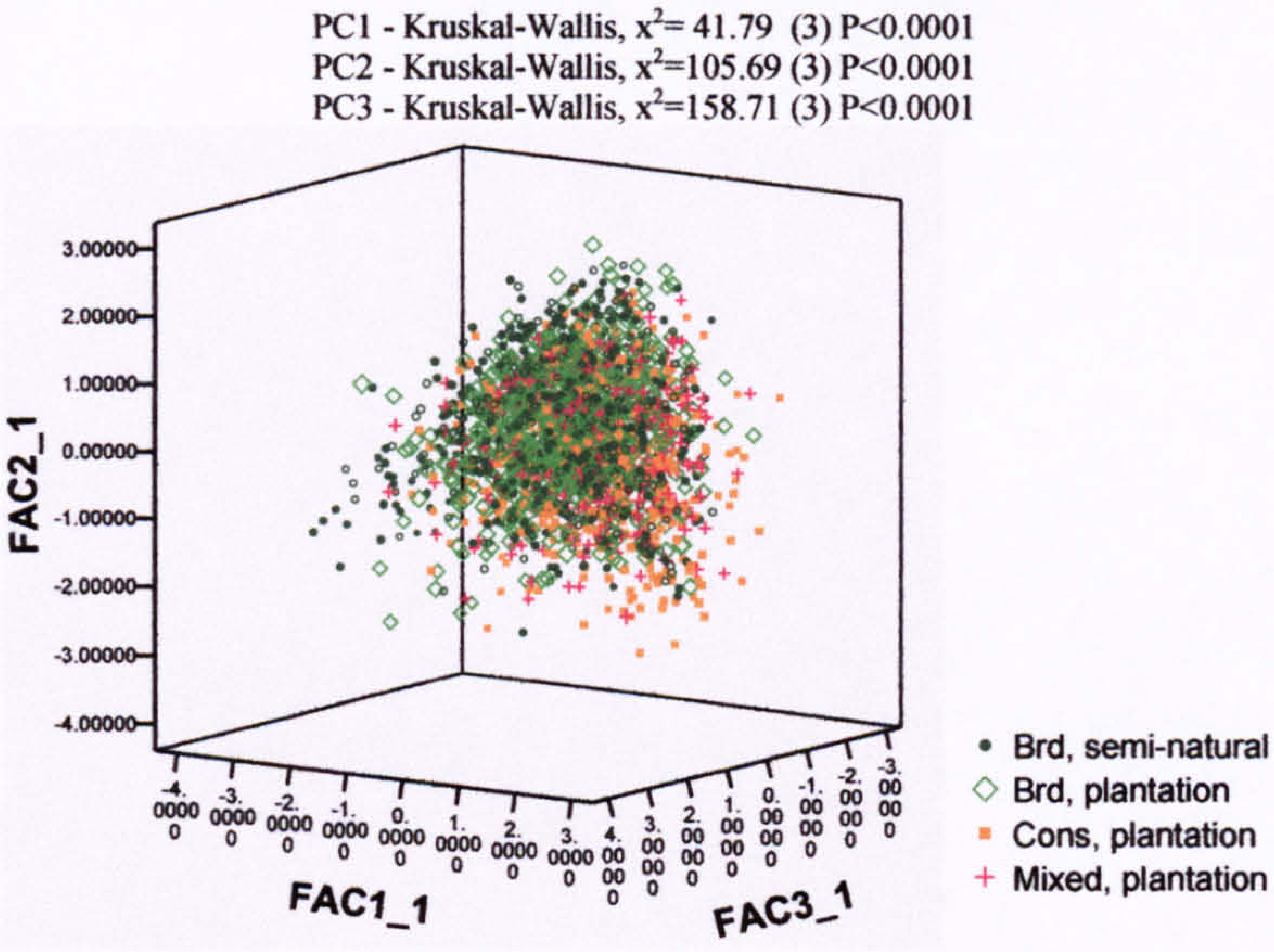


Figure 9.3
PCA plot summarising woodland patch size, shape and topography into 3 principal components, labelled by main woodland type.

Table 9.6
Significant differences among the 3 principal components between woodland types.

	Broadleaved plantation	Coniferous plantation	Mixed plantation
Broadleaved semi-natural	1* 2 NS 3***	1~ (p=.014) 2*** 3***	1~ (p=.032) 2*** 3***
Broadleaved plantation		1*** 2*** 3***	1*** 2*** 3** (p=.0014)
Coniferous plantation			1 NS 2~ (p=.012) 3NS

~= P<0.05, * = P<0.01, **= P<0.001, *** = P<0.0001, NS = not significant

The PCA results showed that the variation in individual woodland characteristics could be explained by a reduced number of functions. These were interpreted as:

- PCA1: summarised a trend from large woods on steep slopes with high ranges in elevation and slope per patch (but low variability in slope range and aspect variability per hectare), to small woods on less steep slopes, lower individual ranges in elevation and slope per patch (but higher topographic variability per unit area).
- PCA2: describes a similar axis of character, from woods with high topographic variability per unit area and small size, again on steep slopes, but additionally with high minimum slopes, suggesting all of these patches occur wholly on steep slopes rather than encompassing areas with low slopes. Therefore distinguishing from sites that cross cloughs or valleys from sites only occurring on valley side slopes.
- PCA3: detailed a range of sites from complexly shaped, long and elongated patches to less complexly shaped and compact patches.

The PCA scores generally differed significantly between the habitats (Fig 9.3, Table 9.6). However some scores did not differ between broadleaved plantation and semi-natural woods or between mixed plantation and coniferous woods. Despite such differences between the habitats overall, examining the plot of PCA scores (Fig 9.3) shows individual woods showed a wide range of values and combinations of characteristics, as evidenced by the wide spread of data points. Woodland habitats have characteristics that overlap widely. Such potential for variation in characteristic within each type showed that although woodland habitat is a very useful predictor of woodland condition it cannot exclusively reveal potential woodland value for conservation or restoration. The use of the original variables such as topographic variability show a range of values even within a habitat such as coniferous woods which typically have low topographic diversity. Within-patch features such as topography must be examined in addition to broad habitat cover type, to describe woodland conditions.

9.3.3.2 Discriminant Analysis

Discriminant analysis was undertaken to explore the relationship between the characteristics that discriminated most between the four woodland types. The analysis gave insight into the potential of these characteristics to classify woodlands of unknown type based on patch size, shape and topography. Prior to analysis variables were examined against test assumptions and transformation attempted. Transformation (log10 and square root, with appropriate constants) led to improvement in normality in some cases but not to such a degree as they were considered normal by statistical tests. The input variables did not show homogeneity of variance (Levene's test and Box's M test). This required that the within-group covariance matrices were used in the analysis and that the discriminant function plots and examination of group differences on the resulting canonical axis must be treated with caution, acting as exploratory analysis, due to violation of test assumptions (McGarigal et al., 2000). However some assumptions can be moderately violated without large changes in correct classification results and the effect of these violations reduce with large sample sizes (McGarigal et al., 2000). The viability of the results were subsequently examined by comparing classification results to a Logistic Regression analysis which has less strict data assumptions. Examination of DA scores showed a mix of normal and non normal distributions (histograms, Kolmogorov-Smirnoff, Shapiro-Wilk tests), suggesting the multivariate normality assumption is unlikely to be true. Variables were tested for multicollinearity and variables removed based on existence of high (0.7+) correlations, ecological interpretation of the variables and importantly on the correlations between each variable and patch area. Variables were retained to maximise description of variability among groups. As an aid to these decisions ANOVA were conducted on variables between groups and for variables with significant differences the variable of a pair of highly correlated variables was retained when it had the greatest among-group variances (highest F value) (McGarigal et al., 2000). Due to the high number of correlated variables analysis was undertaken to compare the effect of removing individual variables so that variables were not removed in an attempt to reduce multicollinearity when their removal may be unnecessary. This was undertaken by conducting the analysis without selected variables and comparing the resulting structure matrix, and its interpretation, in comparison to the model run with the variable included. Additionally a forwards stepwise selection was run to examine the most parsimonious suite of variables selected under this algorithm. Ultimately, comparing interpretation of these outputs, and the overall classification rates, achieved a reduced list of variables that minimised multicollinearity but which retained variables that affect the structure matrix. The discriminant analysis was then run with prior probabilities calculated from group sizes since the numbers of woods were different. Outliers existed for each variable, but these were retained. The analysis resulted in the first 2 discriminant function accounting for 96% of the dispersion in the variables data. The structure matrix and function correlations are shown in Fig 9.4.

Structure Matrix

	Function		
	1	2	3
aspect variability / ha (log10)	.612*	-.300	.207
slope range / ha (log10)	.580*	-.313	.139
fractal (log10)	.556*	.174	.117
elevation range / ha (log10)	.449*	-.428	.045
area (log10)	-.402	.733*	-.134
slope range (sq root)	.085	.616*	-.485
elevation range (log10)	-.148	.438*	-.336
slope minimum (sq root)	.038	-.364*	.235
mean slope (sq root)	.153	.154	-.326*
mean elevation	-.189	.133	-.259*

Figure 9.4
Discriminant analysis structure matrix, detailing correlation between discriminant function and original data variables.

Table 9.7
Differences between the primary and secondary discriminant functions among the woodland groups. Mann-Whitney tests

	Broadleaved plantation	Coniferous plantation	Mixed plantation
Broadleaved semi-natural	1*** 2***	1*** 2*	1*** 2***
Broadleaved plantation		1*** 2***	1*** 2***
Coniferous plantation			1*** 2 NS

* = P<0.01, *** = P<0.0001, NS = not significant

A non-parametric Kruskal-Wallis test, with Monte Carlo confirmed significant differences in the discriminant functions between groups for the 1st and 2nd functions (Fig 9.5). Post hoc Mann-Whitney tests (Monte Carlo) showed pair-wise comparisons were significantly different except for function 2 between coniferous and mixed plantations (Table 9.7).

The results of the DA analysis gave insight into the variables that differed most, not between individual woods as summarised by the PCA, but between the woodland habitats. The DA scores summarised the main discriminating factors between the wood habitats in two effective functions:

- DA1: represented a trend from small complexly shaped woods with high topographic variability per unit area from larger, simple shaped woods with low topographic variability per unit area.
- DA2: summarised a similar trend from large woods with low topographic variability per unit area and large ranges of slope and elevation per patch from the opposite, but without a significant distinction of woodland size or shape.

Function 1: Kruskal-Wallis, x^2= 395.0 (3) $P<0.0001$
Function 2: Kruskal-Wallis, x^2= 99.5 (3) $P<0.0001$

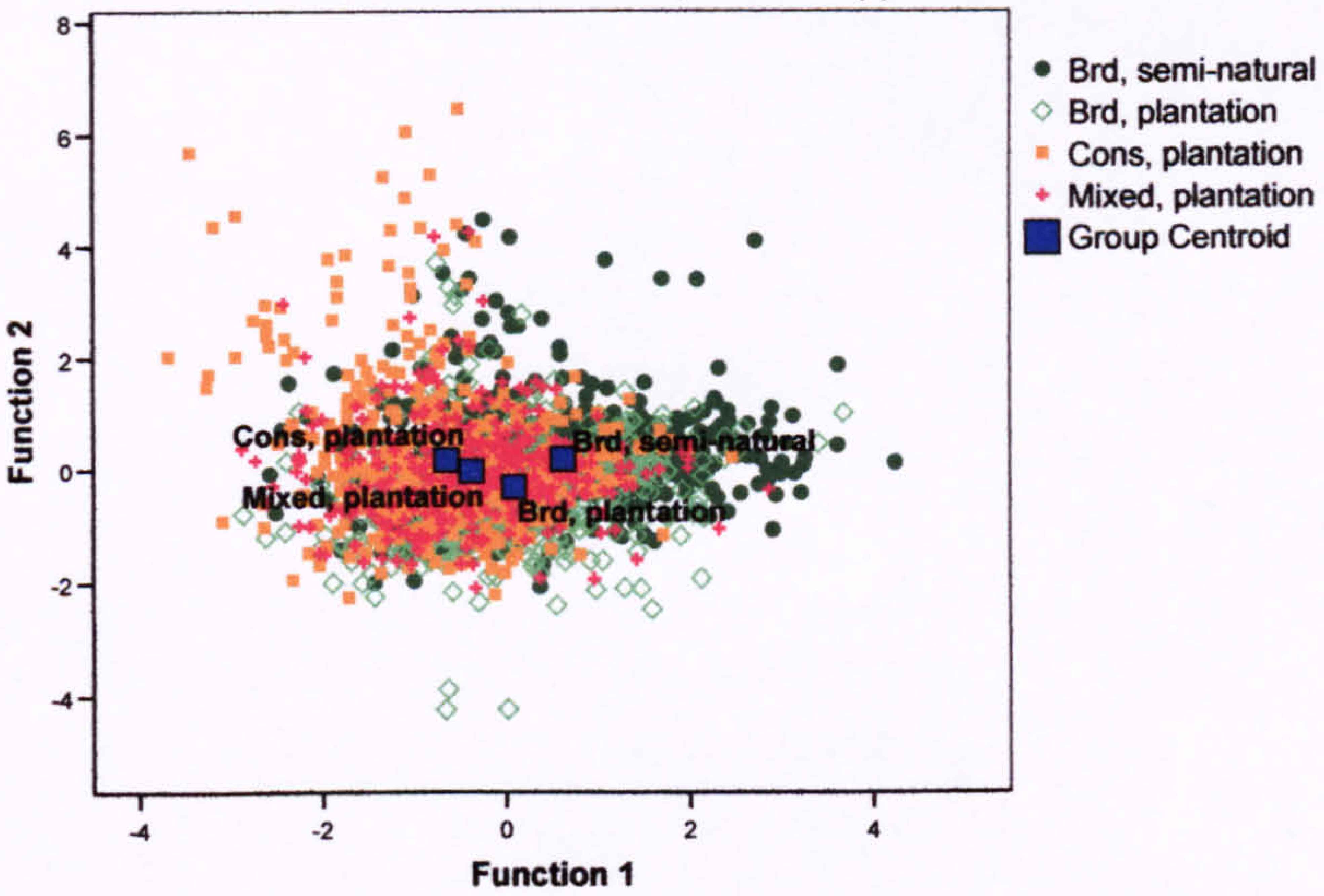


Figure 9.5
Discriminant functions plot detailing group centroid and data point for each of the 4 main woodland habitat types.

The classification results (Fig 9.6) showed relatively weak predictive ability in classifying woodland habitat from patch size, shape and topography. Only 45% of tested cases were correctly classified. However when individual groups were examined this rose to 61% of semi-natural woodland patches. Results compared very closely to the comparable logistic regression analysis which had a pseudo R-Square score of .25 (Nagelkerke). The low predictive ability of these characteristics, applied to unknown woodland sites, confirmed that, as suggested by examination of the PCA and DA plots (Fig 9.3, Fig 9.5), although these factors typically differ between sites each habitat as a whole contains a wide range of values and therefore for conservation purposes both woodland habitat type and within-patch habitat conditions are both useful for describing patch woodland conditions.

			Predicted Group Membership				
		typ	Broadleaved, semi-natural	Broadleaved, plantation	Coniferous, plantation	Mixed, plantation	Total
Original	Count	Broadleaved, semi-natural	377	152	77	6	612
		Broadleaved, plantation	215	286	100	1	602
		Coniferous, plantation	78	166	239	2	485
		Mixed, plantation	82	114	109	7	312
	%	Broadleaved, semi-natural	61.6	24.8	12.6	1.0	100.0
		Broadleaved, plantation	35.7	47.5	16.6	.2	100.0
		Coniferous, plantation	16.1	34.2	49.3	.4	100.0
		Mixed, plantation	26.3	36.5	34.9	2.2	100.0
Cross-validated[a]	Count	Broadleaved, semi-natural	374	153	79	6	612
		Broadleaved, plantation	218	279	103	2	602
		Coniferous, plantation	78	169	236	2	485
		Mixed, plantation	82	114	109	7	312
	%	Broadleaved, semi-natural	61.1	25.0	12.9	1.0	100.0
		Broadleaved, plantation	36.2	46.3	17.1	.3	100.0
		Coniferous, plantation	16.1	34.8	48.7	.4	100.0
		Mixed, plantation	26.3	36.5	34.9	2.2	100.0

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 45.2% of original grouped cases correctly classified.

c. 44.6% of cross-validated grouped cases correctly classified.

Figure 9.6
Discriminant analysis classification results detailing % correctly classified from original and cross-validated data

Table 9.8

Patch results. The four main woodland habitats with superscripts with the same letter do not differ significantly following post hoc Mann-Whitney tests, with a Bonferroni correction requiring tests to be below 0.008 to maintain the overall alpha level of 0.05

		Area (ha)		Fractal index		Circle index		Elev mean	
Habitat	N	Median	Mean	Median	Mean	Median	Mean	Median	Mean
Broadleaved, semi-natural	612	.79^{B}	2.99	1.15	1.16	.78	0.75	245^{A}	242.6
Broadleaved, plantation	602	.76^{B}	1.88	1.12	1.13	.73^{A}	0.70	241.5^{A}	244.0
Coniferous plantation	485	1.76^{A}	6.63	1.10^{A}	1.11	.69^{B}	0.68	258^{B}	256.4
Mixed plantation	312	1.57^{A}	3.62	1.11^{A}	1.12	.70^{AB}	0.69	257^{B}	257.1
Young woods	114	.83	2.81	1.12	1.13	.70	0.69	255	248.7
Scrub	60	.35	0.56	1.10	1.12	.67	0.67	239.5	240.6
Scrub, dense	68	.94	1.75	1.10	1.10	.67	0.65	243	252.4
Scrub, scattered	68	1.57	2.59	1.10	1.10	.72	0.68	232.5	236.0
Scattered trees, close	238	.88	1.80	1.12	1.13	.74	0.71	270.5	269.3
Scattered trees, open	203	1.55	3.64	1.11	1.12	.74	0.72	302	296.3

		Elev range		Elev rng/ha		Aspect var/ha	
Habitat	N	Median	Mean	Median	Mean	Median	Mean
Broadleaved, semi-natural	612	23.5^{A}	33.3	24.5^{A}	34.6	5.1^{A}	8.1
Broadleaved, plantation	602	20.0	26.2	24.2^{A}	30.4	4.3^{A}	6.0
Coniferous plantation	485	25.0^{AB}	35.5	13.5	20.6	2.0^{B}	3.6
Mixed plantation	312	26.0^{AB}	35.7	16.1	22.1	2.5^{B}	4.1
Young woods	114	22.0	31.1	21.5	29.6	2.9	5.0
Scrub	60	17.0	18.8	39.9	43.6	7.4	9.9
Scrub, dense	68	25.0	27.8	22.5	25.5	3.4	4.5
Scrub, scattered	68	37.5	43.6	20.7	25.7	1.9	2.7
Scattered trees, close	238	23.0	29.3	26.3	32.2	4.2	6.0
Scattered trees, open	203	35.0	40.1	20.0	28.4	2.4	4.3

		Slope min		Slope mean		Slope range		Slope rng/ha	
Habitat	N	Median	Mean	Median	Mean	Median	Mean	Median	Mean
Broadleaved, semi-natural	612	2.02^{A}	4.19	13.92^{A}	14.2	21.77^{A}	21.8	21.7	33.8
Broadleaved, plantation	602	3.65	4.80	12.27^{BC}	12.7	15.39	17.4	17.7	25.7
Coniferous plantation	485	3.90^{A}	2.26	11.61^{BD}	12.3	17.88^{B}	19.5	9.0^{A}	16.9
Mixed plantation	312	2.26^{A}	3.94	13.24^{ACD}	13.3	18.81^{AB}	20.7	11.1^{A}	16.9
Young woods	114	5.05	5.2	12.27	12.8	14.65	16.7	15.3	21.5
Scrub	60	6.42	7.28	16.96	16.1	15.68	17.1	39.8	48.3
Scrub, dense	68	4.40	5.41	14.61	13.9	17.02	17.6	14.7	18.6
Scrub, scattered	68	5.80	6.74	16.72	16.5	20.36	20.3	10.6	14.3
Scattered trees, close	238	3.20	4.51	13.09	13.7	19.43	20.1	19.6	26.6
Scattered trees, open	203	2.26	4.39	14.55	14.6	20.79	21.4	12.1	21.2

	Total area (ha)	Core Area (ha)			Class CAI (%)		
Habitat		Total	Patch mean	Patch median	Total	Patch mean	Patch median
Broadleaved, semi-natural	1845	1254	1.98	0.26^{A}	68	36.7	36.0^{A}
Broadleaved, plantation	1126	736	1.17	0.27^{A}	65	39.8	40.2^{A}
Coniferous plantation	3248	2713	5.47	1.13^{B}	84	59.2	65.3^{B}
Mixed, plantation	1125	868	2.73	0.91^{B}	77	58.6	63.6^{B}

	Mean		Median		Max		Std dv	
Habitat	NN	2nd NN	NN	2nd NN	NN	2nd NN	NN	2nd NN
Broadleaved, semi-natural	177	378	50^{A}	230^{A}	2982	3989	306	483
Broadleaved, plantation	193	403	97^{A}	275	2816	3440	285	455
Coniferous plantation	179	372	33	202^{A}	4918	5070	376	523
Mixed, plantation	311	587	156	405	3165	5239	424	637
Young woods	527	961	65	286	6540	6838	1016	1415
Scattered trees, close	460	920	193	622	5809	5998	679	908
Scattered trees, open	492	811	186	563	3611	4684	706	815
All established woodland	74	120	21	112	1254	1526	123	181

Table 9.9
Rank order of pair-wise differences of within-patch variables, where group tests have shown significant differences between habitats. Kruskal Wallis with post hoc Mann-Whitney.

Variable type		Rank range	Brd,semi-nat	Brd, pltn	Mix, pltn	Cons, pltn
Patch area	Patch area	Large – small	2	2	1	1
Patch shape	Fractal index	Complex – simple	1	2	3	3
	Circle index	Complex – simple	1	2	2,3	3
Patch Topography	Elevation mean	High - low	2	2	1	1
	Elevation range	High - low	2	3	1	1
	Slope minimum	High - low	2	1	2	2
	Slope mean	High - low	1	2	1	2
	Slope range	High - low	1	3	1,2	2
Topography / hectare	Elevation range / ha	High - low	1	1	2	3
	Slope range / ha	High - low	1	2	3	3
	Aspect variability / ha	High - low	1	1	2	2
Landscape Effects and connectivity	Core area	High-low	2	2	1	1
	Core are index	High - low	2	2	1	1
	NN	Low – high	2	2	3	1
	2nd NN	Low – high	1	2	3	1

9.3.4 Analysing woodland habitat character: Univariate analysis

The range of variables produced from initial analysis of correlation and exploratory multivariate analysis were further analysed to describe differences and characteristic features between the main woodland groups. Patch variable results are shown in **Table 9.8** indicating which of the 4 main woodland types show significant differences from pair wise comparisons.

9.3.4.1 Woodland patch area

There was a subtle difference in patch size distributions, with broadleaved semi-natural woodland containing a higher proportion of very small woods (**Fig 9.7**, **Fig 9.9**). When placed into broad patch size categories the total area of coniferous plantation had a high contribution from the larger sized woodland patches, over 50ha in size, while relatively small areas of the other habitats were formed from patches of this size (**Fig 9.8**).

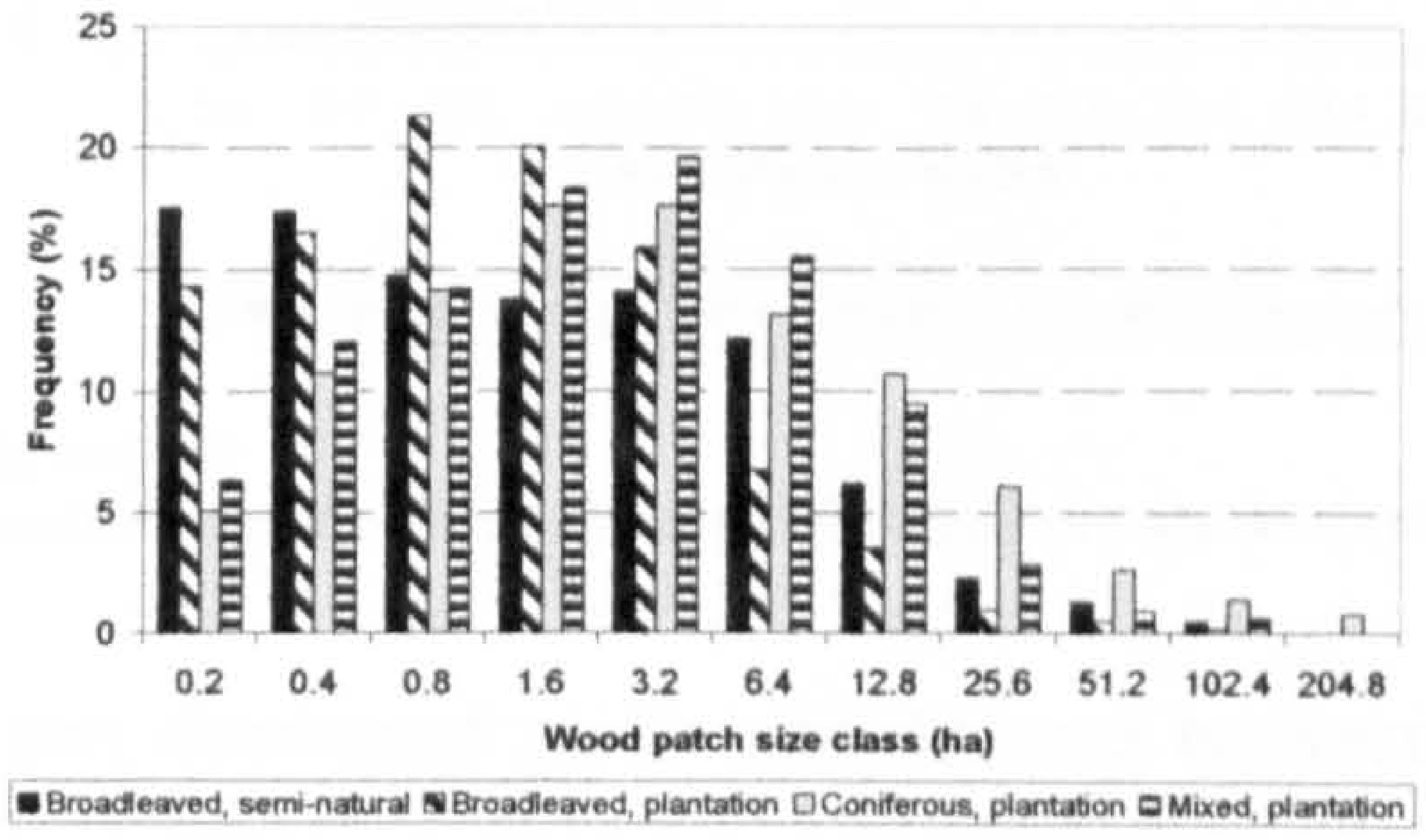


Figure 9.7
Patch size frequency distribution of the main four woodland habitats.

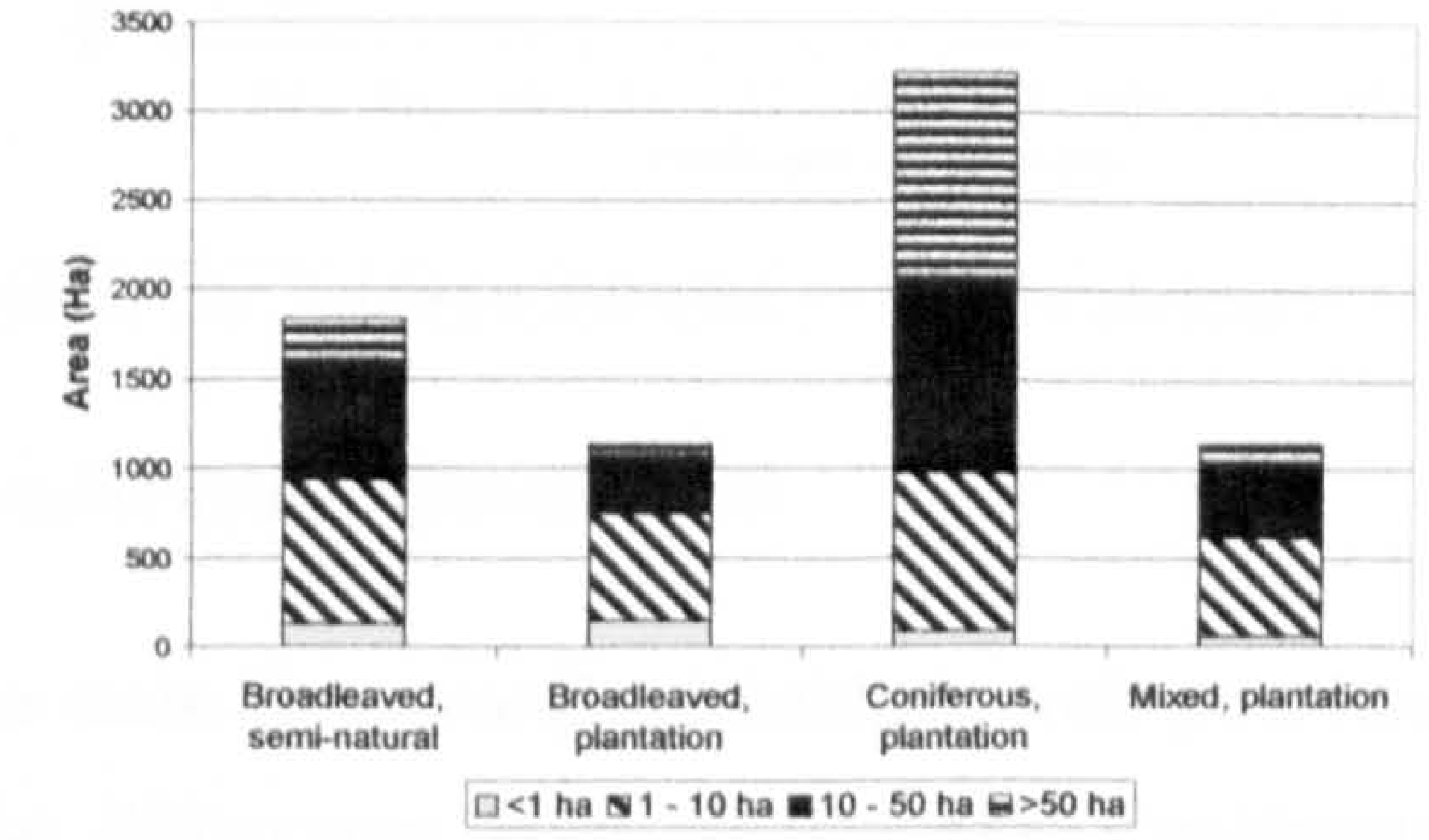


Figure 9.8
The total area in hectares of woodland occurring within four patch size classes among the four main woodland habitats.

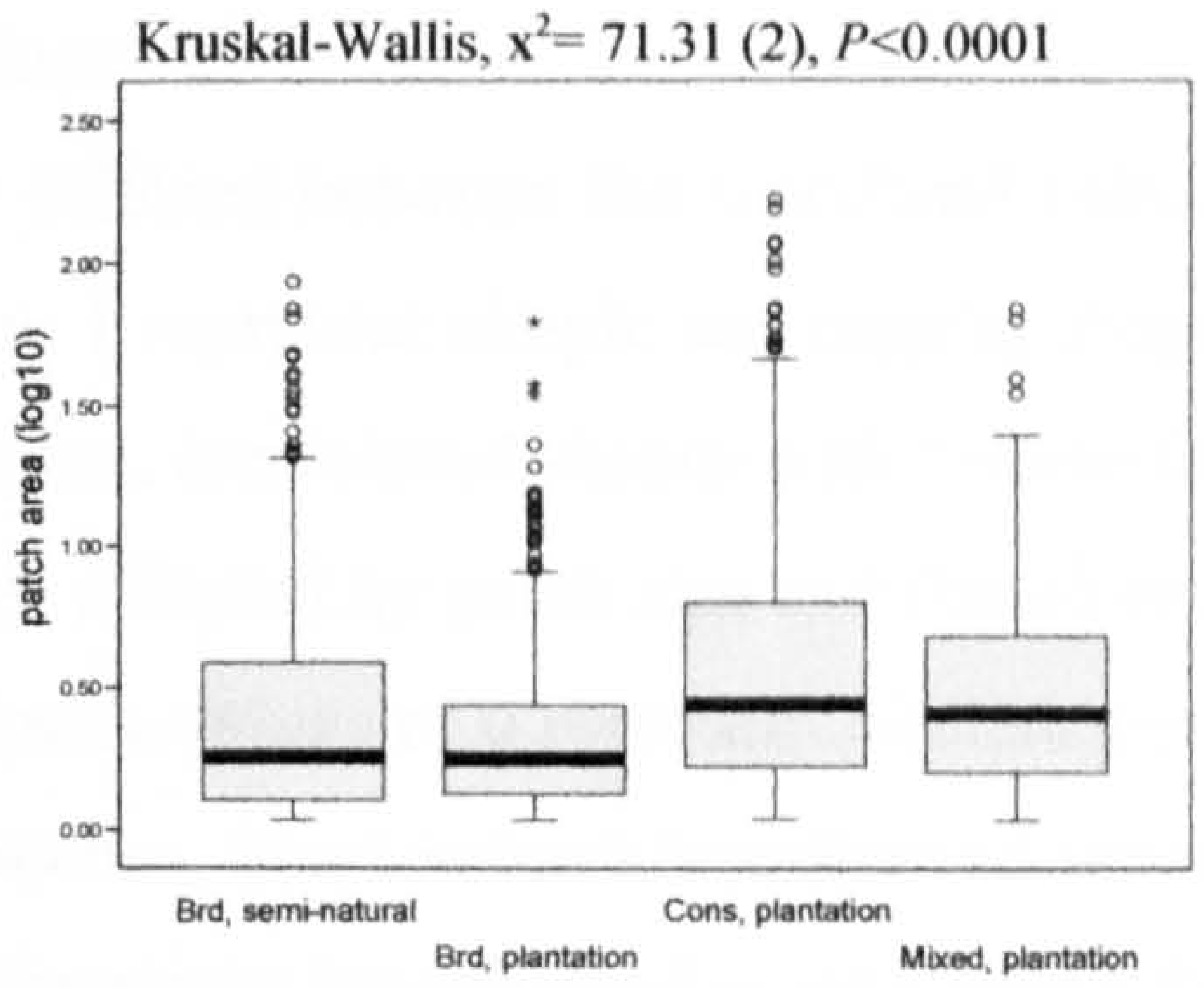


Figure 9.9
Boxplot of patch area (log10) of the main four woodland habitats. (Brd = Broadleaved, Cons = Coniferous). The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by circles and crosses. (Populations: Broadleaved semi-natural = 612, Broadleaved plantation = 602, Coniferous plantation = 485, Mixed plantation = 312).

Cumulative area and patch frequency are shown in Fig 9.10. A larger proportion of the area of broadleaved plantation habitat comprised small wood patches, in contrast to coniferous plantations. Almost 80% of the broadleaved plantation total area comprised patches below 12.8 ha. In contrast under 40% of the area of coniferous plantations comprised patches below 12.8 ha. Similar effects are seen with patch frequency. For semi-natural broadleaved patches over 60% of patches were below 1.6ha in size, while for broadleaved plantations, over 70% of patches were below this size. Conifer plantations tended to have larger patches than the other habitats. When the maximum patch size was examined, the largest woodland patch and most large woods were coniferous plantations.

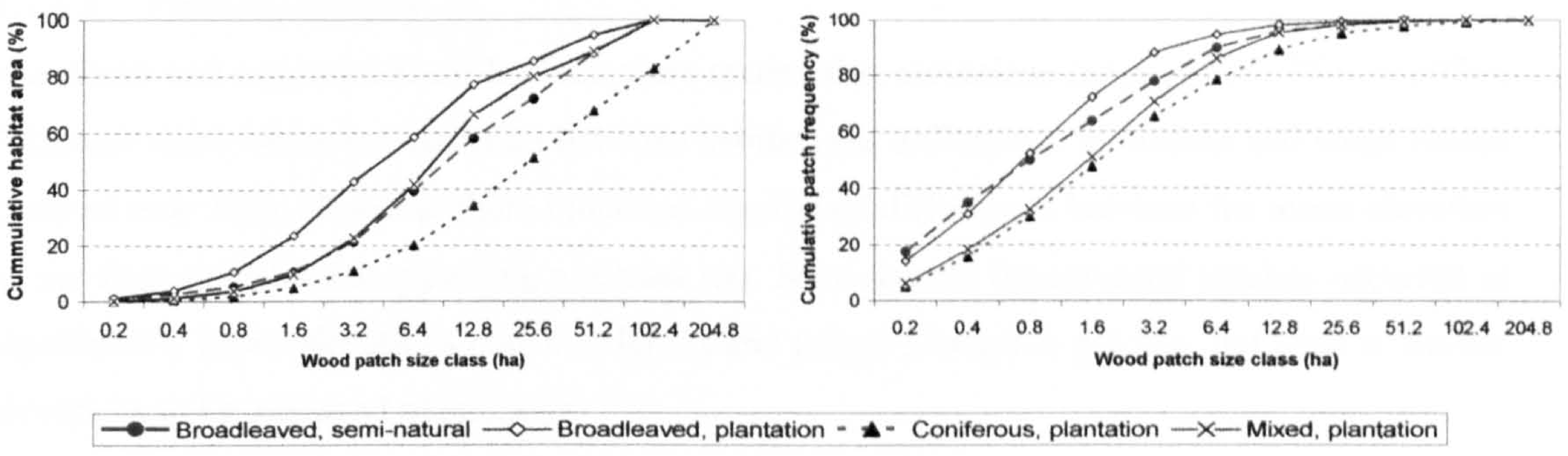
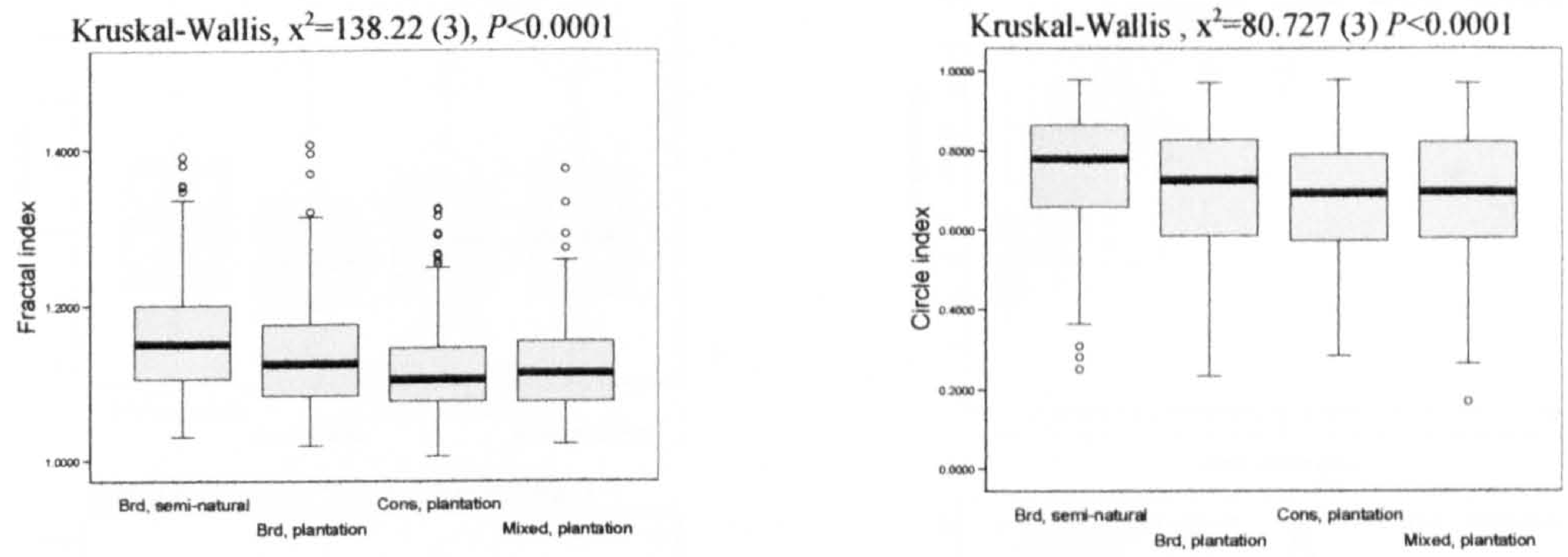


Figure 9.10
Cumulative patch frequency for the four main woodland habitats classified within 11 patch size classes.

Tests confirmed patch area differed between the main four woodland habitats with post hoc Mann-Whitney U tests revealing the pair-wise differences (Table 9.8, Fig 9.9). Coniferous plantations were significantly larger than semi-natural broadleaved woodland and broadleaved plantation patches. Mixed plantation patches were also shown to be significantly larger than broadleaved, semi-natural and broadleaved plantations. No significant difference was found between coniferous and mixed plantation patches, or between broadleaved semi-natural and broadleaved plantation.

9.3.4.2 Woodland patch shape

Patch shape and complexity differed between the woodland habitats (**Fig 9.11, Table 9.8**). Fractal dimension values approaching 1 represent simple and regular shapes, e.g. circles, higher values up to 2 represent highly complex, convoluted shapes with "plane-filling" perimeters (McGarigal et al., 2002). This index is less affected by patch size and therefore able to be compared across a range of patch sizes. Circle index values of 0 represent circular patches, higher values represent elongated and more linear patches. Semi-natural broadleaved woods had more complex shapes than other habitats. Of the plantations broadleaved woods generally had the next most complex shapes. Mixed and conifer plantation were typically similar.

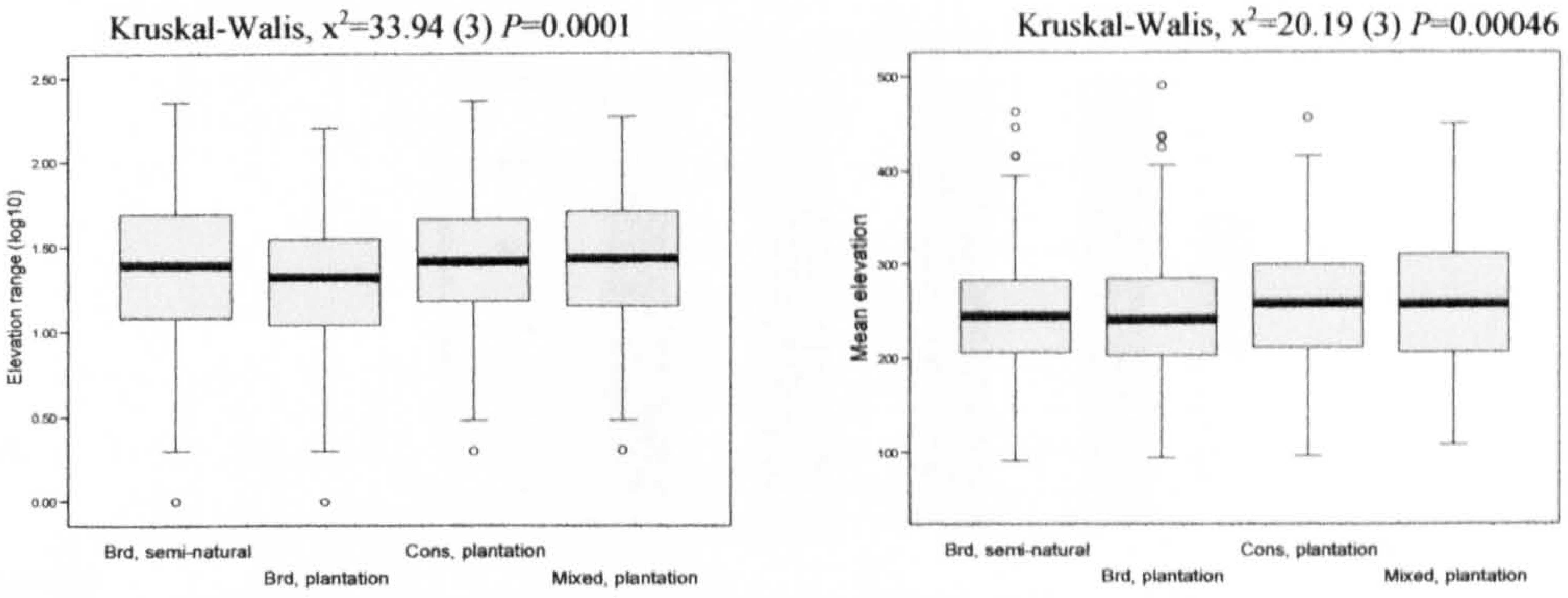

Kruskal-Wallis, x^2=138.22 (3), *P*<0.0001

Kruskal-Wallis , x^2=80.727 (3) *P*<0.0001

Figure 9.11
Boxplot of patch circle index and fractal dimension index of the four woodland habitats. (Brd = Broadleaved, Cons = Coniferous). The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by circles and crosses. (Populations: Brd semi-natural = 612, Brd plantation = 602, Con plantation = 485, Mixed plantation = 312).

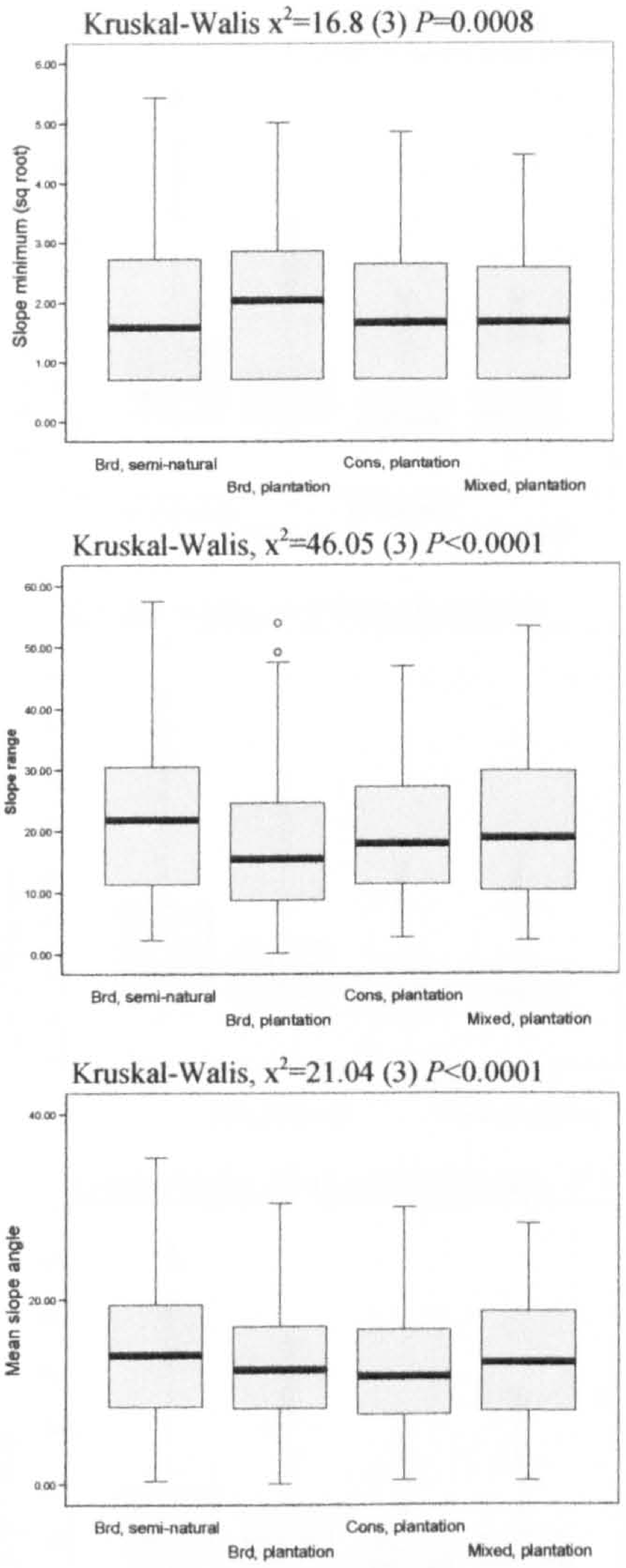
9.3.4.3 Patch topography

Woodland and semi-woodland habitats were recorded at elevations ranging from 85m to 507m. Although there was some variation between habitats the differences in median and mean values spanned only 50m. However there remained significant differences between the mean elevation of the four main habitat types (**Fig 9.12, Table 9.8**). Semi-natural broadleaved patches occurred at significantly lower elevations than coniferous and mixed plantation patches, but were at similar elevations to broadleaved plantations.


Kruskal-Walis, x^2=33.94 (3) *P*=0.0001

Kruskal-Walis, x^2=20.19 (3) *P*=0.00046

Figure 9.12
Boxplot of patch elevation range and mean elevation of the main four woodland habitats. (Brd = Broadleaved, Cons = Coniferous). The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by circles and crosses. (Populations: Broadleaved semi-natural = 612, Broadleaved plantation = 602, Coniferous plantation = 485, Mixed plantation = 312).



Kruskal-Walis x^2=16.8 (3) *P*=0.0008

Kruskal-Walis, x^2=46.05 (3) *P*<0.0001

Kruskal-Walis, x^2=21.04 (3) *P*<0.0001

Figure 9.13
Patch slope values for the main woodland habitats (Brd = Broadleaved, Cons = Coniferous). The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are shown by circles and crosses. (Populations: Broadleaved semi-natural = 612, Broadleaved plantation = 602, Coniferous plantation = 485, Mixed plantation = 312).

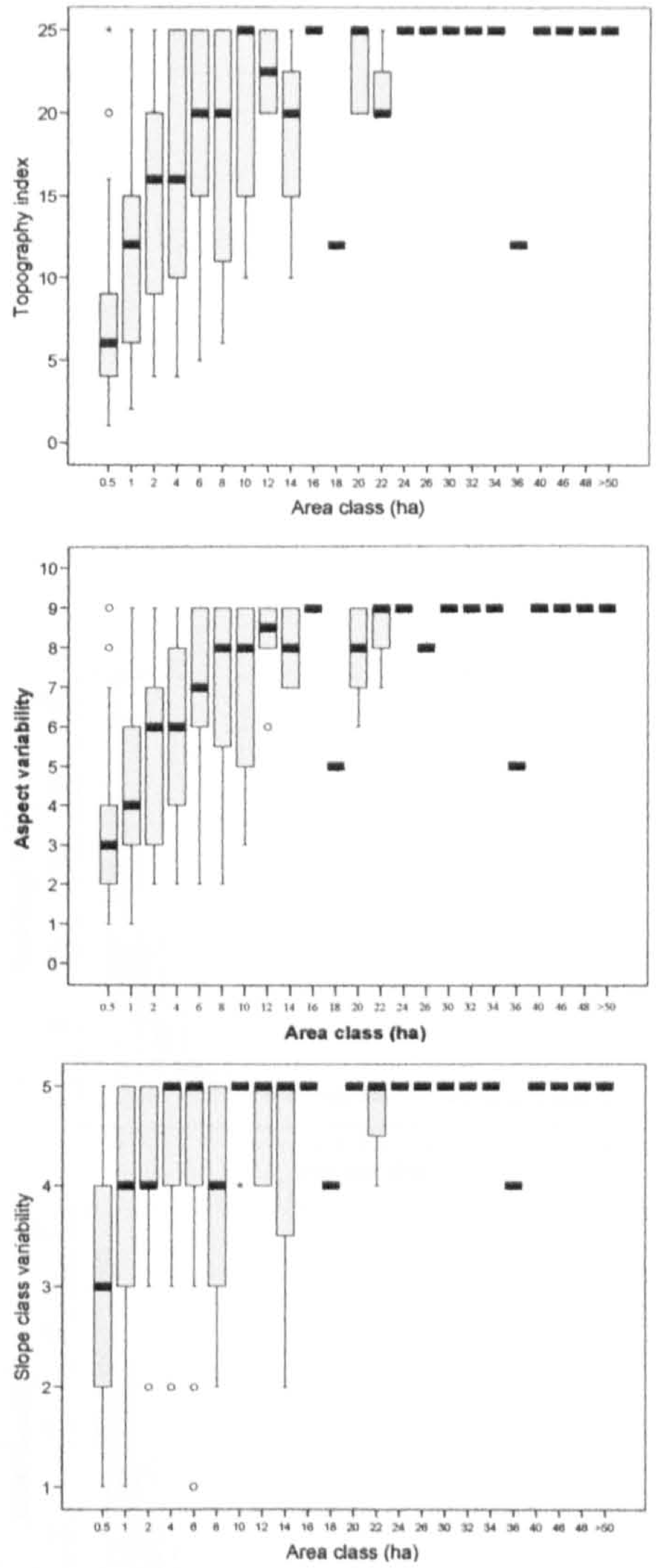


Figure 9.14
Topography index (patch slope class x patch aspect class) and aspect and slope class variability for semi-natural broadleaved woodland habitat. The plot details the median value as a thick bar and interquartile range of values as the box.

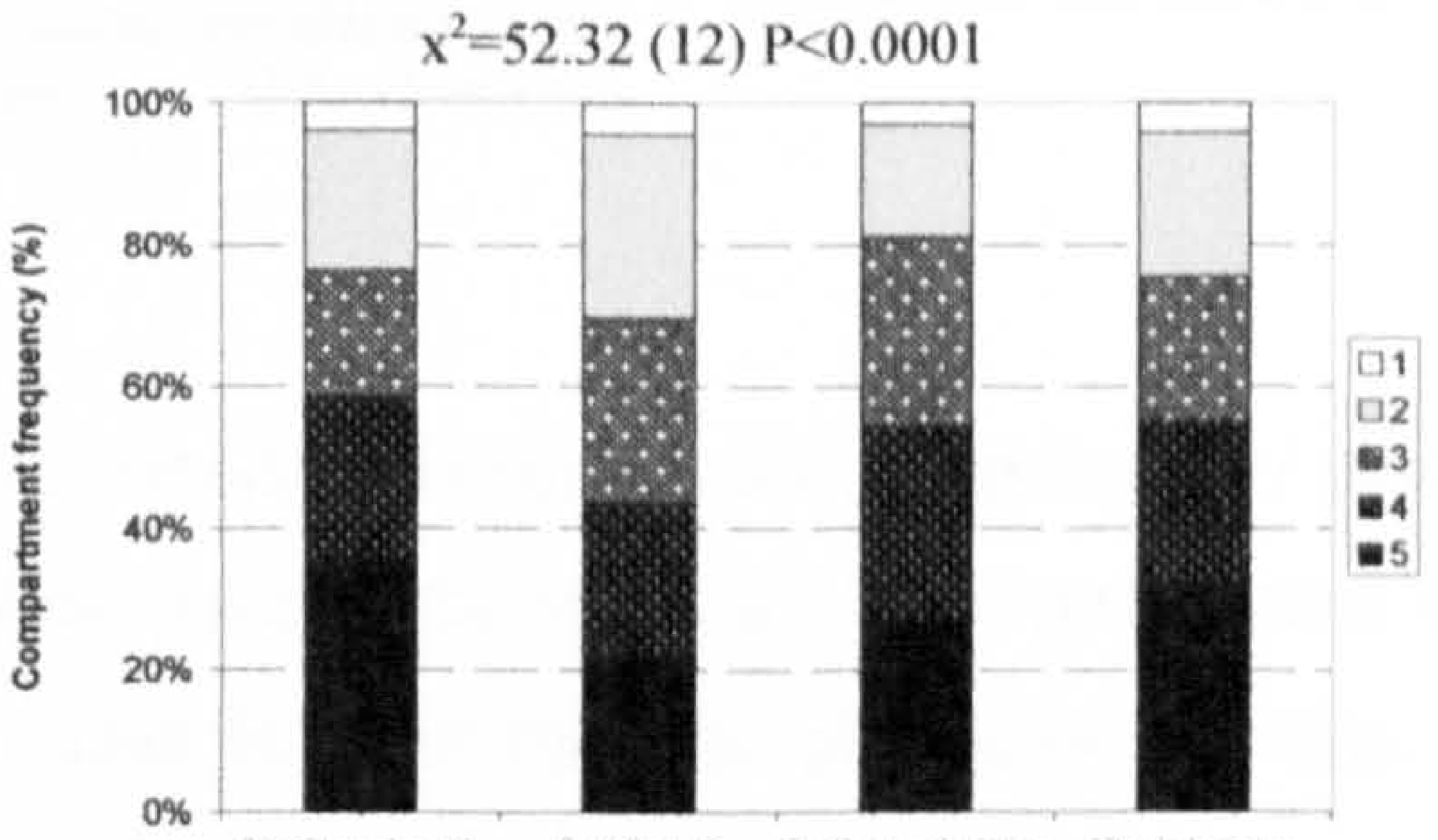


Figure 9.15
The frequency of compartments with records of the five slope steepness classes.

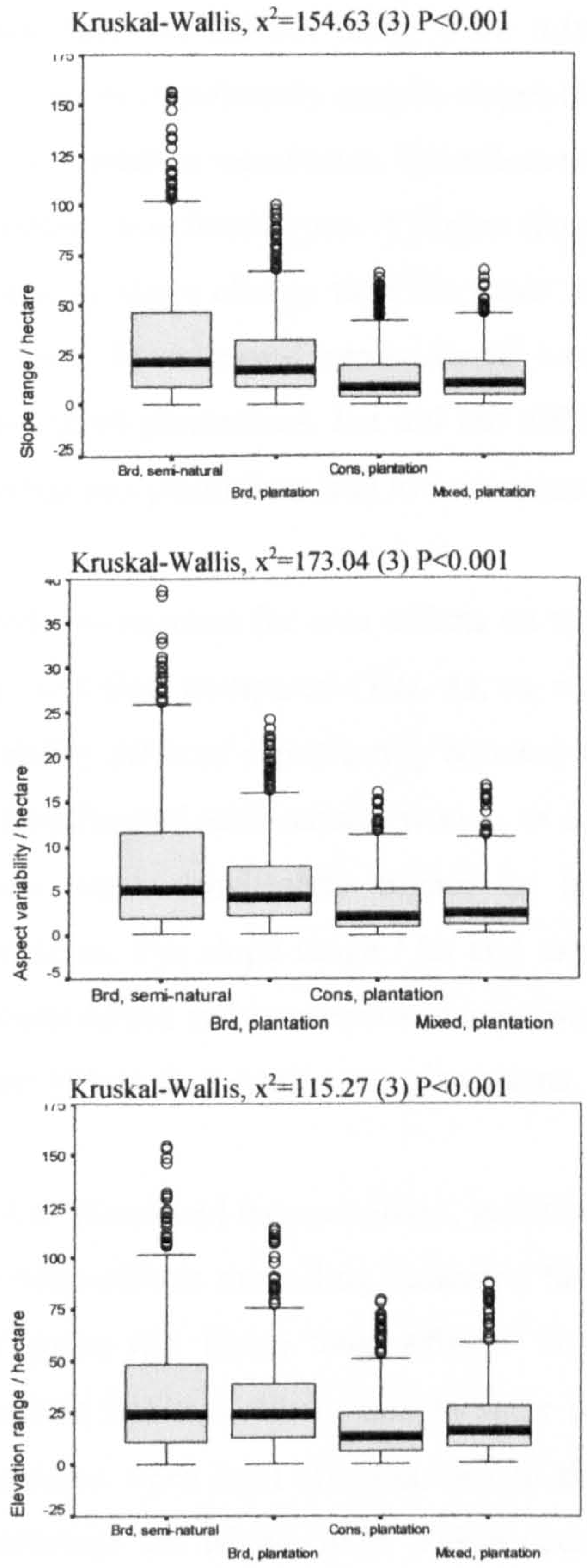


Figure 9.17
Patch topographic variability / hectare values for the main woodland habitats (Brd = Broadleaved, Cons = Coniferous). The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are shown by circles and crosses. (Populations: Broadleaved semi-natural = 612, Broadleaved plantation = 602, Coniferous plantation = 485, Mixed plantation = 312).

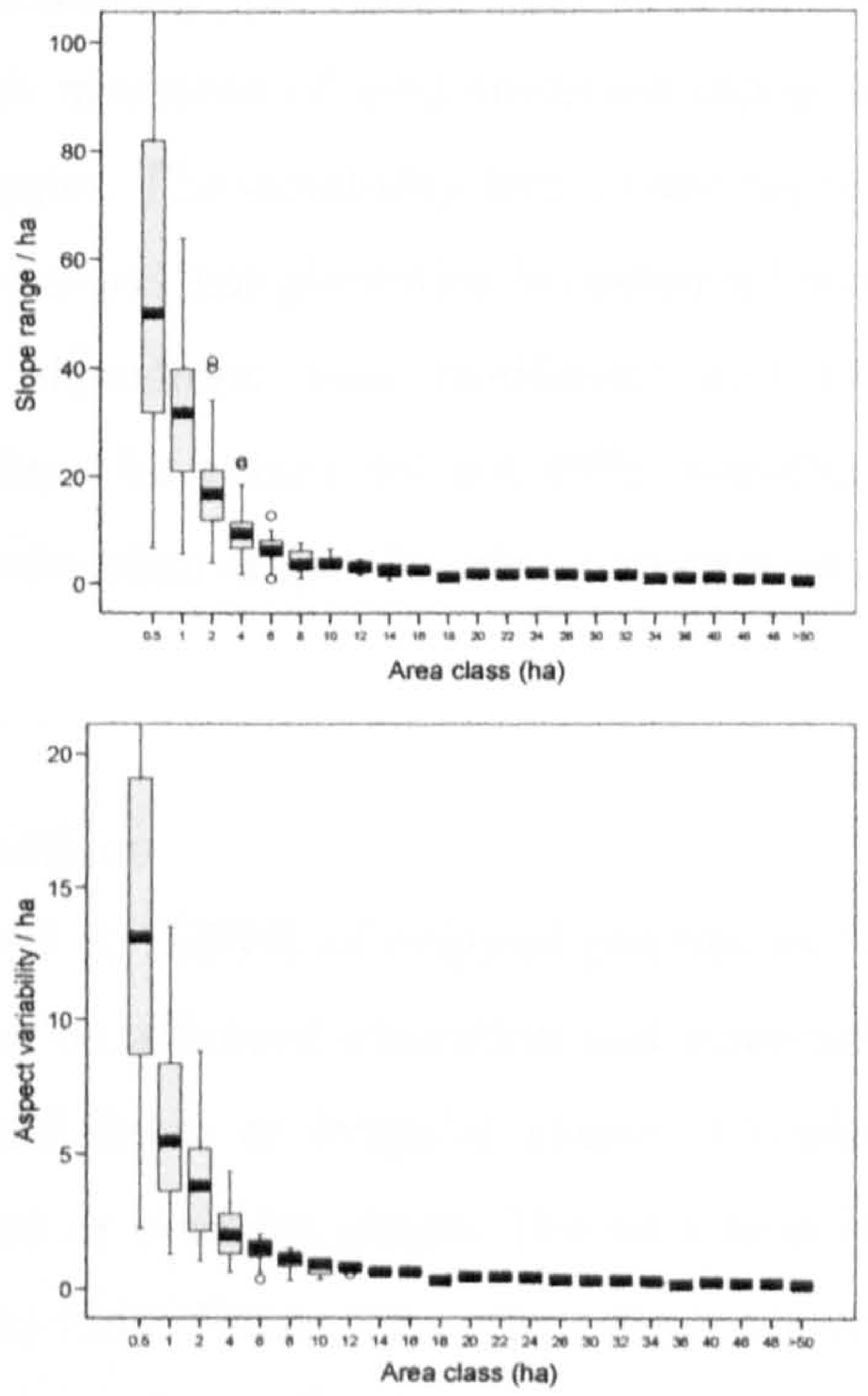


Figure 9.16
Slope range / ha and aspect variability / ha boxplots for a range of patch area size class values for broadleaved semi-natural woodland habitat patches. The plot details the median value as a thick bar and interquartile range of values as the box.

The habitats also differed in elevation range / patch, slope range / patch, mean slope angle, and minimum slope angle / patch (Fig 9.12, Fig 9.13, Table 9.8). Semi-natural broadleaved patches were generally more diverse in these features than the plantation habitats. Conditions in mixed and coniferous plantations were often similar. For some characteristics the mixed plantation woods held higher interest features than some of the other plantations, e.g. in slope range per patch and with lower slope minimum values than broadleaved plantation, indicating a wider span of ground conditions in these woods. For some measures the broadleaved plantations had lower patch variability than the other plantation types (elevation range, slope range). Broadleaved semi-natural woodland patches had higher patch slope range than broadleaved and coniferous plantations, but did not differ from mixed plantations. Broadleaved semi-natural woodlands occurred on significantly steeper slopes than broadleaved and coniferous plantation but not from mixed plantation woodlands. Broadleaved plantations had significantly steeper minimum slopes than other woodland types. A higher frequency of broadleaved semi-natural patches had higher number of slope classes than the other habitats, with typically broadleaved plantations having the least. Broadleaved semi-natural woods had significantly higher aspect variability than broadleaved plantations, but did not differ from levels within coniferous or mixed plantations. Broadleaved plantations had lower aspect variability than coniferous and mixed plantations.

In order to account for area effects on topographic variability, the values were standardised by area, and then compared (**Table 9.8, Fig 9.17**). All three measures of area-corrected topographic variability differed significantly between the habitat types. The variability levels were highest in the broadleaved semi-natural woods, or in both semi-natural and plantation broadleaved woods. Levels were consistently higher in broadleaved plantations than coniferous and mixed plantations. For slope range / ha and aspect variability / ha values did not differ significantly between mixed and coniferous plantations, while for elevation range / ha mixed plantations held higher values than coniferous plantations.

9.3.4.4 Woodland fragmentation, isolation and connectivity

The edge-effects modelling indicated habitats retained 65%-84% of original patches as "core area" (**Table 9.8**). These "edge-effects" were highest in broadleaved plantation and semi-natural woodland habitats, likely due to their small size and linear or irregular shapes. Coniferous plantations were least affected, due to their large size or compact shape. The core area index summarises the edge-effects within each habitat (**Fig 9.18**). These core area effects show the influence of the current landscape form and structure on each woodland type (**Fig 9.19**).

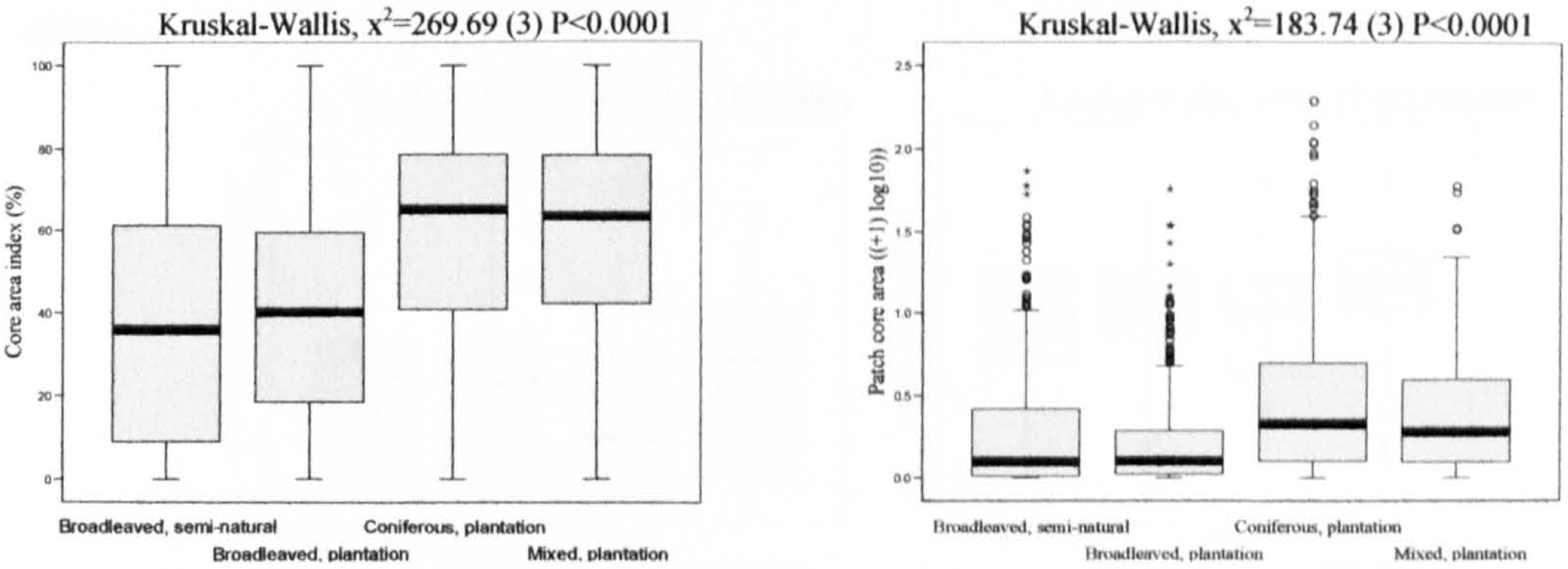


Figure 9.18
Boxplots of patch core area index and patch core area values for the main woodland habitats. The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by crosses and circles. (Populations: Broadleaved semi-natural = 612, Broadleaved plantation = 602, Coniferous plantation = 485, Mixed plantation = 312).

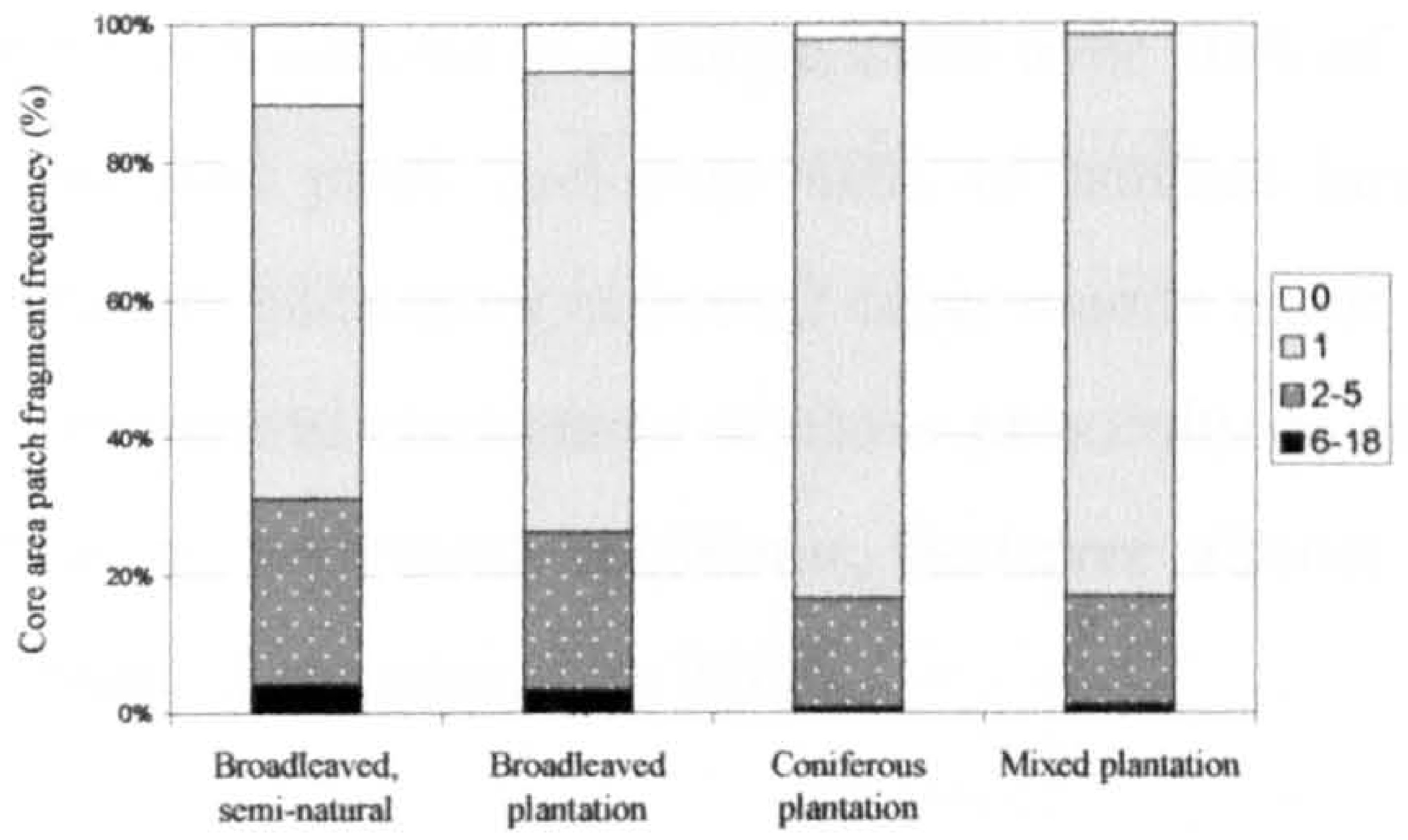


Figure 9.19
The percentage frequency of core area fragments recorded within each original habitat patch as a result of the application of edge fragmentation analysis.

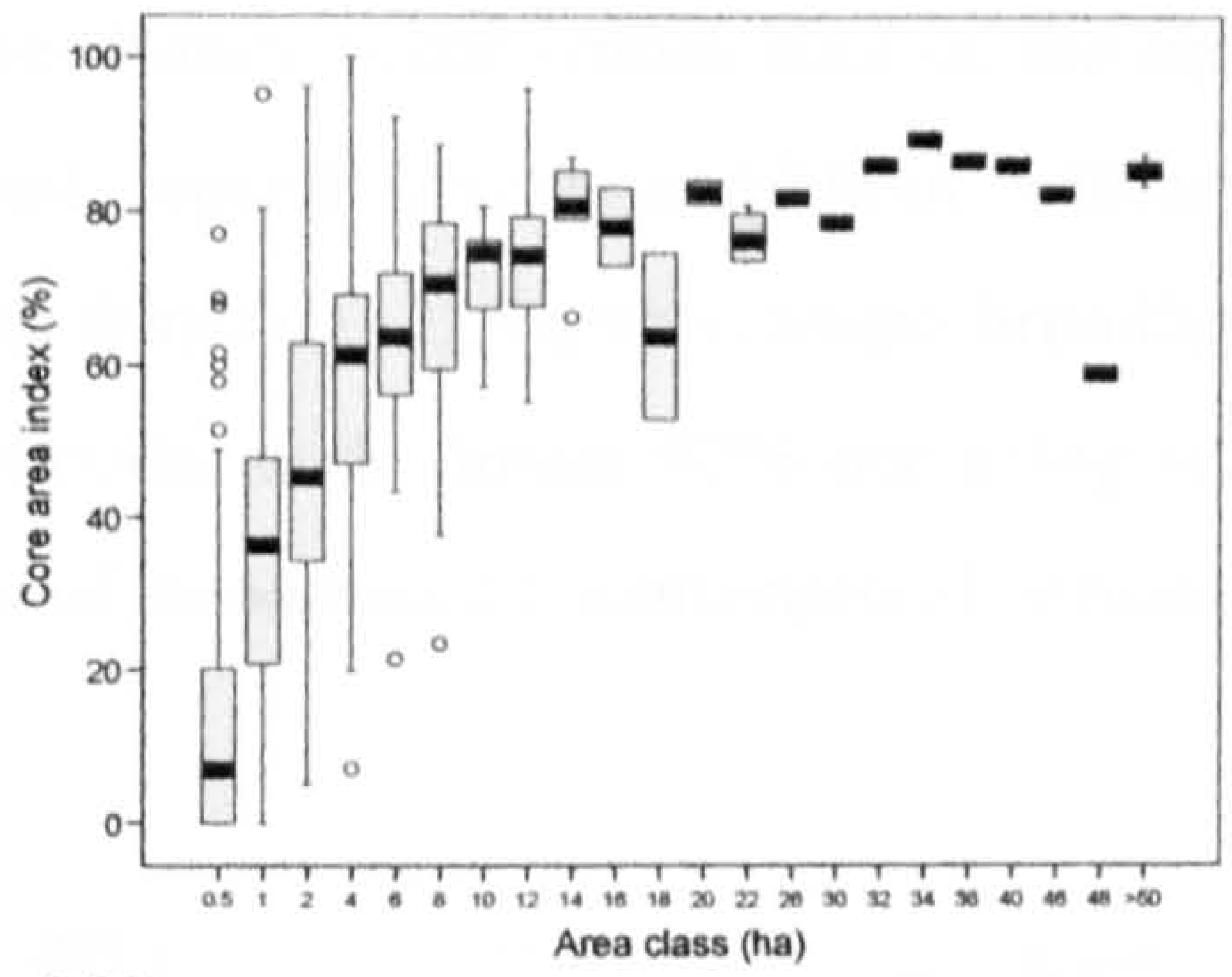
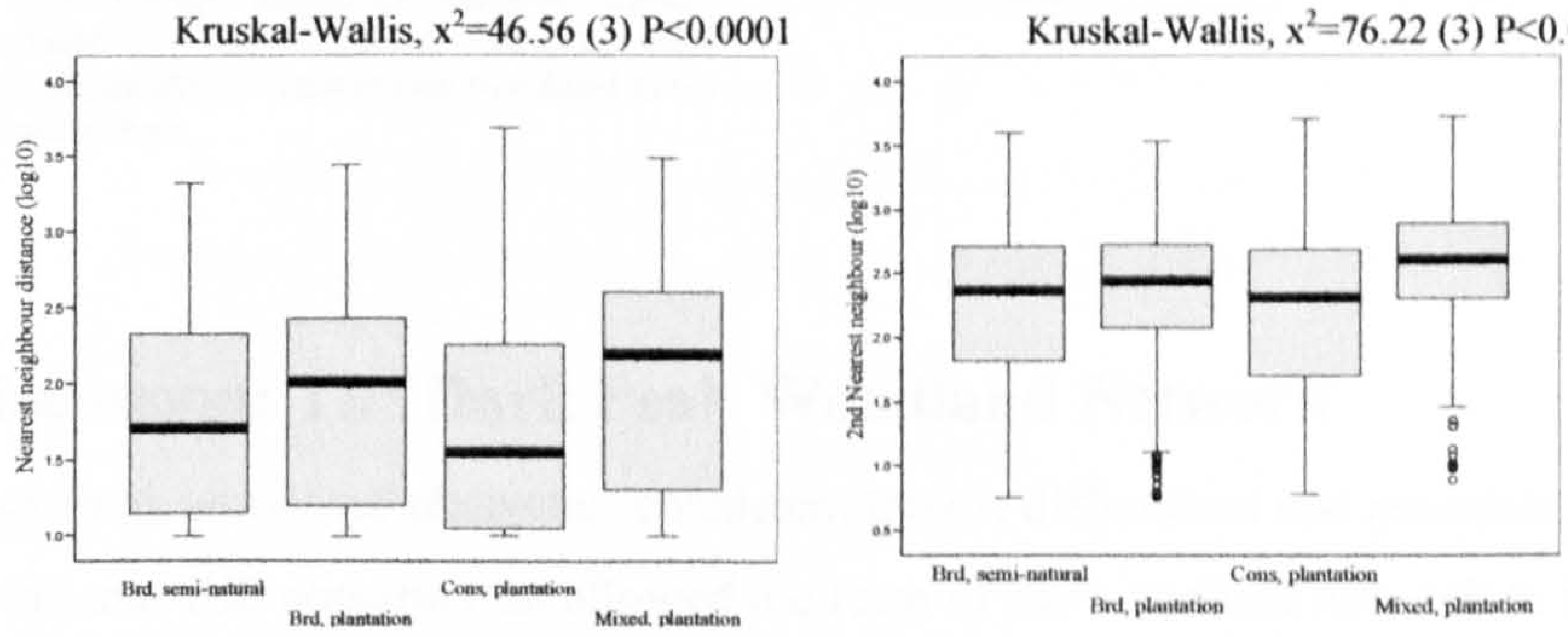


Figure 9.20
Core area index (%) plotted against patch area class for broadleaved semi-natural woodland habitat. The plot details the median value as a thick bar and interquartile range of values as the box

Patch core area and the core area index both differed significantly between habitats (Fig 9.18). Broadleaved semi-natural woods did not differ significantly from broadleaved plantations. Additionally the core area did not differ between coniferous and mixed plantations, remaining comparisons differed. The core area index of broadleaved semi-natural woods also did not differ from broadleaved plantation woods. The core area index did not differ between coniferous and mixed plantations, the remaining comparisons differed.

A common measure of patch isolation / connectivity is the nearest neighbour distance (NN). Due to the fact that woodland may occur in clusters the distance to the second nearest woodland of each habitat class were also calculated. NN distances ranged from 8m to almost 5km. Mean distances ranged from 176m to 310m. Both the 1st and 2nd NN values were found to differ significantly between habitats (Fig 9.21). For the 1st NN broadleaved semi-natural woods did not differ significantly from broadleaved plantations. However the semi-natural woods differed significantly from both coniferous and mixed plantations, all other comparison differed. Within the 2nd NN distances broadleaved semi-natural woods did not differ significantly from broadleaved plantations, but did differ from coniferous plantations. All remaining comparisons differed.


Kruskal-Wallis, x^2=46.56 (3) P<0.0001

Kruskal-Wallis, x^2=76.22 (3) P<0.0001

Figure 9.21
Boxplots of patch mean nearest neighbour and 2nd mean nearest neighbour for the main woodland habitats. The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by circles and crosses. (Populations: Broadleaved semi-natural = 612, Broadleaved plantation = 602, Coniferous plantation = 485, Mixed plantation = 312).

When considered as a single class over 70% of all woodlands occur within 80m of the nearest woodland patch and over 40% of patches have their second nearest neighbour within this distance, indicating at least 2 other woods occur within 80m (Fig 9.22, Fig 9.23). Many broadleaved semi-natural sites occur in close proximity to other woods, with almost 60% occurring within 80m of a nearest neighbour, however almost 20% of broadleaved semi-natural woods are separated by more than 320m.

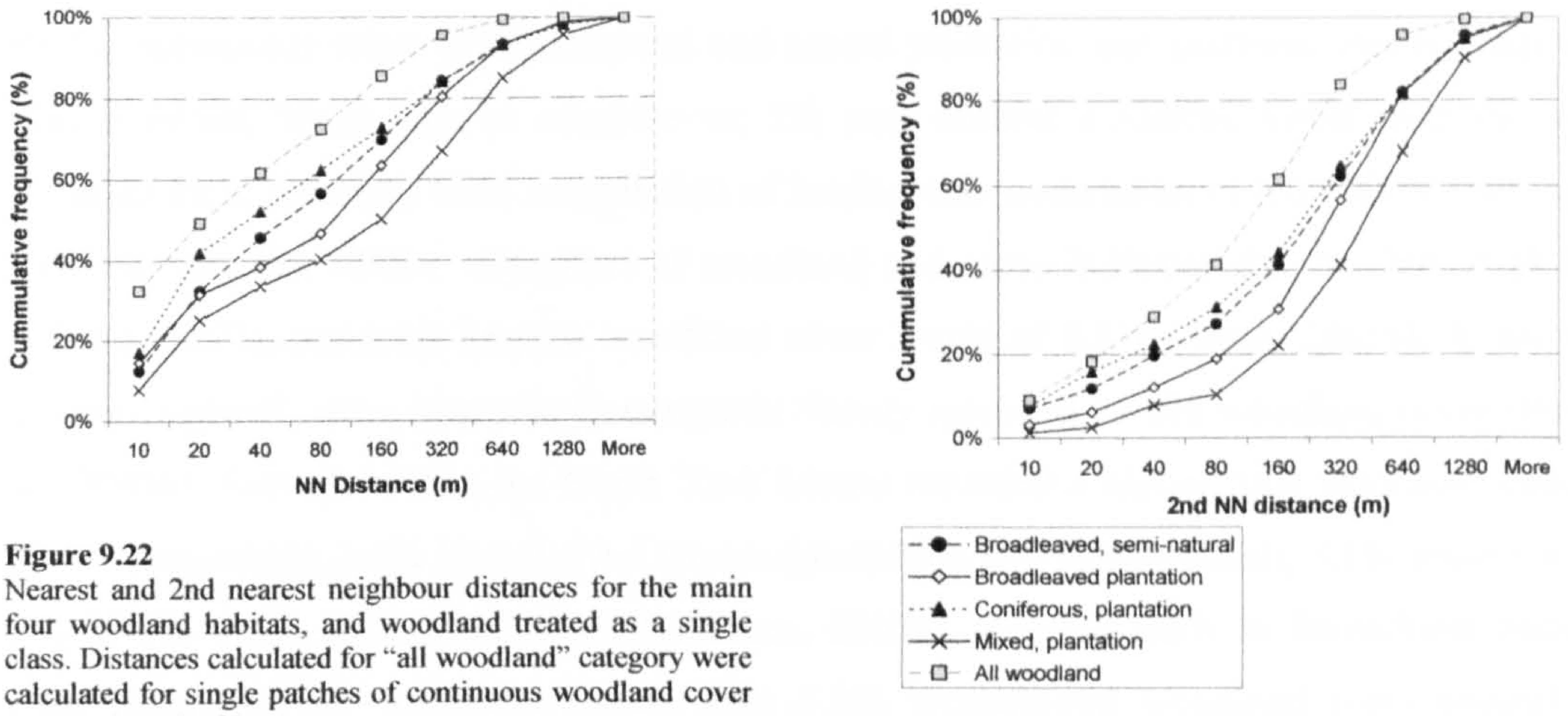


Figure 9.22
Nearest and 2nd nearest neighbour distances for the main four woodland habitats, and woodland treated as a single class. Distances calculated for "all woodland" category were calculated for single patches of continuous woodland cover irrespective of habitat type.

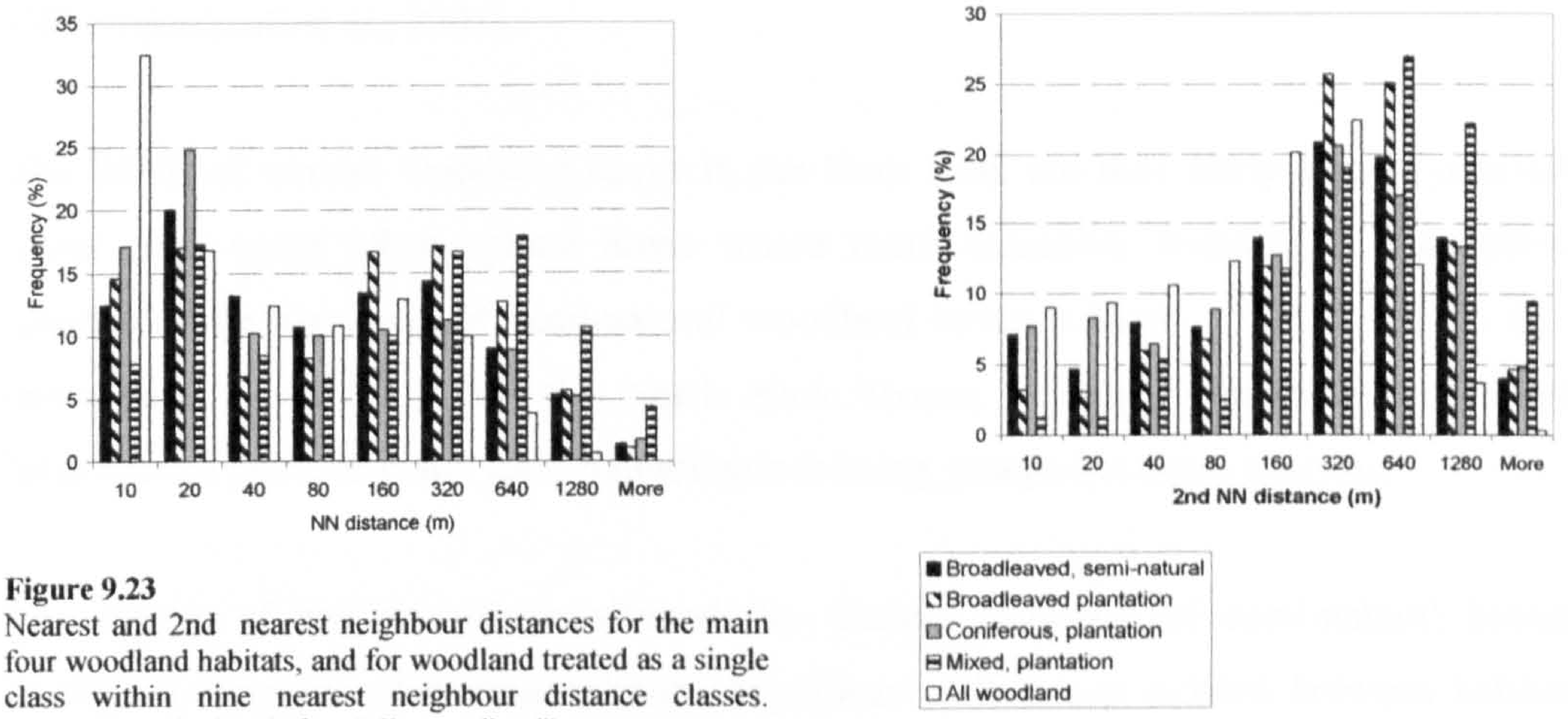


Figure 9.23
Nearest and 2nd nearest neighbour distances for the main four woodland habitats, and for woodland treated as a single class within nine nearest neighbour distance classes. Distances calculated for "all woodland" category were calculated for single patches of continuous woodland cover irrespective of habitat type.

9.4 Discussion: The Dark Peak Woodland Network

9.4.1 Dark Peak woodland character: consistent trends, differences and associations

The fieldwork and GIS construction allowed the form of the woodland network to be examined. Hypotheses generated from the literature review proposed that differences existed between the main woodland types, in terms of woodland size, shape, topographic variability and connectivity. However it was unknown how consistent such differences would be, whether they would be statistically significant, or would be sufficiently strong to allow classification or quality assessments to be made of woodland type from such variables, in the absence of known habitat type. Interpretation of the differences and trends in patch variables was expected to provide insight into the ecological associations and character of each habitat and inform conservation management options.

The Dark Peak holds approx 9% total woodland cover. The majority comprised coniferous plantations, however 25% of cover was semi-natural broadleaved woodland (c.2% of Dark Peak). Substantial areas of broadleaved and mixed plantation and scattered tree habitats were also recorded. These figures compare to: 2% semi-natural woodland cover over the wider National Park, resulting from compilation of habitat data undertaken in the 1990's (Ecological Advisory Service, 1993), 6% cover of woodland and scrub indicated for the Dark Peak ESA (ADAS, 1997), and total English woodland cover levels of 8.6% (Anon, 2005a). Analysis of sample "upland" areas from the Countryside Survey recorded 11.8% woodland cover (Petit et al., 2004b). Surveys within the North York Moors recorded a higher total woodland cover of 21.6% comprising 4.4% broadleaved woods (plantation and semi-natural), 3.1% mixed woods and 13.9% cover of conifer woods (Peterken, 2002a). Another study in Snowdonia National Park reported 15% woodland cover, with 3.8% broadleaved woodland (semi-natural and plantation) and 0.6% scrub (Gkaraveli et al., 2001). Broadleaved patches were typically mean of <4ha (Gkaraveli et al., 2001).

The levels of overall woodland cover in the Dark Peak are thus fairly typical nationally but lower than some other upland areas where more extensive commercial plantations have occurred. The low level of semi-natural woodland cover is likely to be similar to the levels recorded in Snowdonia and the North York Moors, although fine analysis is limited by broadleaved plantation and semi-natural woods being grouped in those analysis.

The results of the analysis confirmed the distinct character of semi-natural broadleaved woodland from the plantation habitats. Significant differences existed between habitats in a wide range of variables, although the characteristics of individual woods varied widely within each habitat type, as evidenced by the spread of data points within the PCA plot (Fig 9.3). The PCA results showed that the variation in individual woodland characteristics could be explained by several functions. Trends were apparent in woods between woodland size and shape and topographic variability. Woods with high topographic variability (aspect, slope range) tended to be small. However at a patch level high topographic variability was associated with larger patch size. Woodlands occurring on steeper slopes often had higher topographic variability levels. Examination of the trends within woods showed that generally indicators of patch topographic variability were correlated with each other, and the measures of area corrected topographic variability were also inter-correlated. The measures of patch shape were also correlated and showed a range of woodland shape complexity, although these generally explained less variance among sites than topography. The PCA also showed that woods with a higher slope minimum value, occurring mostly on slopes, tended to have high topographic variability per unit area, and be small. The initial analysis and PCA analysis revealed the value of using the slope minimum patch value which can be interpreted together with slope range and slope mean values to indicate if woodlands span a wide range of topography including level stream valleys, as within cloughs, as opposed to woodland sites occurring wholly on sloping valley sides.

The DA analysis gave insight into the particular abiotic variables that differed most between the woodland habitat types. High correlating variables on function DA1 were aspect variability / ha, slope range / ha, elevation range / ha and fractal index. High correlating variables on function DA2 were area, slope range and elevation range. These indicate the variables differing most between the habitat types. The DA analysis revealed how the two measures of topographic variability per unit area – aspect and slope range were particularly effective at discriminating between the different habitat types, semi-natural woods have higher variability per unit area, even where, due to their often small size they may have low topographic variability per patch, compared to the larger plantation woods. Slope range per patch and patch area were also shown to be particularly effective at distinguishing between the different habitat types (Fig 9.4).

Overall the analysis confirmed a strong association between small woodland size, shape complexity and topographic complexity being associated with semi-natural woodland cover and larger more simple shaped woods with low inherent topographic complexity per unit area in plantation woods. However the predictive ability of these characteristics applied to unknown woodland sites resulted in low classification ability, confirming that, as suggested by examination of the PCA and DA plots (Fig 9.3, Fig 9.5), that although these factors typically differ between sites each group contains a wide range of values. This association of semi-natural woods with topographically diverse locations and steeper slopes confirmed results found by previous authors (Stahle and Chaney, 1994, Therrell and Stahle, 1998, Larson et al., 2000). The classification accuracy utilising these relationships was lower than studies in America that used examination of patch elevation values and patch terrain type to distinguish different woodland types using a numeric terrain index which achieved an accuracy rate of 54% to 57%, using a 30m DTM to derive topography (Bolstad et al., 1998).

Examination of the group centroids on the DA plot (Fig 9.5) reveals association between mixed and coniferous plantation woods and shows broadleaved plantations closer to semi-natural woods. The key differences in patch size, shape and topography were supported by analysis of the univariate differences in variables between groups (Table 9.8). Although interpretations of the DA axis should be treated with some caution due to the violation of some test assumptions the associations and differences are backed up by univariate analysis of the individual variables and by a comparable Logistic Regression analysis which is not subject to the same range of assumptions as DA which confirmed very similar classification rates and retention of significant input variables. The PCA functions also differed among groups when tested, but some characteristics did not differ between pair-wise comparison of habitats (Fig 9.3, Table 9.6). The woods showed some similarity in size and topography per unit area between broadleaved semi-natural woods and broadleaved plantations. Additionally patch size, patch topography and shape conditions were shown to be similar between coniferous and mixed plantations (Table 9.6). Interpretation of the results of individual univariate analysis confirmed trends in similarity between the two broadleaved habitats, and between the mixed and coniferous plantations (Table 9.9). For many variables there is no difference between values in semi-natural broadleaved woods and broadleaved plantations on one hand and between mixed plantation and coniferous plantation on another: area, core area, core area index, mean elevation, aspect variability / ha. For some variables however mixed plantations show higher interest features than broadleaved plantations or the levels between the two are similar. The circle index recorded similar values in broadleaved and mixed plantations, while broadleaved plantations had the lowest elevation range and slope range of each habitat. The fact that broadleaved plantations had such low topographic variability values and also higher slope minimum values than other habitats indicates these woods tend to occur on uniform slopes of valleys rather than within cloughs, where woods cover a wider range of conditions, including level valley floors. Therefore often mixed plantation patches will be more variable and topographically diverse than broadleaved patches. However such relationships are strongly influenced by the association of topography with patch size. When topographic variability per ha variables are examined it can be seen that per unit area broadleaved plantation do tend to be more similar to semi-natural woods and more diverse than mixed plantations.

Moving beyond analysis of within-patch features to an examination of the association between woodland patches and their surrounding landscapes revealed a number of interesting features in core area and isolation. Semi-natural broadleaved woodland was highly affected by the modelled edge-effects. Even with the modest edge distances examined (lower than some UK studies) the median core area within semi-natural woodland patches was only 36% of the patch while a median of 65% of coniferous woodland patches was recorded. This is a factor of the typically small size of these woods and their complex shapes causing edge-effects to comprise a significant proportion of each wood. In the North York Moors National Park Peterken used 100m for core area calculations and found 51% of woodland occurred as core areas, but noted that typically broadleaved woods contained very little (8%) core area due to their size and shapes, with conifer plantation having much higher 68% as core area (Peterken, 2002a). Another study in Snowdonia National Park also utilised 100m buffers and consequently reported very low areas of core woodland habitat. Additionally the analysis showed these woods were often fragmented into separate areas such that previously single wood may hold several isolated areas of core habitat (Fig 9.19). The nearest neighbour (NN) isolation shows the spread of woodland adjacency values and clustering between the woodland types. Broadleaved semi-natural woods have 60% of sites within 80m of a nearest other semi-natural wood. However the wide range of NN distances includes woods isolated by much larger distances, with 20% of semi-natural broadleaved woods being isolated by more than 320m. Comparison of NN and 2nd NN distances reveals that while many woods may have a neighbour in relatively close proximity they are not necessarily close to several other woods at this distance. 2nd NN distances are considerably further than 1st NN with many being several hundred metres isolated from a second nearest neighbour (Fig 9.22, 9.23, Table 9.8). In semi-natural broadleaved woods while 45% of sites lie within 40m of a nearest neighbour, 40% lie more than 160m from their second nearest neighbour.

This analysis of Dark Peak woodland patch character showed that, as expected from past research, that many patch variables were strongly inter-correlated. The results showed a strong association of patch size with topography levels and highlighted that area-corrected topography values differed strongly between the habitats, plantations being much more uniform per unit area than semi-natural woods. These topographic variability (aspect / ha, slope range / ha, elevation / ha) proved to be important in distinguishing between the woods, suggesting value as measures of diversity in such conditions. Despite overall differences in conditions between habitats patches of each wood type exhibited a wide range of abiotic conditions such it is useful, to summarise woodland conditions to sue both woodland habitat type and abiotic values as measures. The results also highlighted that small woodland sites can be complex and topographically variable, and that although generally topographic variation increases with patch size, small woods should not be dismissed as being uniform and less variable. Although woodland habitat is a very useful predictor of woodland condition it does not exclusively reveal potential woodland abiotic conditions, for example for conservation or restoration. The use of the original variables such as topographic variability show a range of values even within a habitat such as coniferous woods which typically have low topographic diversity

9.4.2 Causes of woodland habitat character: interaction of management and topography

The differences in character between the woodland types reflect differences in woodland origin and management. There are likely to be strong associations between management factors and accessibility, land value and features related to woodland origin, either through deliberate woodland creation or where wood existence has been resultant on land management actions.

Figure 9.24
Clough woodland sites

Semi-natural broadleaved woods were shown to be the most topographically variable, typically to be small, long, elongated and complexly shaped (Fig 9.24). These characteristics reflect the frequent occurrence of semi-natural woods within clough and valley landscape features. Semi-natural woodlands have not held high economic value in recent times and occupy positions on landholdings or estates that are unproductive and have not been utilised for other forms of agriculture. These are therefore the steep sided valleys, slopes and narrow ravines / cloughs where such woodland has been retained. This is reflected in the high variability such sites hold, valleys holding many ranges of slope and aspect. There may also be some association between these extreme conditions on semi-natural sites and a lack of grazing where some such sites may be relatively inaccessible to stock. Wood shape and complexity values also largely reflect the woods occurrence in valley cloughs. However where such woods occur within, or border, enclosed farmland they may reflect the fact that such wood boundaries and enclosing walls are very old in construction, following natural topography lines, parish boundaries or old landholding areas in an irregular form, rather than the more rectangular lines of farmland typified by the enclosures acts. The distribution of these woods may also reflect differences in the current management and value of broadleaved plantation woods and semi-natural woods. Less accessible and perhaps remote older broadleaved plantation are less likely to have been managed in recent times and therefore may have reverted to become semi-natural woods. Conversely some of the larger more uniform and accessible semi-natural woods may have been removed or converted to plantation in recent times, leaving only the more remote, inaccessible semi-natural woods occurring in the cloughs and valleys. Because of their current small size, complex shapes and location away from other woodland types, these semi-natural woods are predicted to be highly affected by edge-effects resulting in low core areas within such woods.

The occurrences of woodland within the Dark Peak are constrained by landscape features such as the central moorland core and the many areas of floodplain or farmland plateau, where woodland is very rare. These cause woodland to be highly typical of the riparian network which, at a landscape level, due to its dendritic pattern, is inherently clustered. On an individual patch level wide ranges of isolation from nearby native woodland occur. This is a reflection of the low cover of semi-natural broadleaved woods, that they are scattered through areas of the riparian network and although locally may be clustered in areas of valleys also include some very remote sites in the moorland fringe where other nearby semi-natural woodland cover is now very rare, leaving them isolated. Examining the isolation distances shows that there is a slight trend for woods at lower elevation and with more complex and elongated shapes to have lower isolation values, again fitting with the explanation that the larger clough valleys and networks in the moorland fringe areas have more closely connected woods while the upper moorland slopes and more isolated smaller moorland cloughs tend to hold increasingly isolated woodland. There is some indication that the fragmentation of these woods may be due to high grazing levels over past decades such that many semi-natural woods have been lost or declined (Anderson, 1982, Good et al., 1990), while in other areas they may have been converted to plantation cover, leaving the current isolated and fragmented resource.

Broadleaved plantations show a number of affinities to the semi-natural woods, being relatively topographically varied per unit area, and occupying smaller and more complexly shaped sites than mixed or coniferous plantations. These characteristics may reflect the fact that such broadleaved plantation may be the older long managed and more traditional locations of plantation woodland in the Dark Peak, possibly occupying areas of unproductive land within a farm or estate, where traditional woodland management techniques could allow timber to be grown and extracted where other land-uses were not applicable. Such locations therefore may have been close to the farmstead in steep ravines, cloughs or sloping banks similar to semi-natural woods. However these sites were typically more compact in shape and had higher minimum slope angles but lower mean slope angles than semi-natural woods reflecting the fact they probably occur as features on single-sided slopes within farms spanning the steeper unproductive slopes but do not extend onto lower slopes or occupy the full clough position of double sided valleys including the stream floor / floodplain and very steep upper slopes as semi-natural clough woods do. The less complex shapes probably reflect the fact these areas, although possibly with irregular boundaries, must have been fully enclosed and stock-proof to allow management and prevent grazing. These drystone walls therefore may enclose the site and some such plantation woods may date from the times of the enclosure act where boundaries would have been highly regular with low shape complexity. The current distribution and character of these woods may also reflect differences in their current management and value. The larger and more accessible traditional broadleaved plantations which may previously have existed within the area may have been more likely to have been converted in modern times to mixed or conifers plantations, leaving the small and less accessible sites that remain as broadleaved plantation today. Because of their current small size, complex shapes and locations broadleaved woods are predicted to be highly affected by edge-effects, resulting in low core areas within such woods. The broadleaved plantations have a wide range of isolation values.

These sites have higher isolation levels than broadleaved semi-natural woods, although this was only significant for 2nd NN values. This indicates that such woods are less clustered than some semi-natural woods, occupying sites that, although associated with the riparian network in places, are also spread though areas of steeper slopes and banks within farmland and therefore may be less closely associated with neighbours than semi-natural woods. Overall broadleaved plantations are likely to reflect a mix of relatively long-established plantations (that have been traditionally managed and close to farms, producing local timber), to woods in areas of commercial plantation woodland (which individually are likely to occur as compartments within larger plantation sites, including broadleaved and mixed plantation areas). Recently planted commercial broadleaved plantations are more likely to occur on richer soil on level areas than other plantation types in order to achieve sufficient yields from the timber.

Mixed plantation woods show a range of similarities and affinities to conifer woods having similar size and low topographic variability. However they tend to occur on steeper slopes than conifer plantations and have slightly more complex shapes, and be more elongated. Mixed plantations occupy a total area similar to that of broadleaved plantation and lower than that of coniferous plantations. These plantations occur at similar elevations to coniferous plantations and are generally higher than broadleaved plantation and semi-natural woods.

Mixed plantations may arise from a variety of sources. They may occur as purely recent plantations on ground that was previously open, e.g. grazing land on the moorland fringe, or they may arise from planting into broadleaved plantations or broadleaved semi-natural woodlands. Mixed plantations have some features typical of low variability plantation sites, having similar area and shape to conifer plantations. However these woods have patches with high patch topographic variability (slope, elevation, aspect, variability). On a patch basis they span a range of conditions, but when variability per unit area is examined the levels of variation are less than both the semi-natural broadleaved and broadleaved plantation sites. Mixed woods have lower edge-effects than broadleaved woods. This is likely to be due to their frequent occurrence within larger plantations. Mixed woods have higher nearest neighbour values than all other woods. This may be due to the fact that these woods occur as a component of commercial plantations, found on the moorland fringe. These woods are likely to be divided by expanses of moorland or areas of conifer plantation. Mixed plantation were also found to have the highest nearest neighbour isolation value in a recent study in Snowdonia National Park (Gkaraveli et al., 2001).

The range of features displayed by mixed plantations can be explained by their origin. Most were probably created on previously unwooded land as commercial plantations and are likely to occur as part of large commercial plantations. This explains their low topographic diversity and simple shapes. In the moorland fringe many sites were created from open habitats and bordered by fencing, rather than the irregular boundary drystone walls typical of the enclosed farmland. However mixed plantation woods also occur where conifers were planted into longer established broadleaved woodland or where broadleaves naturally colonised or re-grow within conifer plantations. In such cases the conifers may subsequently have struggled, or the planting failed, allowing varying levels of broadleaved cover, some of it natural, to remain. These may be the sites which cause some of these woods to have higher topographic diversity or more elongated shapes than coniferous sites and thus have a higher conservation / restoration value.

Coniferous woods were the most distinct woods from semi-natural broadleaved woods, being larger, less complexly shaped, more compact and with lower topographic variability per unit area. The total area of these woods is also much larger than of any other wood type. These woods occur at high elevation and have much lower edge-effects. This is likely to be due to the methods of creation of these woods. Coniferous plantations are a relatively new habitat within the Dark Peak only becoming increasingly frequent from the late 1800's / early 1900's and most current commercial plantations date from the 1950's onwards. These woods occupy large, easily planted sites, often following ground preparation such as ploughing. They are likely to occur as part of larger plantation complexes with other plantation types, accounting, together with large patch size, for the low edge-effects. These woods are often divided by access roads and tracks or otherwise occur in highly accessible areas with good road access, they are frequently separated from adjacent forestry compartments only by short distances of road, track or firebreaks, resulting in the low NN values recorded. The relatively strong aggregation of this habitat, as indicated by the low isolation values reflect the occurrence of several key clusters of conifer plantations occur, e.g. around Matlock Moors, and around most of the larger reservoirs.

9.4.3 Landscape-scale conservation strategies and patch quality assessment

9.4.3.1 Conservation opportunities and habitat type

The analysis of the woodland habitats and of the associations between patch occurrence, size, shape and topography provide a number of insights of use to assessing habitat quality and planning conservation strategies. Initially in assessing the different areas of each habitat the high occurrence of scattered tree habitats was noted as representing a strong potential habitat for targeting to conversion / restoration to native woodland cover. This is due to its high frequency, the total area covered, and the fact such habitat may represent areas that were previously wooded, but have been reduced by grazing to scattered tree cover. In assessing the differences between the woodland types the strong association between broadleaved plantation and semi-natural woodland informed that such plantation are likely to offer high conversion potential to native wood cover, especially where high topographic diversity occurs. In contrast coniferous plantation was shown to differ significantly and is expected to generally offer very poor conversion or restoration potential to native woods, especially where locations are on gentle slopes on the moorland plateau. This contrasts with some previous studies that noted the most practical and appealing way of creating new native woods in the uplands would be through conversion of existing conifer plantations (Worrell et al., 2002). In addition to conifer woods mixed plantations were shown to hold low similarity to native wood types, although situations were considered to exist where mixed wood could occur in topographically diverse locations, where restoration potential may be high and such woods may represent previous broadleaved plantation or semi-natural woods that have been converted to commercial plantation cover. For scoring purposes mixed plantation woods is to be more highly favoured for restoration than coniferous plantations.

9.4.3.2 Measures of habitat quality and abiotic indicators of diversity

Despite the strong associations of particular abiotic conditions with habitat type, the analysis has shown that there is a strong spread of values within each habitat and therefore while broad generalisations can be made on patch condition using habitat type as an indicator, that where possible habitat quality assessments should relate directly to measurement of patch conditions. Overall the analysis showed the important use of topographic diversity and patch shape complexity and compactness in distinguishing key characteristics of semi-natural woodland sites. If new semi-natural woodland were created, or plantation woods were converted to semi-natural cover that lacked this range of abiotic conditions, they would be expected to prove slow to acquire the range of ecological interest and diversity present in existing semi-natural woodland sites.

In analysing the range of conditions within the Dark Peak network the results showed a strong relationship between patch size and topographic diversity. The positive association between variability measures and patch size is to be expected from landscape ecology and island biogeography theory, but very few studies have measured, compared or reported such features, e.g. topographic diversity between woodland types. One exception is a study showing the expected positive correlation between elevation range and patch size (termed topographic diversity) ($r=0.61$) (Dumortier et al., 2002). Several other studies have noted the correlation between factors such as number of soil types, range in soil pH or occurrence of features such as streams and ponds (Peterken and Francis, 1999, Peterken and Game, 1984). Similarly several studies have modelled soil formation or type by examining topography variables (Gessler and al, 1995, Thomas et al., 1999, Thompson et al., 2001a), but no studies were found that recorded the detailed range of woodland patch topography as within the current study. However, a number have examined a broader range of features associated with topographic diversity and could be termed more broadly "habitat diversity". Slope class and aspect variability are both thought likely to affect soil development within a patch. Past studies have shown that numbers of soil types and soil pH range have been associated with patch size (Peterken and Game, 1984). Past studies have used various forms of surrogate data including slopes and terrain information to model soil type occurrence and form e.g. (Ryan et al., 2000, Thomas et al., 1999), while others have explicitly used indicator variables such as patch fractal dimension index as a surrogate for micro-environment diversity within woodland (Honnay et al., 1999a). Studies in Holland recorded a positive association between the number of forest communities and patch size, which may be thought to be positively affected by both topographic diversity and patch size, although it was not measured directly (van Dorp and Opdam, 1987).

9.4.3.3 Woodland size thresholds and diversity

In terms of creating new semi-natural broadleaved native woods or improving the woodland network, analysis of the existing conditions provides insight into a number of thresholds or size / range limits. Most existing native woods are small, over 60% are less than 1.6ha, almost 80% are less than 3.2ha and 90% less than 6.4ha. However some big sites do occur and these contribute strongly to the total area of the habitat with almost 40% of the total resource occurring in woods of larger than 12.8ha. Therefore while patches sizes currently are small, bigger woods are important, although woods larger than 50ha are very uncommon and therefore not characteristic. These size ranges match those examined in previous UK studies examining avian fauna. These examined woods in the range 0.02 – 30ha (Bellamy et al., 1996a, Bennett et al., 2004), 0.7 – 14.5ha (McCollin, 1993), 0.12 – 62ha (Helliwell, 1976), and several European studies showed similar values (van Dorp and Opdam, 1987, Opdam et al., 1985, Opdam et al., 1984). The majority of woods in these studies also tended to lie to the lower end of the patch size range. In such landscapes woods above 10-20ha in size were considered to be large while woods beyond 50ha were atypical. In his study of woodland cover in the North York Moors National Park Peterken considered woods below 5ha to be small, between 5-30ha to be medium and those above 30ha to be large (Peterken, 2002a).

Due to the potential for association of biodiversity with topographic variability and patch size analysis was undertaken to determine if any thresholds existed over which diversity was highest, which may be of use in conservation planning. Slope range, slope class variability and aspect variability and variability / ha values were examined over a range of patch size classes (Fig 9.14, 9.16). In semi-natural broadleaved woods aspect variability rises rapidly with patch size class until approx 16 ha, above which most woods include all the aspect ranges, although the relationship is complicated by the lower numbers of woods in the higher size categories. Additionally most woods above 8ha show evidence of 8 of the 9 aspect classes, and even by 2ha the typical median is 6. Slope class variability indicated most woods above 1ha held 4 of the 5 possible slope classes, while woods above 4ha tended to include all possible slope classes. Examination of the range in values of the combined topography index showed a more gradual increase until maximum topographic diversity values were reached. It was not until patches reached between 16ha-24ha that the highest ranges of diversity were constant. Additionally, the core area index also shows a more gradual relationship to patch area, with patches approaching 80% of the patch as core habitat, once size reaches approx 12ha or 14ha. Crude summaries of these trends could be used to note that typical semi-natural broadleaved woods would be expected to hold high levels of topographic diversity and core conditions above thresholds of approximately 2ha, 10ha and 20ha. Generally larger woods are preferable, and will be expected to hold a more diverse range of conditions, but the analysis of within-patch area corrected variability levels also shows that small woods should not be dismissed outright. Some small woods can contain high within-patch diversity features, compared to their size. For future conservation planning purposes examining woodland creation / restoration where woodland size is being utilised independently as a diversity predictor then such thresholds can be of use in indicating likely abiotic diversity level for woods in the Dark Peak. However wherever possible such planning is recommended to be based on measurement of the actual underlying abiotic diversity features as they will not always reflect the size of the wood.

9.4.3.4 Landscape position and connectivity

Insight from the analysis can also be gained on suitable landscape position for woodland conservation. Current woodland cover does not occur above 507m, while areas of scattered trees all lie below 449m. Established woods were limited to slopes below 57 degrees and scattered trees below 54 degrees. These limits are of use in considering the current potential environmental limits of woodland cover when planning further expansion or creation areas. Examination of results shows that native woods at higher elevation are more uncommon than expected. This is perhaps due to such locations being beyond the limit of enclosure where high grazing may have eliminated such woods in comparison to woods bounded by walls within farmland or due to the constant negative effects of intensive moorland burning regimes. Therefore consideration should be given within strategies to considering woodland expansion towards the higher elevations where native woodlands are currently uncommon.

Broadleaved semi-natural woodlands tended to occur together in riparian systems and conifer plantations to be clustered in several areas, such as around the major reservoirs, along valley edges or in locations along the moorland fringe. This shows the relative clustering of woods, and that potential exists in many areas to link woodland sites over relatively short distances. In particular due to the clustering of plantation sites opportunities exist to reduce semi-natural broadleaved isolation by converting nearby plantation to semi-natural woods. Many woods are likely to currently experience detrimental isolation effects at the levels recorded. Previous authors having classified woods as isolated when more than 10m (Peterken and Game, 1984) or 100m (Jacquemyn et al., 2003) from potential source woods. Therefore careful use of woodland buffering, stepping stone or envelop planting strategies may need to be considered for Dark Peak native woods (Buckley and Fraser, 1998).

9.4.3.5 GIS and landscape planning summary

The presentation and analysis of the data for the Phase 1 woodland network hold several implications for using GIS data for conservation planning. The distribution of the woodland cover is not random within the Natural Area but is significantly clustered into particular landscape zones, within which each of the main woodland habitats are also clustered. Examination of the data confirm several hypothesis used in landscape planning. Data confirmed that larger patch size were associated with more variable topography and greater presence of internal core area indicating a general preference for the enhancement or creation of larger sized woodland patches to ensure diverse conditions exist for potential variations in woodland community development. The analysis of the existing network suggests that patch size, shape and importantly topography can be used to define characteristics that are similar and characteristic of the current woodland network. Patch size threshold to achieve this diversity may be able to be set or alternatively direct analysis of topographic diversity and patch shape could be used to assess potential patch value for conversion, restoration and creation.

Figure 9.25
Distribution of woodland and associated habitats in the Dark Peak

Figure 9.26
Distribution of classified woodland habitats in the Dark Peak

9.4 Chapter Summary

Dark Peak woodland cover and context

- Woodland habitats comprise approx 9% of the Dark Peak landcover
- Smaller but significant areas of scattered trees habitat also occur (1.3% of Dark Peak)
- Woodland cover is dominated by coniferous plantations (44% of woodland cover)

Broadleaved semi-natural woodland character

- Cover a small proportion (2%) of the Dark Peak Natural Area
- Typically small, complex shaped, elongated / linear in and have high levels of topographic complexity for their size
- Occur in clough valleys where they span a wide range of slopes (often including the low or level slopes of the stream valley floor), aspect and therefore soils and ecological conditions

Comparing Dark Peak woodland character between habitats

- Semi-natural broadleaved woods differ in abiotic conditions from plantation woodland
- Most extreme differences exist between semi-natural woodland and coniferous plantations, followed by mixed plantation, while broadleaved plantations often show similarities to broadleaved semi-natural sites
- Mixed plantations, although often with similarities to conifer plantation conditions hold some features such as low minimum slope angle and high topographic variability per patch that indicate they may occur in clough features and have diverse features per patch compared to broadleaved plantations
- Semi-natural woods show a wide range of isolation conditions, many sites are isolated but also many sites occur close to similar native woods
- Due to the dominance in the Dark Peak of the moorland plateau semi-natural woodland cover is often restricted in occurrence to the cloughs and valleys
- The riparian network is key to the occurrence of Dark Peak semi-natural woodland

Woodland patch quality / diversity assessment and abiotic conditions

- Analysis revealed a number of abiotic variables useful to describe woodland patch condition
- Many of these abiotic variables are correlated and can be reduced to a limited set of key variables defining differences in woodland patch size, shape and topographic variability
- Topographic variability was found to be important in summarising within-patch diversity

Conservation opportunities and woodland habitat type

- Semi-natural broadleaved woods are diverse and hold a range of internal patch diversity features
- The large area of scattered tree habitat offer opportunity for woodland creation / conversion
- Plantation woods can be assessed for their likely value if converted to native woods
- Broadleaved plantations hold many features similar to semi-natural woods and thus have high conservation value compared to the other plantation

- However broadleaved plantations tend to occur on open valley sides rather than within cloughs and the conditions experienced by single patches may be limited, therefore in some situations, the often larger and more topographically varied per patch woods of mixed plantation may hold more promising conversion opportunities
- Conifer plantations tend to be relatively uniform and lack within-patch diversity features and therefore have lower value as conversion sites, although within the wide range of conditions recorded, exceptions do exist

Woodland size thresholds and diversity

- Woodland diversity, as indicated by patch topographic variability, increases with patch size
- However small sites can be highly topographically diverse for their size
- Crude thresholds indicative of increasingly diverse patch condition for existing woodland or woodland creation assessment are: 2, 10 and 20ha

GIS and landscape planning summary

- Many indicators of patch diversity are highly correlated
- Patch size, shape and topographic diversity variables are valuable for defining woodland patch conditions and can be linked to typical values within individual habitat types
- Habitat types and patch size thresholds may be used to be indicative of likely within-patch diversity features, but generally it is preferable to utilise both habitat type and measurement of actual patch diversity features to define woodland patch conditions

Chapter 10
Dark Peak Ancient Woodland Sites

Assessing the current ecological condition and conservation interest of the Ancient Woodland resource and analysing habitat and abiotic associations of use in conservation planning

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10.1 Introduction

This chapter presents and analyses Dark Peak Ancient Woodland sites. Analysis addresses a number of research aims. The focus is on examining the associations between ancient woodland habitat, site biodiversity levels and abiotic conditions. Previous research has detailed a range of biodiversity, abiotic and "habitat quality" associations within woodland habitats (Chapter 5). These have been used to devise the current research postulates. Research suggests ASNW and PAWS sites will differ in both biodiversity interest and habitat quality, in areas such as botanical or AWIS richness. Expected differences within the individual PAWS habitats were less clear but may be related to canopy type and cover, density or management intensity. The factors hypothesised to be most important in the current research were habitat type and site abiotic conditions. The chapter therefore aims to:

- Detail the frequency and extent of Dark Peak ancient woodland habitats
- Detail woodland biodiversity levels and highlight differences between habitat types
- Examine redundancy in explanatory indicators of biodiversity / composition / structure
- Report the compilation of a score summarising compartment biodiversity interest
- Report the efficiency of surveyed indicators in summarising woodland biodiversity
- Examine abiotic factors driving woodland biodiversity in Dark Peak Ancient woodland
- Consider potentially useful predictive woodland biodiversity variables for use in landscape conservation planning

10.2 Methods

10.2.1 Data collection

10.2.1.1 Biodiversity data

A wide range of biodiversity variables were initially collected within each woodland compartment during surveys, prior to analysis (Table 10.1 and see Chapter 7.2.5.2). Variables were selected from the literature (Lindenmayer, 1999, Lindenmayer et al., 2000, Ferris and Humphrey, 1999, Spellerberg, 1995, Zavala and Oria, 1995), while a number of variables were devised within the current study. Biodiversity assessment was not limited to recording of biological species presence but incorporated broader assessment using indicators of woodland composition and structure, in addition to presence / richness of species of conservation interest.

Table 10.1
Biodiversity and management values recorded within each compartment during fieldwork.
AWIS= ancient woodland indicator species, BAP = biodiversity action plan, LBAP = local biodiversity action plan.

Conservation interest	AWIS / patch and / ha
	Notable + LBAP species / patch and / ha
	BAP species / patch and / ha
Composition	Ground-flora species presence
	Oak % cover
	Birch % cover
	NVC communities / patch and / ha
	Native trees richness / patch and / ha
	Native shrub richness / patch and / ha
Composition	Native tree cover (%)
	Native shrub cover (%)
	Total canopy cover (%)
	Canopy structure layers
	Veteran tree presence score
	Canopy age score
	Ground-flora cover (%)
	Potential ground-flora cover (%)
	Deadwood presence score
Management	Management activity
	Invasive species presence

10.2.1.2 Abiotic data

A range of abiotic data (area, shape, topography and landscape isolation / connectivity) were compiled within the GIS and using Fragstats (Chapter 8) and were selected to capture the main environmental woodland characteristics (Table 10.2). Variables were collected to assess both within-patch conditions, and information relating to the landscape / ecological neighbourhood around patches, at multiple scales. Analysis aimed to capture key differences in woodland topography. Some variables were selected that had been important in analysis of the broader Phase 1 woodland network (Chapter 9), such as minimum slope angle, which allowed identification of patches spanning conditions including areas of level valley floor, as may occur within cloughs. Abiotic variables were collected to act as indirect variables, from an individual species perspective (Guisan and Zimmermann, 2000), e.g. aspect and slope angle, recognising that at the community level such variables may be causally associated with diverse abiotic conditions at a patch or local landscape scale. Such variables are used as being representative of unmeasured, direct, or casual factors such as the detailed variations in soils chemistry, fertility and hydrology, and variations of exposure and insolation seen at the sites.

Abiotic variables included a number of patch area and shape metrics frequently collated in landscape ecology studies. Additionally a range of topography and spatial landscape data were collected. Topography data were extracted from the DTM. The landscape data collected was partially determined by variables found to be predictive in previous studies (Chapter 4) and key successful landscape metrics (Chapter 3). However in order to increase the application of this data these were collected at multiple scales informed by the results of the literature review of woodland species dispersal distances (Wiens and Milne, 1989, Wiens, 1989)(Chapter 5). Research must acknowledge that measures of connectivity can be species specific and are affected by both species characteristic and landscape structure (Wiens et al., 1997, With and Crist, 1995). Therefore study species groups must be chosen within the scales of available data in addition to resources and existing research background / justification. Following previous studies (Hansen and Urban, 1992, Lambeck, 1997, Watson et al., 2001, Wessels et al., 1999, Jansson, 1998, Lindenmayer et al., 2000, Ratcliffe et al., 1998) the current study aims to use functional groups types to avoid overemphasis on individual species, which may or may not be present in the landscape. Several authors have examined the use of guilds and grouping of species by similar life-history traits in relation to surrogate and indicator species (Landres, 1983, Block et al., 1987, Verner, 1984, Bayer and Potrter, 1988, Jansson, 1998) suggesting planning and habitat associations can consider closely similar sets of species rather than individual species. The literature review has examined a number thresholds and associations that are of use in examining woodland fragmentation from hypothetical species orientated perspectives, at a number of scales. Such values can be used to represent combined species groups as research tools.

Multi-scale landscape analysis was carried out at 20m, 100m, 500m and 1km from woodland focal patches, designed to capture a range of potential movement distances for different specialist woodland dependant species profiles. This is akin to the hypothetical "focal" species or "ecoprofiles" of previous studies (Ray et al., 2004b, Ray et al., 2004a, Latham et al., 2004, van Rooij et al., 2004). This data was collected using buffer polygons derived from the woodland sites, at the 4 scales. Importantly the landscape data was collected as both structural and functional measures (**Table 10.2**). Structural measures (isolation and proximity) were based on simple nearest neighbour distances, while functional measures were based on least-cost and contrast/similarity distances, incorporating assessments of the landscape matrix. These were created utilising the Dark Peak GIS with polygons classified by cost and contrast values, such that distances represented potential functional cost movement across the landscape, based on potential focal species groups. Information detailing the calculation of each data variable / metric is included in **Appendix 10.1–10.4**.

Although the calculation and suitability of certain landscape connectivity metrics have been criticised (Belisle, 2005, Winfree et al., 2005), they remain a useful method to define species-landscape relationships. A number of papers have used least-cost modelling and functional connectivity assessment in their work (Verbeylen et al., 2003, Rouget et al., 2006, Pichon et al., 2006, Bunn et al., 2000, Marulli and Mallarach, 2005, Nikolakaki, 2004, Nikolakaki, 2001, Knappen et al., 1992, Pascual-Hortal and Saura, 2006, Rudd et al., 2002, Adriaensen et al., 2003). Such functional metrics are theoretically favourable to structural metrics in situations where species dispersal or movement are affected by landscape form. Previous studies have shown functional metrics to be more successful or more predictive of species presence, biodiversity factors or movement than simple structural metrics (Verbeylen et al., 2003). When landscapes are small or the number of source patches within cost distance calculations are low, then cost-distance can be calculated separately for each individual source patch, and such values combined with data on the area or quality of each source patch to derive sum proximity or Hanski isolation measures (Verbeylen et al., 2003). Such calculations can be achieved readily with the Pathmatrix GIS extension (Ray, 2005). However in larger study areas, when the number of patches involved is large, such calculations become impractical and more rapid methods to assess the effect of multiple patches around a focal cell / patch using least-cost modelling must be found. These generalised cost movement and resistance / functional connectivity measures are not limited to modelling exact lines of movement between sites. The current study applied broad landscape functional connectivity measures, including a version of area-weighted isolation, which has previously been used in other studies, e.g. (Turchi et al., 1995), but is not as common as proximity itself or normal NN distance or the area in the search / focal zone. Of the structural metrics, area based metrics and those based on the proximity index or total area of habitat within buffer distances, have been found to be more successful than structural isolation in biodiversity associations therefore these were used in the current study (Pichon et al., 2006, Hargis et al., 1999, Moilanen and Nieminen, 2002, Vos and Stumpel, 1995). However the known insensitivity of proximity indexes to features such as high cost landscape barriers or inhospitable habitat (Gustafson and Parker, 1994) means that such structural measures, when utilised, are usefully examined in conjunction with functional least-cost modelling methods.

Table 10.2
Abiotic, GIS derived values recorded within each compartment

Area	Area (m^2)
Shape	Shape index, Fractal dimension, Circle index, Para, Perimeter
Topography	Elevation : minimum, maximum, mean, range, range / ha
	Slope : minimum, maximum, mean, range, range / ha
	Aspect variability, variability / ha
Landscape (structural)	Distance to stream (m), and distance to clough (m)
	Area of clough in 1km, and urban area in 1km
	Area of contiguous ancient woodland site
	Number of ancient woodland sites
	Total area of ancient woodland
	Proximity score of ancient woodland
	Area weighted isolation score of ancient woodland
	Mean patch isolation of ancient woodland
	Mean patch area of ancient woodland
	Number of semi-natural woodland sites
	Total area of semi-natural woodland
	Proximity score of semi-natural woodland
	Area weighted isolation score of semi-natural woodland
	Mean patch isolation of semi-natural woodland
	Mean patch area of semi-natural woodland
Landscape (functional)	Compartment core area and core area index
	Contrast value (patch – Fragstats)
	Mean contrast value of landscape
	Mean cost value of landscape
	Area weighted "least cost" isolation of ancient woodland
	Area weighted "least cost" isolation of semi-natural woodland
	"Least cost" proximity of ancient woodland
	"Least cost" proximity of semi-natural woodland

* all variables were collected at 20m, 100m, 500m and 1km landscape distances where applicable

10.2.2 Analysis methods

Analysis was conducted in SPSS (14), PC-Ord 5 (McCune and Jefford, 2006), ArcView 3.2 (ESRI, 1999) and ArcGIS 9.2 (ESRI, 2006). Data were transformed to approximate normality where possible and variables were relativised by maximum (biological) or by standard deviate (abiotic) prior to multivariate analysis to account for the different measurement scales used between variables. In order to increase analysis clarity, eliminate redundancy and multicollinearity, and to meet the requirements of certain statistical tests the initial data variables (**Table 10.1, 10.2**) were reduced to a refined selection for analysis. Within multiple regression the analysis of particular habitats was limited by recommendations on sample / variable ratios (Tabachnick and Fidell, 2001). Therefore *a priori* theoretical selection of variables was used to produce a subset for analysis. Analysis was conducted separately for each of the four main ancient woodland habitats except where data limitations required analysis to be conducted on grouped ancient woodland data, in which case dummy variables were used to indicate habitat type. Due to the low occurrence of Mixed Ancient Semi-Natural Woodland (4 compartments), these results are typically omitted. Analysis was therefore conducted on all ancient woodland data N= 298, and subsets of ASNW N=114, broadleaved PAWS N=61, coniferous PAWS N=57, mixed PAWS N=66 and combined PAWS N=184.

10.3 Results: Ancient woodland biodiversity and abiotic conditions

10.3.1 Biodiversity indicator results

10.3.1.1 Fieldwork biodiversity indicators

105 "Ancient Woodlands" were examined covering 1,269ha, within 145 geographically distinct woodlands. These were mapped into 427 compartments. Access permission was received for 302 of 308 compartments holding established woodland (98% of the resource was surveyed). There was an almost exact division between the areas classified as Plantations on Ancient Woodland Sites (PAWS) and Ancient Semi-Natural Woodland (ASNW) (**Fig 10.1**).

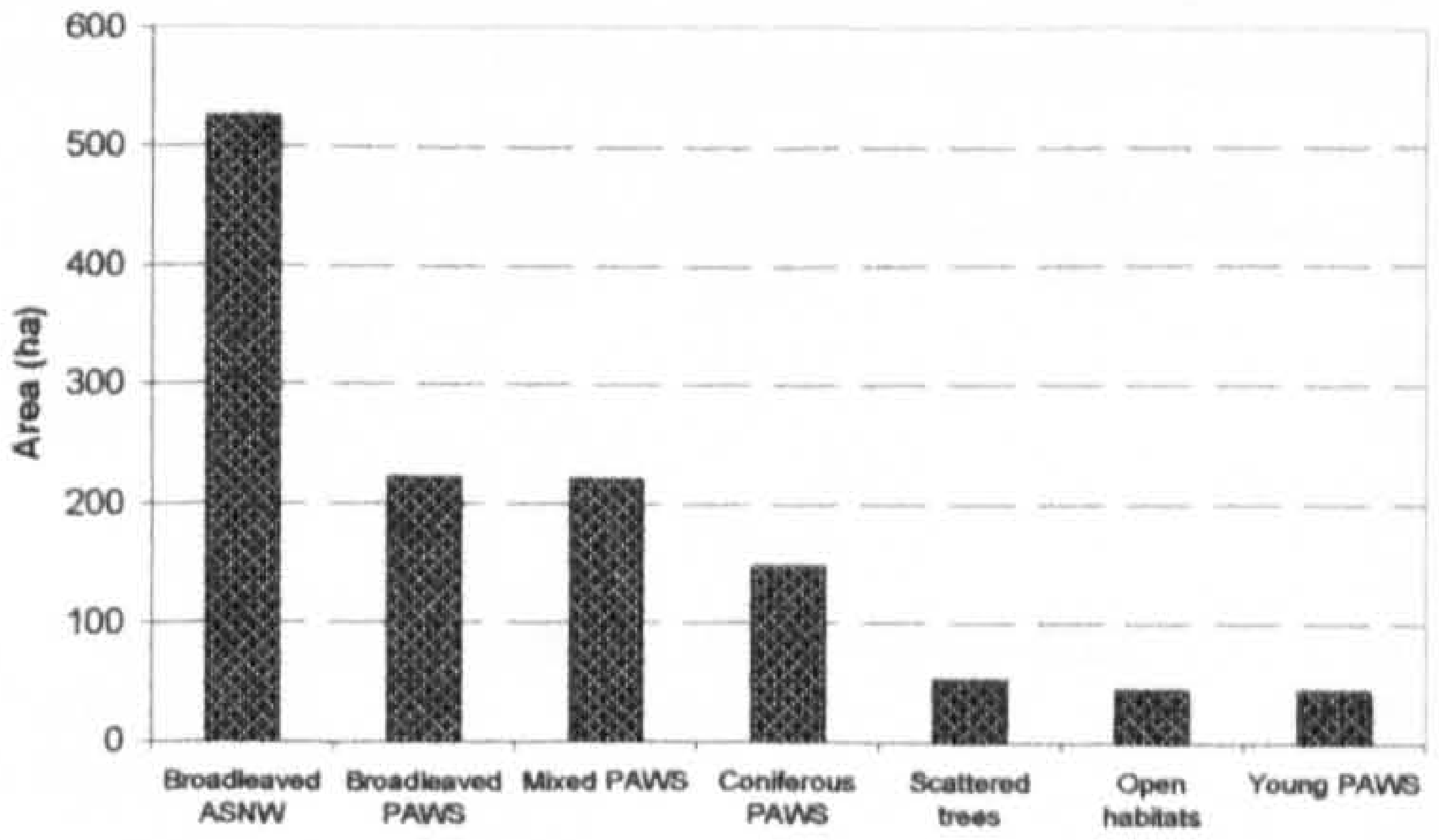


Figure 10.1
Habitat areas occurring on Ancient Woodland Sites, habitats with less than 5 ha of total habitat have been omitted for clarity. Scrub and Mixed PAWS both occupy 4ha in total. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

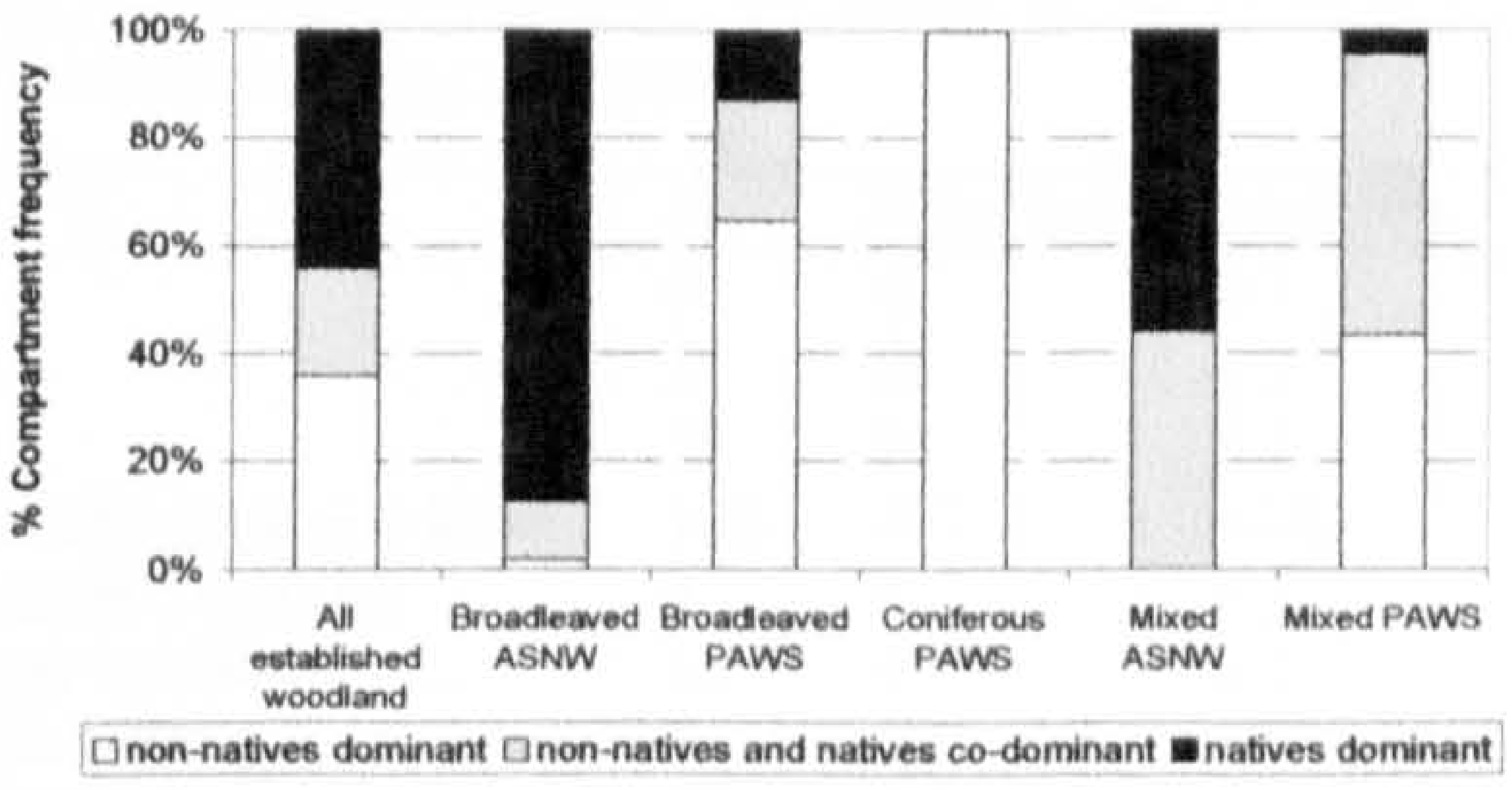


Figure 10.2
% frequency of Ancient Woodland classified into three canopy naturalness categories. Classifications: Natives dominant= >50% cover native species, or only native species were present and canopy cover >40%. Non-natives = where <20% of the canopy comprised native species, and non-natives >40% of canopy cover. Natives and non-natives= between 20%-50% native species cover. ASNW= Ancient Semi-Natural Woodland, PAWS=Plantation on Ancient Woodland Site.

Mixtures of native and non-native species were seen to occur within each habitat (**Fig 10.2, and 10.3**). Significant covers of remnant, recently regenerated or planted native species occur, that represent potential for sensitive restoration of these sites. Native species occurred as self-sown, recently planted forestry stands, and also as historically planted stands (120 yrs +), now over-mature or even re-grown from past historic felling operations. When sufficiently old and holding semi-natural ground-flora these stands were classified as semi-natural, in line with Phase 1 Habitat Survey methodology (JNCC, 1993) (**Fig 10.3**).

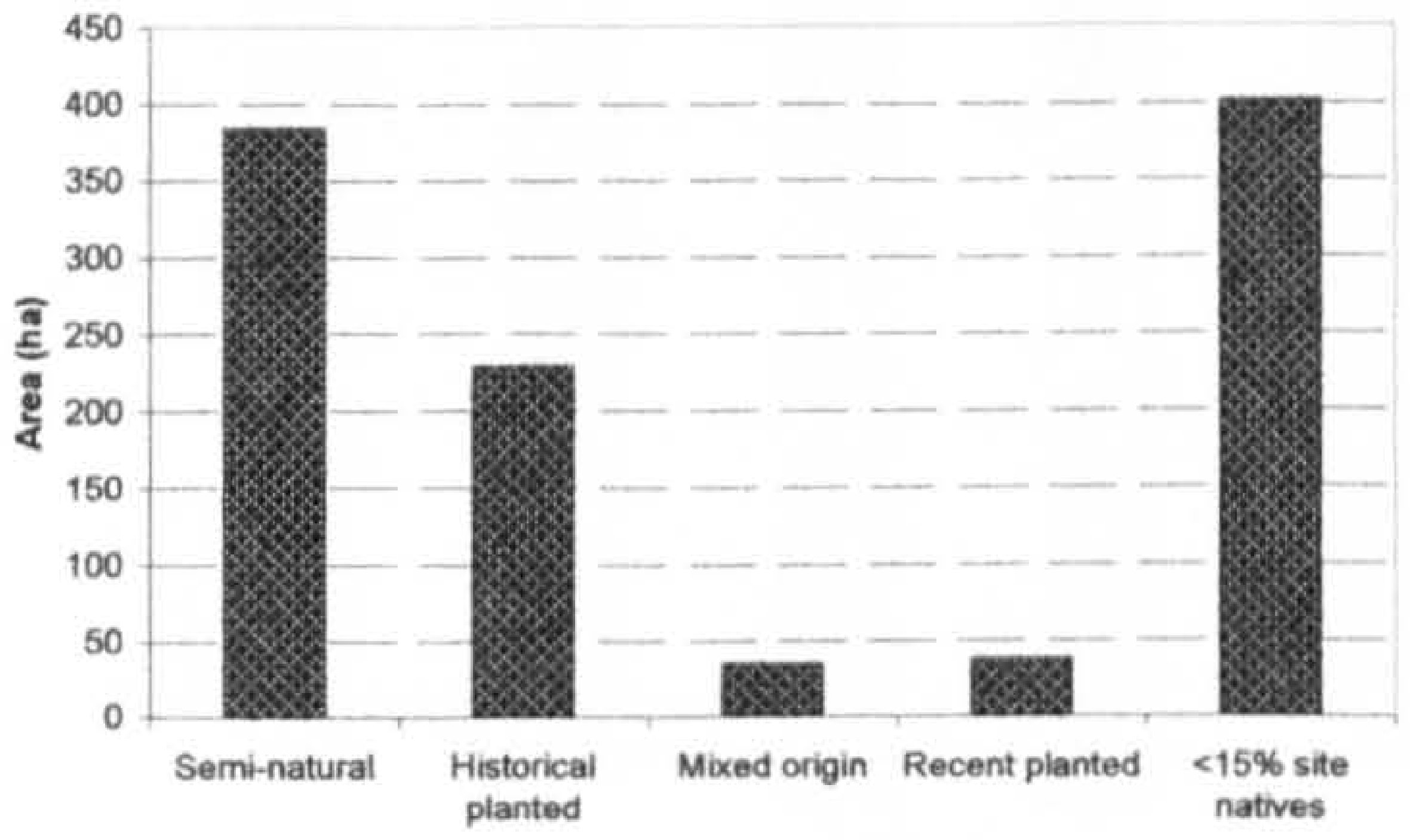


Figure 10.3
The areas of ancient woodland falling within five categories of native species origin. All compartments holding more than 15% site-native cover were placed within a category best summarising the origin of the compartment site natives.

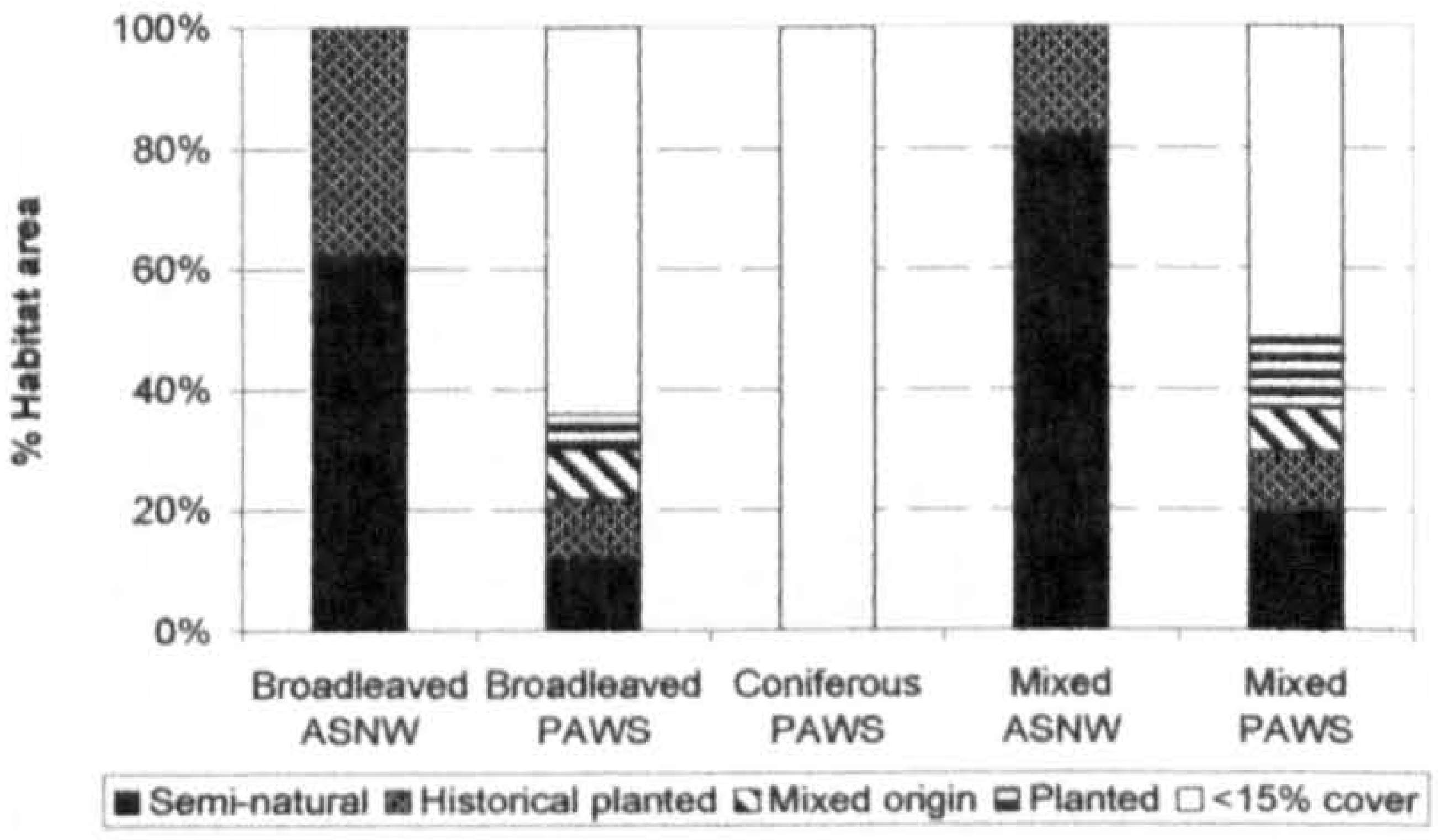


Figure 10.4
The area of Ancient Woodland, by habitat, classified according to the origin of site native species, for all compartments within more than 15% site native species cover. ASNW= Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

Most native tree cover had a semi-natural origin (**Fig 10.4**), however significant covers of historically planted natives also occurred. The influence of recently planted native species was rather less, forming a minority of sites. Within Broadleaved ASNW almost 40% of the total area showed influence of historical planted natives (**Fig 10.4**). The occurrence of native species was varied within the PAWS woods, however, the potential restoration interest within the PAWS was apparent. Broadleaved PAWS held almost 40% and Mixed PAWS almost 50% of total habitat area holding significant covers of site-native species.

Table 10.3
Summary results detailing the frequency and area of habitats recorded on Ancient Woodland sites. The results are based on data for all sites within the GIS including sites that were not fully surveyed due to a lack of access permission.

Broad habitat	N	Area (ha)	Area (%)	Detailed habitat	N	Area (ha)	Area (%)
Ancient Semi-Natural Woodland	227	632	49.8	Scrub	6	4	0.3
				Scattered trees	31	53	4.2
				Open habitats	68	45	3.5
				Semi-natural broadleaved woodland	118	527	41.5
				Semi-natural mixed woodland	4	4	0.3
Plantation on Ancient Woodland	200	637	50.2	Young plantation woodland	14	44	3.5
				Broadleaved plantation	61	222	17.5
				Coniferous plantation	58	149	11.7
				Mixed plantation	67	222	17.5
All woodland	427	1269	100	All habitats	427	1269	100

Conservation interest indicators During fieldwork two NBAP species, four LBAP species, 10 notable species and 50 ancient woodland indicator species (AWIS) were recorded (**Appendix 10.5**). A maximum of 2 LBAP species were recorded within any one compartment. 10 of the 13 compartments holding LBAP records were Broadleaved ASNW. 32% of compartments contained records for notable flora, while 92% of compartments contained AWIS records, richness ranging from 0 to 24 species. A higher frequency of ASNW held notable species records, while presence levels within Broadleaved and Mixed PAWS appeared similar (**Fig. 10.4**). AWIS richness also differed between the habitats (**Table 10.4**), with broadleaved ASNW holding higher richness (**Fig. 10.6**) and mixed PAWS being intermediate between ASNW and other PAWS.

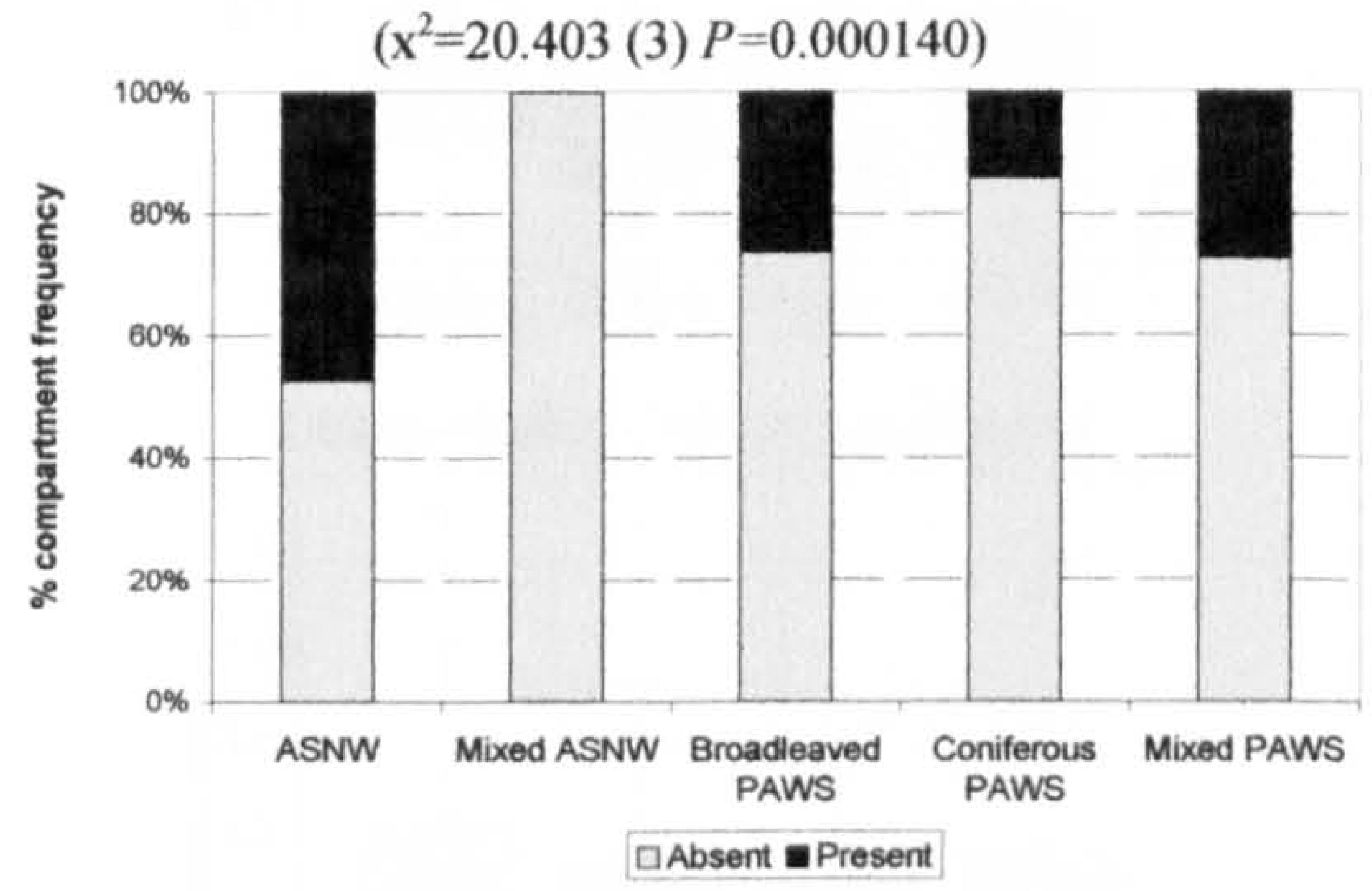


Figure 10.5
The % frequency of each main habitat type with notable species present or absent. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. ASNW N=114, Mixed ASNW N=4, broadleaved PAWS N=61, Coniferous PAWS N=57, Mixed PAWS N=66.

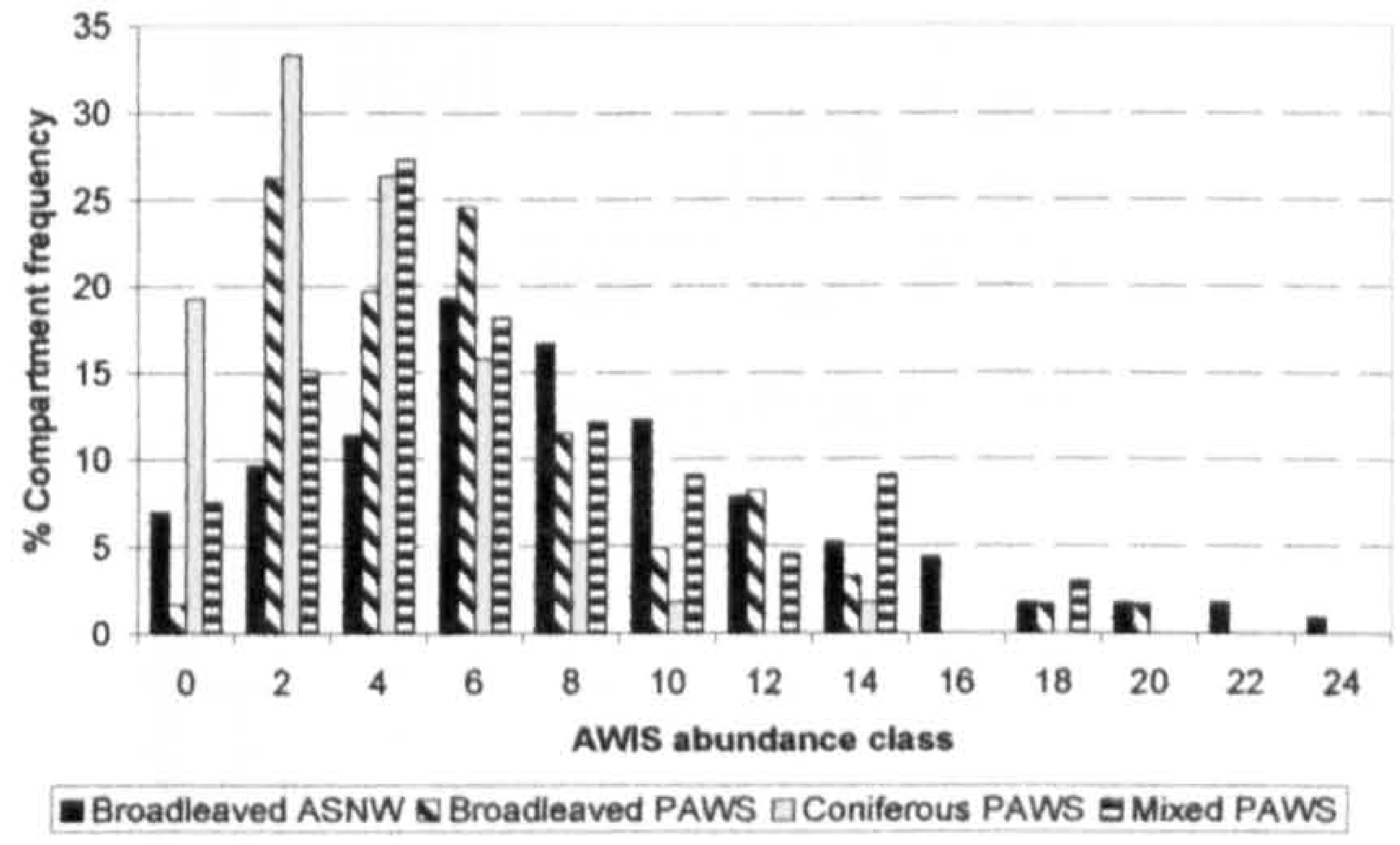


Figure 10.6
Frequency of compartments within 13 classes of AWIS richness. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. AWIS = Ancient Woodland Indicator Species. N = ASNW: 114, Brd PAWS: 61, Cons PAWS: 57, Mix PAWS: 66.

Table 10.4
Ancient Woodland Indicator Species (AWIS) richness. Values with the same letter in their superscripts do not differ significantly according to pair-wise tests (Mann-Whitney tests with a Bonferroni correction test with a .05 limit on familywise error rate). ASNW = Ancient semi-natural woodland / PAWS = Plantation on Ancient woodland site

		AWIS		AWIS/ha		BAP and notable / ha	
Habitat	N	Mean	Median	Mean	Median	Mean	Median
Broadleaved ASNW	114	7.6	7^A	4.8	2.4^A	1.0	$.41^A$
Broadleaved PAWS	61	5.6	5^A	3.4	2.5^A	.71	$.46^A$
Coniferous PAWS	57	3.1	3	1.9	1.5^A	.46	$.15^A$
Mixed PAWS	66	6.1	6^A	3.0	2.2^A	.54	$.32^A$

The frequency of individual AWIS ranged from 0.3% to 81% of compartments (**Fig. 10.8**). The majority of species occurred at low frequencies. 22 species were recorded in at least 10% of one of the main ancient woodland habitats (**Fig. 10. 9**). 14 species were recorded in more than 10% of each habitat type: *Oxalis acetosella, Hyacinthoides non-scripta, Ilex aquifolium, Lysimachia nemorum, Chrysosplenium oppositifolium, Lonicera periclymenum, Stellaria holostea, Luzula pilosa, Lamiastrum galeobdolon, Oreopteris limbosperma, Carex remota, Ulmus glabra, Luzula sylvatica, Mercurialis perennis, Carex laevigata, Viola palustris, Corydalis claviculata, Dryopteris affinis, Prunus padus, Bromus ramosus, Taxus baccatta.*

In summary, compartment conservation interest varied between the habitats types. As expected, higher levels remained within Broadleaved ASNW, and the lowest levels were seen within replanted Coniferous PAWS. Both notable species presence and AWIS richness were similar in Broadleaved and Mixed PAWS. The levels of AWIS richness recorded within the study were relatively low. A low variety of species occurred in each woodland compartment and very few species were common to all compartments even within a single habitat type, with for example only 8 AWIS occurring in more than 40% of all Broadleaved ASNW compartments.

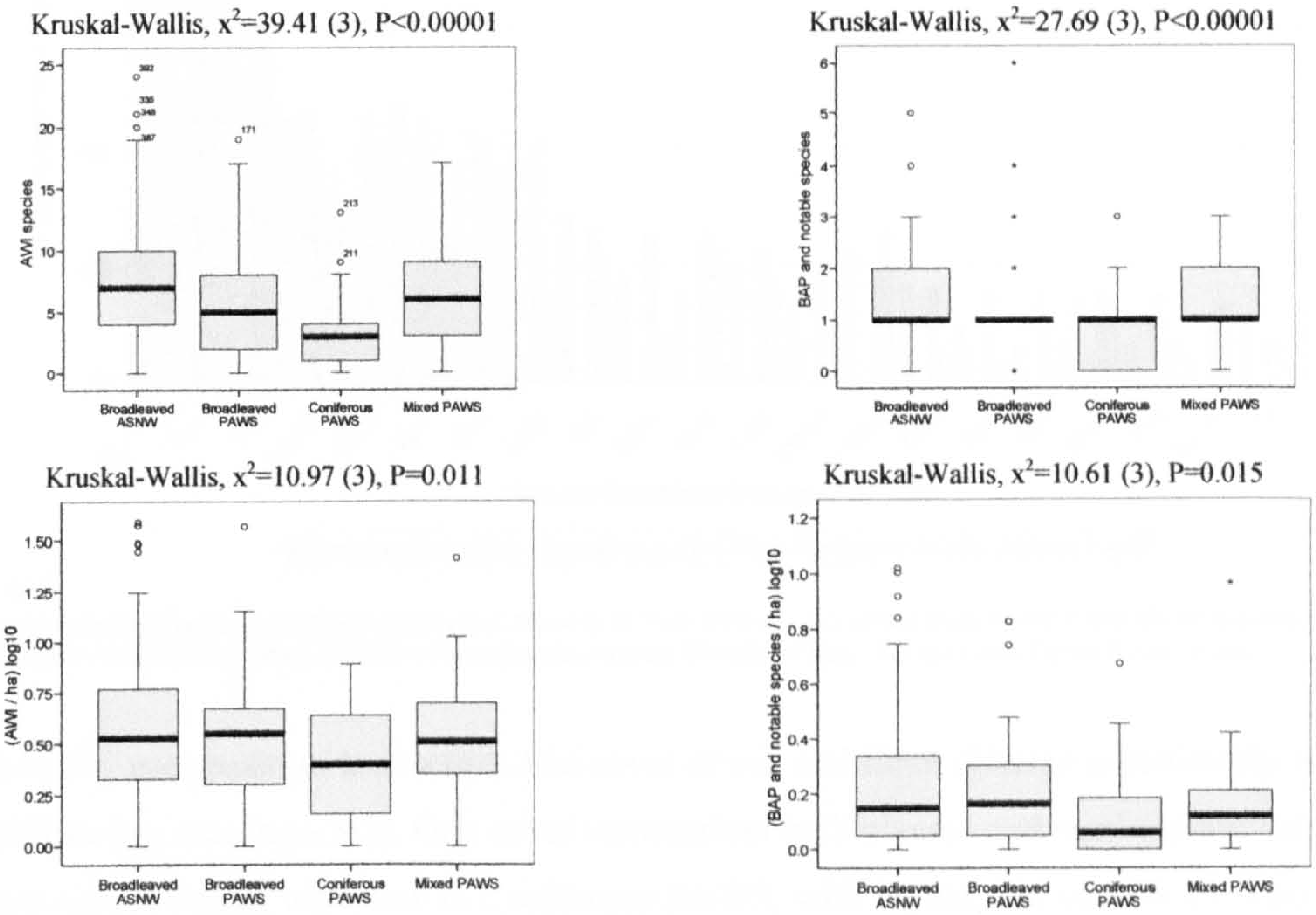


Figure 10.7
Boxplot of AWIS and BAP+Notable combined richness per compartment and area corrected values. The plot details the median value as a thick bar and interquartile range of values as the box. (Populations: Broadleaved semi-natural = 612, Broadleaved plantation = 602, Coniferous plantation = 485, Mixed plantation = 312). Extreme compartment values are indicated by circles and stars.

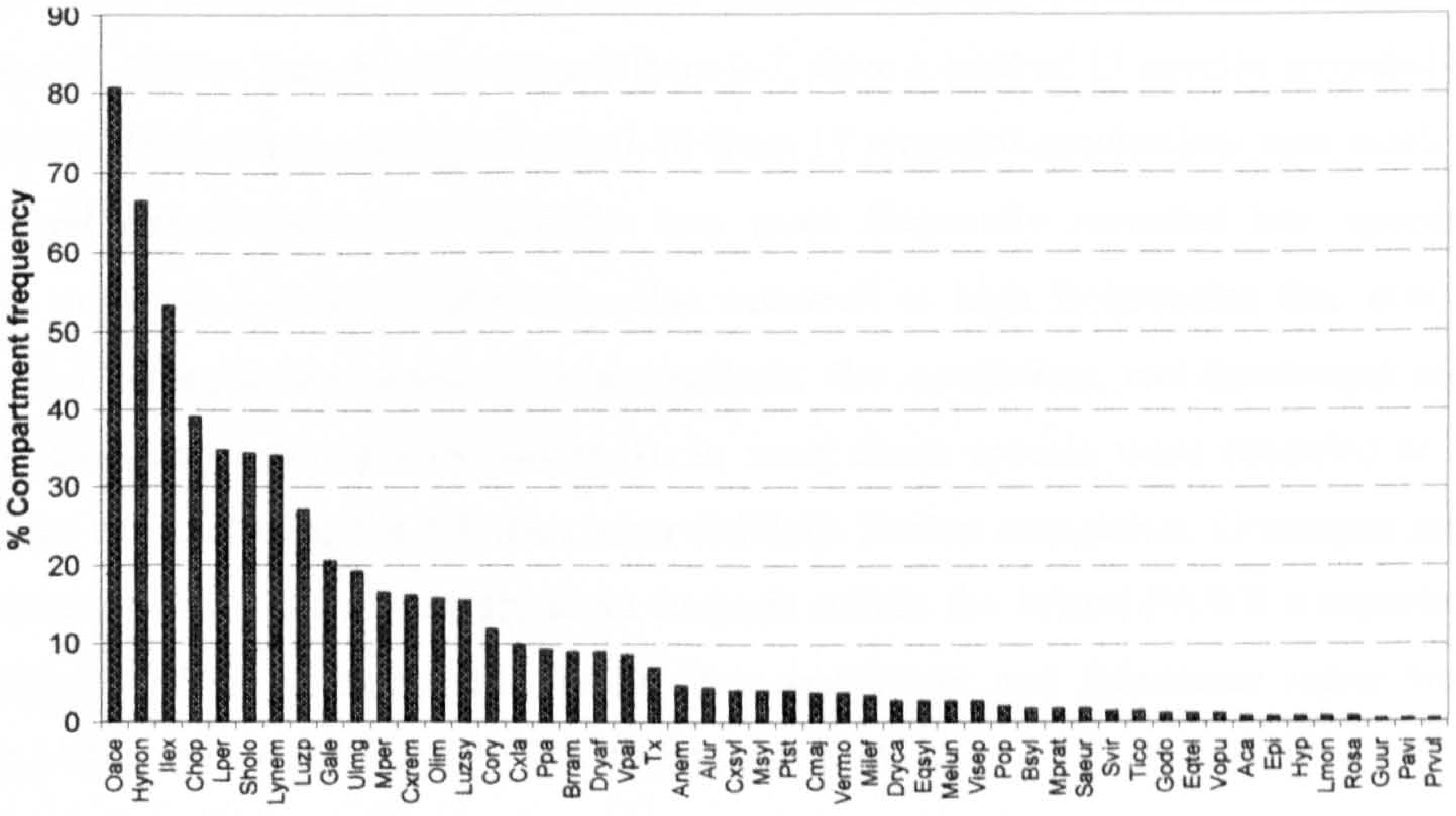


Figure 10.8
% frequency occurrence of Ancient Woodland Indicator Species (AWIS) recorded among all surveyed Ancient Woodland compartments. Oace = *Oxalis acetosella*, Hynon = *Hyacinthoides non-scripta*, Ilex = *Ilex aquifolium*, Chop = *Chrysosplenium oppositifolium*, Lper = *Lonicera periclymenum*, Sholo = *Stellaria holostea*, Lynem = *Lysimachia nemorum*, Luzp = *Luzula pilosa*, Gale = *Lamiastrum galeobdolon*, Ulmg = *Ulmus glabra*, Mper = *Mercurialis perennis*, Cxrem = *Carex remota*, Olim = *Oreopteris limbosperma*, Luzsyl = *Luzula sylvatica*, Cory = *Corydalis claviculata*, Cxla = *Carex laevigata*, Ppa = *Prunus padus*, Brram = *Bromus ramosus*, Dryaf = *Dryopteris affinis*, Vpal = *Viola palustris*, Tx = *Taxus baccatta*, Anem = *Anemone nemorosa*, Alur = *Alium ursinum*, Cxsyl = *Carex sylvatica*, Msyl = *Malus sylvestris*, Ptst = *Potentilla sterilis*, Cmaj = *Conopodium majus*, Vermo = *Veronica montana*, Millef = *Millium effusum*, Dryca = *Dryopteris carthusiana*, Eqsyl = *Equisetum sylvatica*, melun = *Melica uniflora*, Visep = *Vicia sepium*, Pop = *Populus tremula*, Bsyl = *Brachypodium sylvaticum*, Mprat = *Melampryum pratense*, Saeur = *Sanicula europaea*, Svir = *Solidago virgaurea*, Tico = *Tilia cordata*, Godo = *Galium odoratum*, Eqtel *Equisetum telmateia*, Vopu = *Viburnum opulus*, Aca = Acer campestre, Epi = *Epipactis helleborine*, Hyp = *Hypericum pulchrum*, Lrnon = *Lathyrus linifolius*, Rosa = *Rosa* sp, Gur = *Geum rivale*, Pavi = *Prunus avium*, Prvul = *Primula vulgaris*.

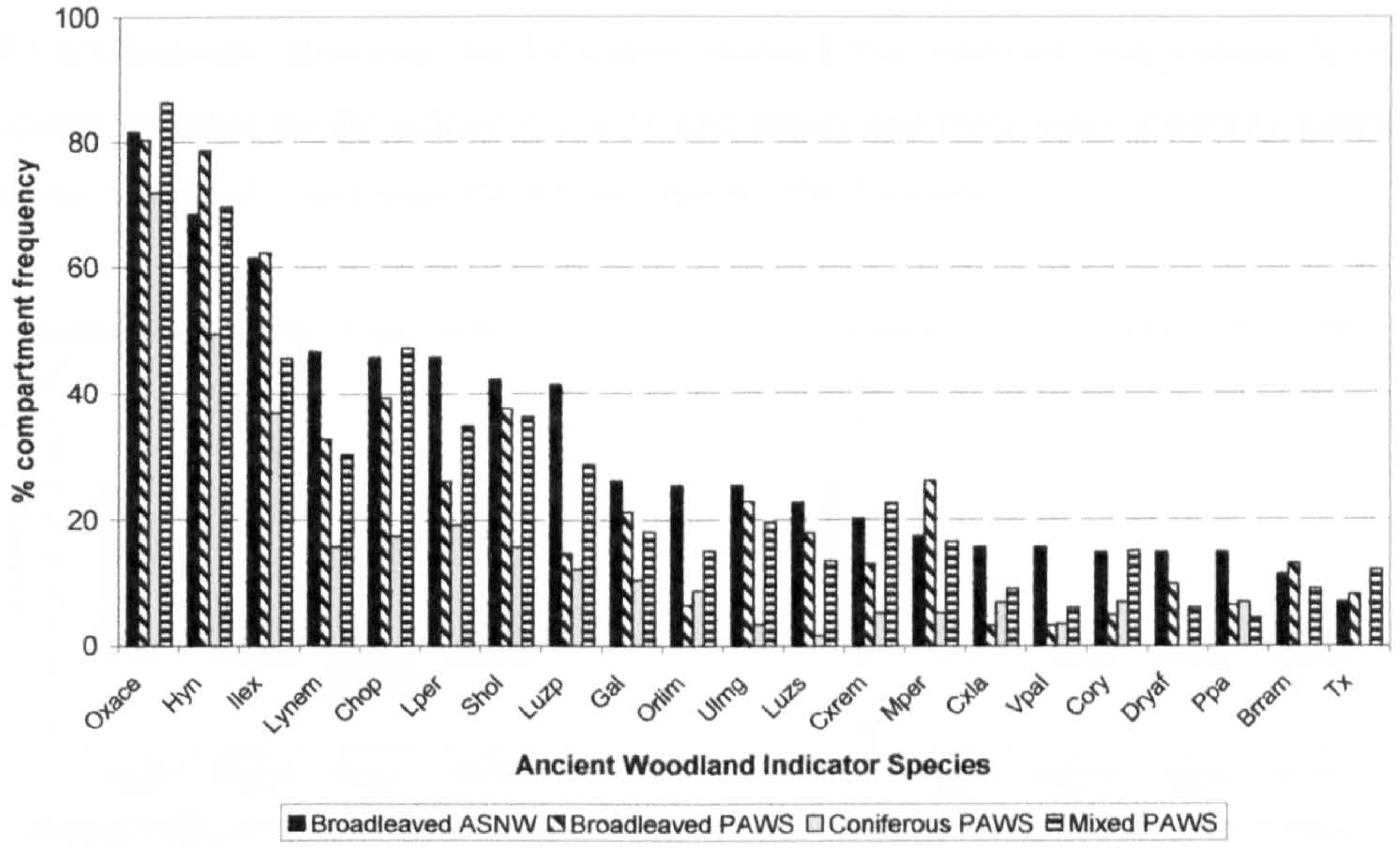
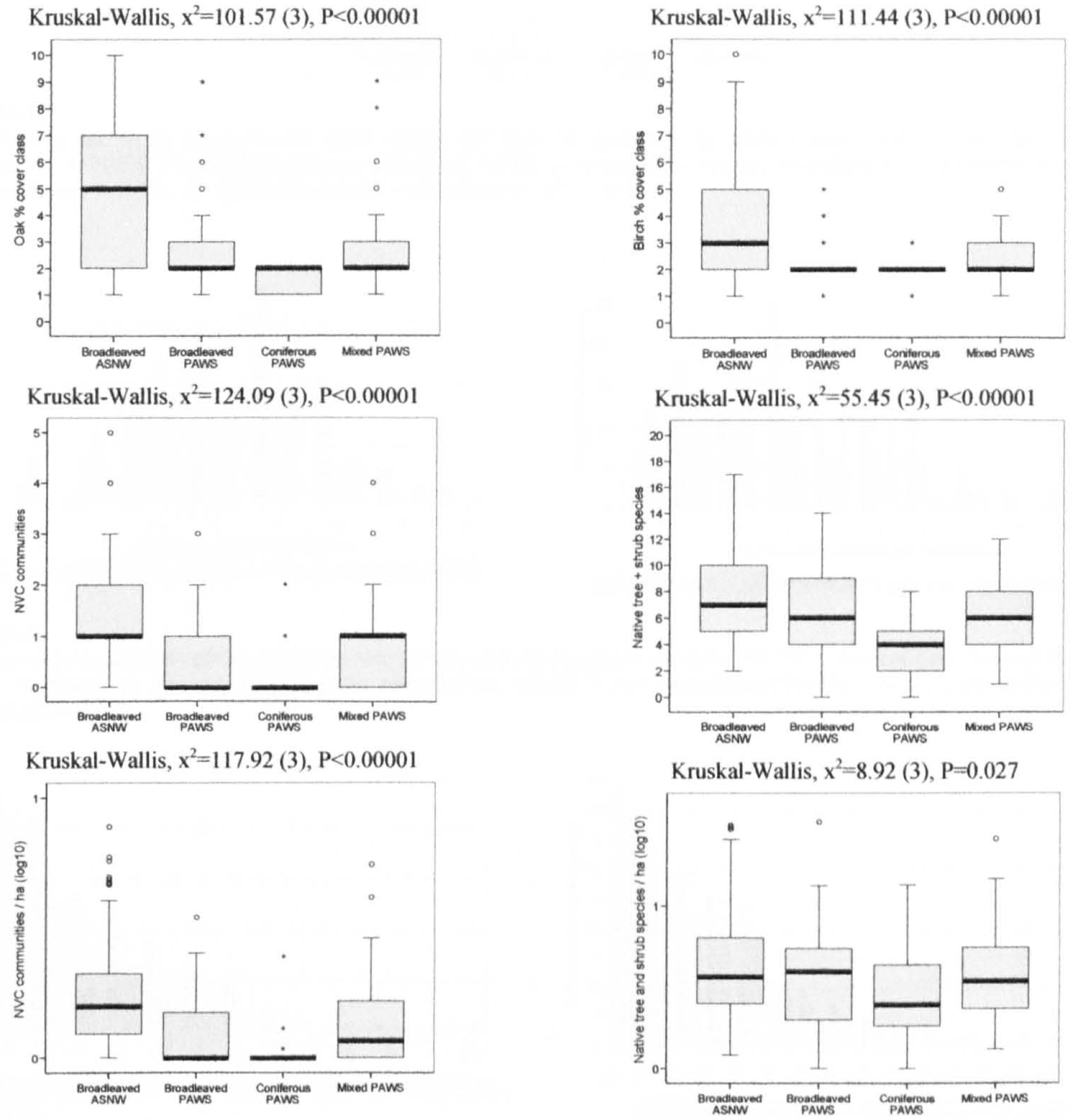


Figure 10.9
The % compartment frequency of AWI species that occur in at least 10% of each of the main Ancient Woodland habitats. ASNW = Ancient Semi=-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. See previous Figure for sp. codes.

Biodiversity composition indicators The cover of oak and birch differed significantly between the habitats (Fig. 10.11, Table 10.5). Oak cover summarises both planted and semi-natural oak cover, into one value. Values were low in Coniferous PAWS, with higher, but variables covers within the Broadleaved ASNW where 20% of compartments had no more than 10% oak cover (Fig 10.28, Fig 10.29). Higher Birch cover occurred in Broadleaved ASNW than other habitats, although a wide range of cover values were observed (Fig. 10.11). Most compartments held examples of at least one NVC community, with the number present differing between the habitats (Fig. 10.12, Table 10.5, 10.6). Native tree richness ranged from 0-7, from a total of 13 species recorded (Fig. 10.13, 10.14). Native shrub richness ranged from 0-10 from 17 recorded species (Fig. 10.13, 10.15). *Quercus petraea* and *Betula pubescens* were the two most frequently recorded tree species, while *Fraxinus excelsior* and *Alnus glutinosa* also occurred at high frequencies (Fig. 10.14). *Sorbus aucuparia, Crataegus monogyna, Corylus avellana, Ilex aquifolium,* and *Sambrucus nigra* were the most frequent shrub species (Fig. 10.15). In most cases species were recorded at lower % frequencies in Coniferous PAWS than other habitats. *Sorbus aucuparia, Crataegus monogyna,* and *Corylus avellana* were typically more frequent within the Mixed PAWS compartment than Broadleaved PAWS compartments, while *Ilex aquifolium* and *Sambucus nigra* were more frequent within the Broadleaved PAWS than Mixed PAWS.

In summary, the compositional indicators showed a number of differences between the habitats. The analysis confirmed the hypothesis that composition would differ between the habitats (Fig 10.10). Broadleaved ASNW proved to be the most diverse and species rich of the habitats, holding higher levels of keystone species, stand diversity and richness in NVC, tree and shrub communities. Post hoc tests revealed differences between the three PAWS habitats (Table 10.5).

As expected coniferous PAWS had lower diversity and compartment interest levels than the other PAWS habitats. However the indicators showed that remnant composition levels were often similar between the Broadleaved and Mixed stands and these were generally intermediate between the replanted Coniferous PAWS and the ASNW habitats


Kruskal-Wallis, x^2=101.57 (3), P<0.00001

Kruskal-Wallis, x^2=111.44 (3), P<0.00001

Kruskal-Wallis, x^2=124.09 (3), P<0.00001

Kruskal-Wallis, x^2=55.45 (3), P<0.00001

Kruskal-Wallis, x^2=117.92 (3), P<0.00001

Kruskal-Wallis, x^2=8.92 (3), P=0.027

Figure 10.10
Boxplots of patch composition indicators. The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by points. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66). ASNW = ancient semi-natural woodland, PAWS = plantation on ancient woodland site.

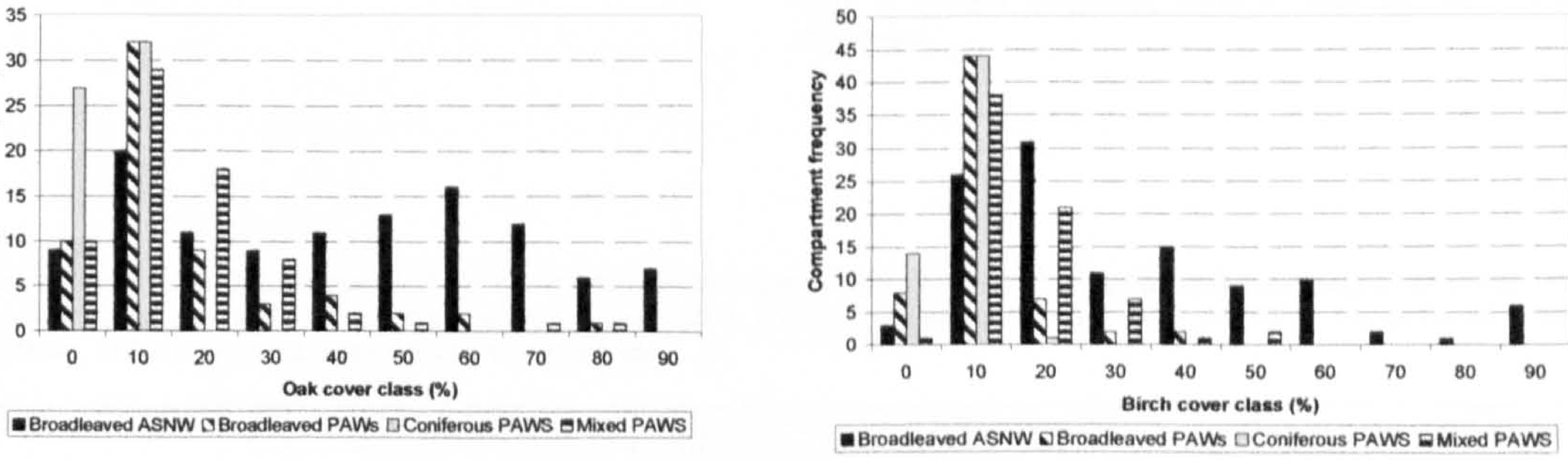


Figure 10.11
The % of compartments of each of the main habitats occurring within 10 oak and birch cover classes. ASNW = Ancient Semi=-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66)

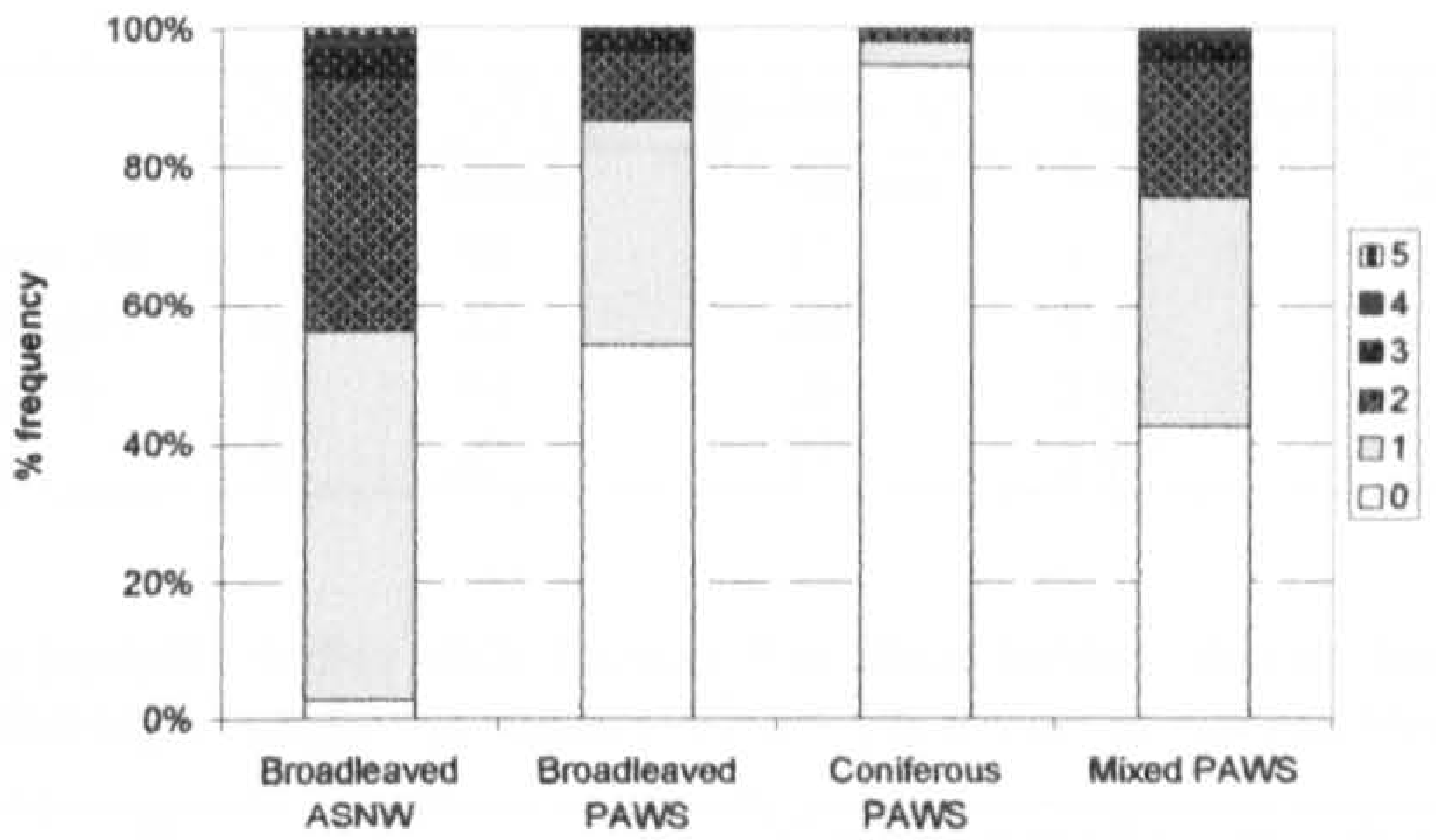


Figure 10.12
Chart showing the % of compartments with records for NVC communities for each habitat. NVC = National Vegetation Classification, ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66).

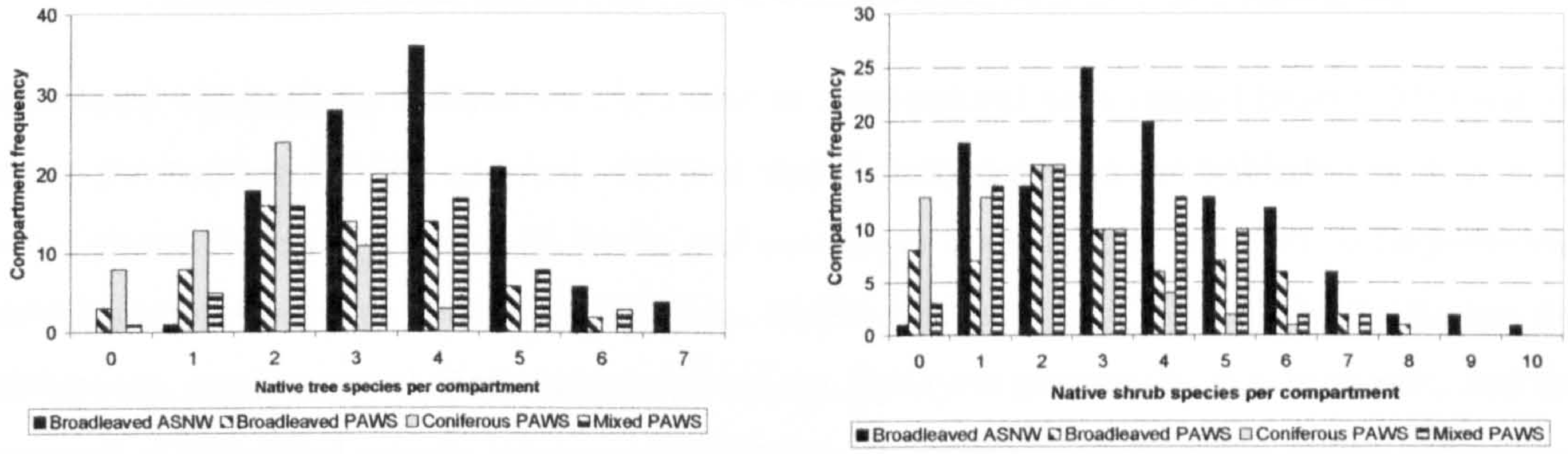


Figure 10.13
Frequency of compartment records for native tree species and shrub species richness. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland site. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66).

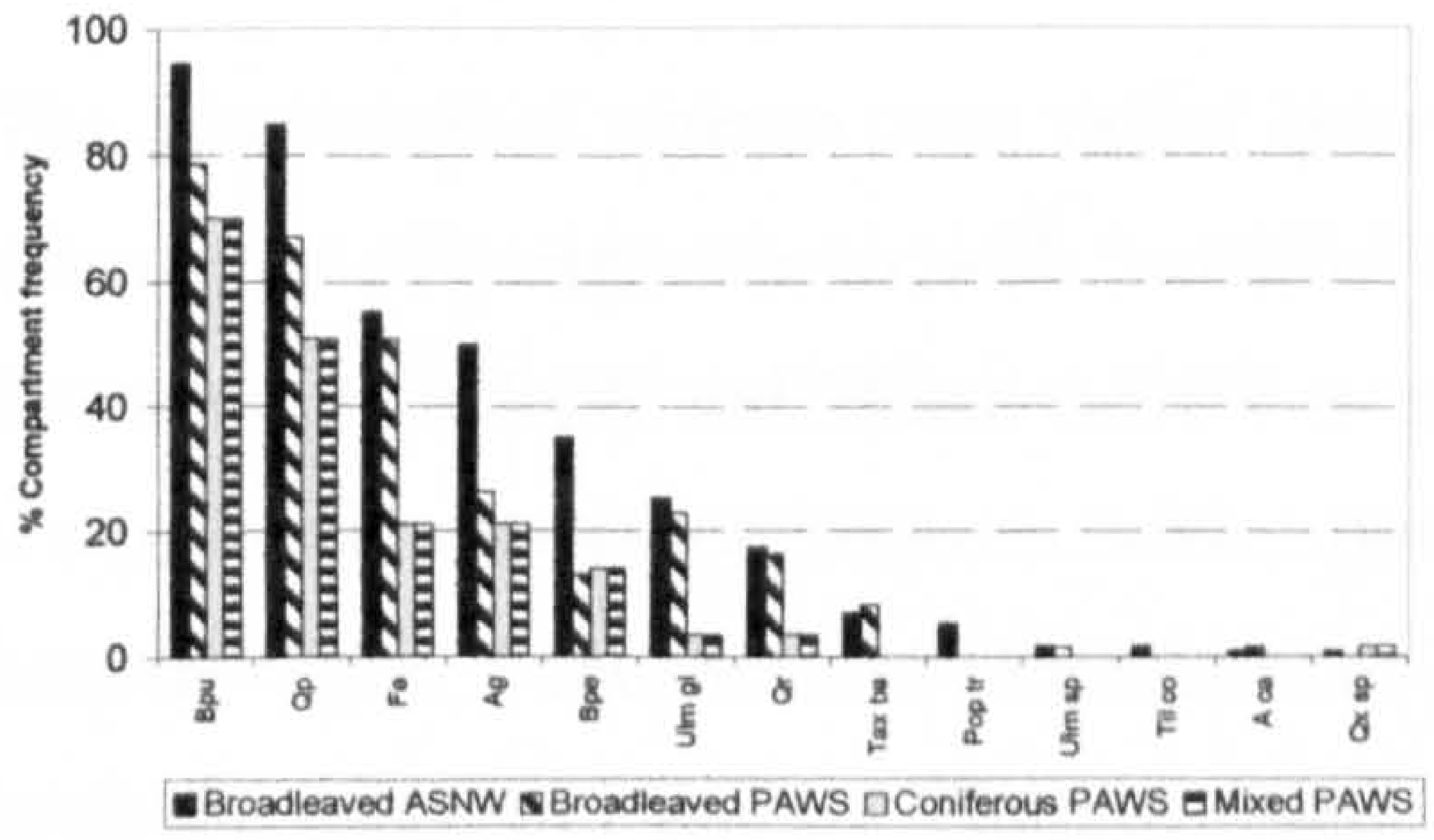


Figure 10.14
% frequency occurrence among the main habitat for each recorded native tree species.
Aca = *Acer campestre*, Qx = *Quercus sp.*, Qr = *Quercus robur*, Qp = *Quercus petraea*, Bpu = *Betula pubescens*, Bpe = *Betula pendula*, Fe = *Fraxinus excelsior*, Ulmg = *Ulmus glabra*, Ulm = *Ulmus species*, Ag = *Alnus glutinosa*, Popt = *Populus tremula*, Tilc = *Tilia cordata*, Tax = *Taxus baccatta*

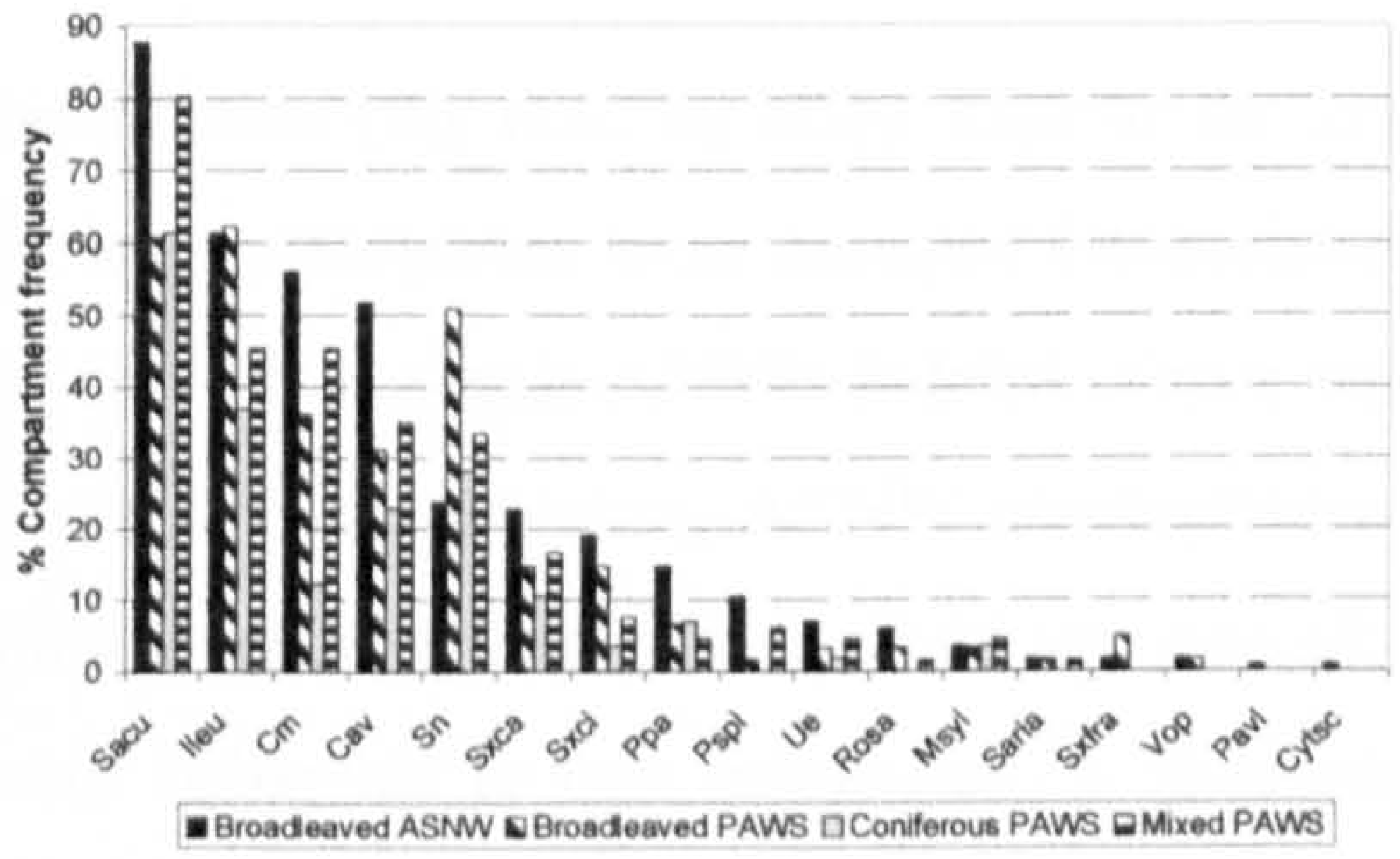


Figure 10.15
% frequency occurrence among the main habitat for each recorded native shrub species Sacu – *Sorbus aucuparia*, Saria – *Sorbus aria*, Sxca – *Salix caprea*, Sxfra – *Salix fragilis*, Sxci – *Salix cinera*, Masyl – *Malus sylvestris*, Cm – *Crataegus monogyna*, Psp – *Prunus spinosa*, Ppa – *Prunus padus*, Ileu – *Ilex aquifolium*, Vop – *Viburnum opulus*, Sn – *Sambucus nigra*, Cysc – *Cytisus scoparius*, Rosa – *Rose sp*, Ue – *Ulex europeaus*.

Table 10.5
Compositional indicators. Values with the same letter in their superscripts do not differ significantly according to pair-wise tests (Mann-Whitney tests with a Bonferroni correction test with a .05 limit on familywise error rate). ASNW = Ancient semi-natural woodland, PAWS = Plantation on Ancient woodland site

Habitat	N	% Oak cover		% Birch cover		NVC communities		Native tree and shrub species	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
Broadleaved ASNW	114	41	40	32	20	1.5	1	7.5	7
Broadleaved PAWS	61	16	10^{A}	11	10^{A}	0.62	0^{A}	5.8	6^{A}
Coniferous PAWS	57	5	10	08	10^{A}	0.07	0	3.7	4
Mixed PAWS	66	17	10^{A}	15	10	0.88	1^{A}	6.1	6^{A}

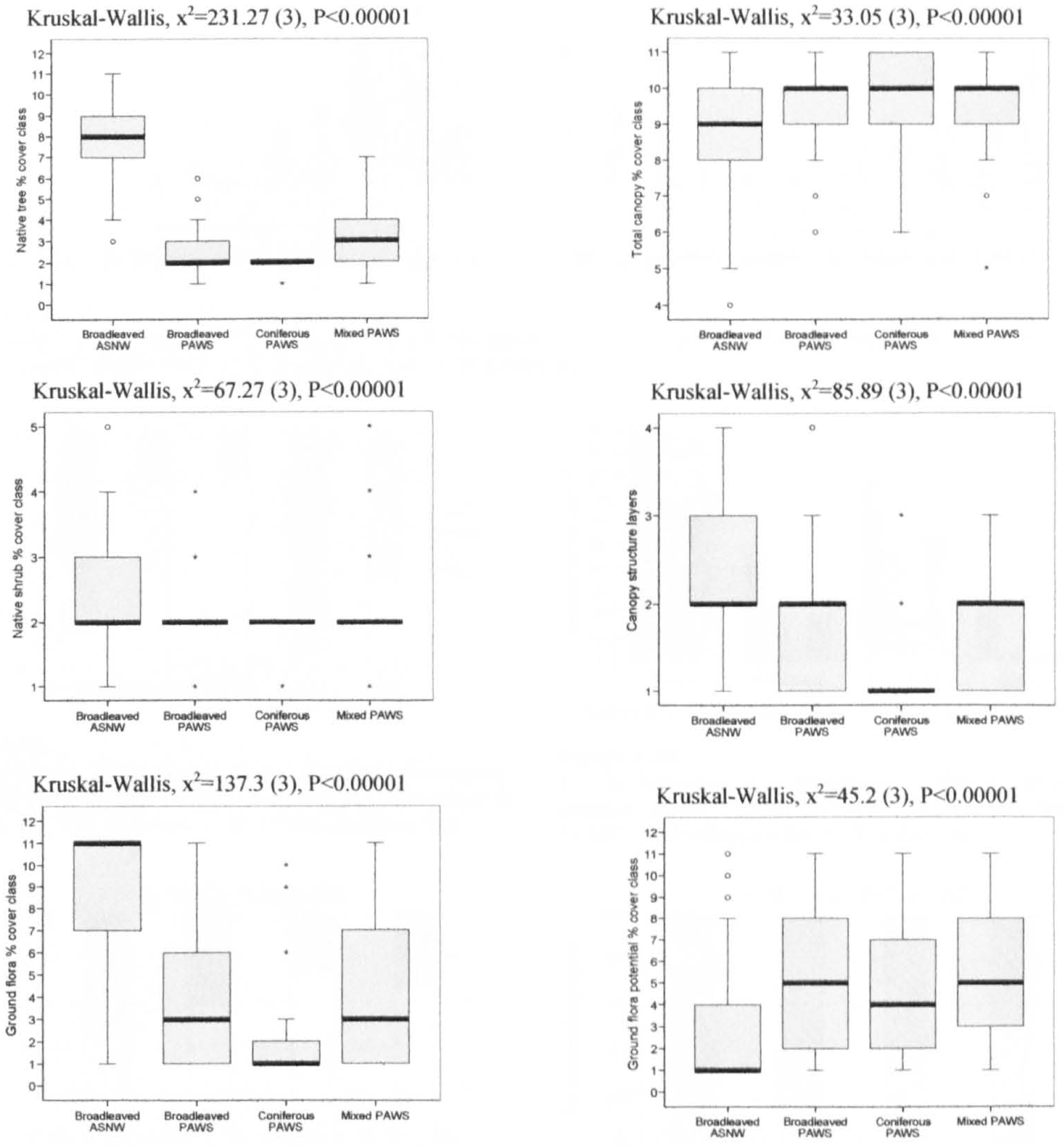
Habitat	N	NVC communities/ ha		Native tree and shrub sp / ha	
		Mean	Median	Mean	Median
Broadleaved ASNW	114	.99	.57	5.14	2.64^{A}
Broadleaved PAWS	61	.26	$.00^{A}$	3.59	2.94^{AB}
Coniferous PAWS	57	.03	.00	2.54	1.46^{B}
Mixed PAWS	66	.47	$.16^{A}$	3.49	2.45^{AB}

Table 10.6
% frequency of NVC communities recorded within each Ancient Woodland habitat. Results based on all fully surveyed Ancient Woodland habitats. ASNW = Ancient semi-natural woodland, PAWS = Plantation on Ancient woodland site

Habitat	N	Compartment frequency (%)					
		0 NVC	1 NVC	2 NVC	3 NVC	4 NVC	5 NVC
Broadleaved ASNW	114	2.6	53.5	36.8	4.4	1.8	0.9
Broadleaved PAWS	61	54.1	32.8	9.8	3.3	0.0	0.0
Coniferous PAWS	57	94.7	3.5	1.8	0.0	0.0	0.0
Mixed PAWS	66	42.4	33.3	19.7	3.0	1.5	0.0

Structural biodiversity indicators The cover of semi-natural trees ranged from 0-95% and of native shrubs from 0-35%, and both differed significantly between the habitats (Fig. 10.16, Table 10.7). Canopy cover ranged from 25-100% and non-native cover ranged from 0% in Broadleaved ASNW compartments to 100% in Coniferous PAWS compartments, both differed between the habitats (Fig. 10.18, Table 10.7). Both the number of canopy layers present (Fig 10.16, Table 10.7), and the presence of individual canopy layers varied between the habitats. There was a higher occurrence of each of the canopy layers within the Broadleaved ASNW compartments (Fig. 10.20), while occurrences were intermediate in the Broadleaved and Mixed PAWS compartments.

The abundance of veteran trees varied between the habitats (Fig. 10.21, Fig 10.26). Due to the low occurrence of compartments with "notable" veteran trees, categories were grouped for analysis. Broadleaved ASNW and Mixed ASNW were collapsed into a single ASNW habitat. There was a significant association between habitat type and veteran tree presence, ASNW compartments holding higher frequencies of presence. The association between habitat and stand age was also analysed using Chi Square. The age categories were collapsed to two categories by grouping shrub and pole age and mature and over-mature classes. Broadleaved and Mixed ASNW were also collapsed into a single habitat. Following this analysis there was a significant relationship between habitat type and compartment age. Broadleaved ASNW had a larger proportion of sites holding mature canopy stands than the other habitats (Fig. 10.22). When the ground-flora covers were examined (Fig. 10.23, Table 10.7) broadleaved ASNW had significantly higher covers than the other habitats. Broadleaved PAWS and Mixed PAWS both had significantly higher cover than Coniferous PAWS. Perhaps surprisingly the ground-flora cover within Broadleaved PAWS did not differ significantly from the cover within Mixed PAWS compartments. A wide variation in the occurrence of deadwood was recorded within each habitat (Figure 10.24). The relationship between habitat and deadwood presence was analysed using Chi square, due to the low occurrence of Mixed ASNW the Broadleaved and Mixed ASNW were collapsed into a single habitat prior to analysis. The analysis confirmed there was a significant relationship between habitat type and deadwood presence.


Kruskal-Wallis, x^2=231.27 (3), P<0.00001

Kruskal-Wallis, x^2=33.05 (3), P<0.00001

Kruskal-Wallis, x^2=67.27 (3), P<0.00001

Kruskal-Wallis, x^2=85.89 (3), P<0.00001

Kruskal-Wallis, x^2=137.3 (3), P<0.00001

Kruskal-Wallis, x^2=45.2 (3), P<0.00001

Figure 10.16
Boxplots of patch structural indicators. Plots detail the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated as points. Class values are: 0=0%, 1=1-10%, 2 =11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41 – 50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, 9 = 81-90%, 10 = 91-100%. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66).

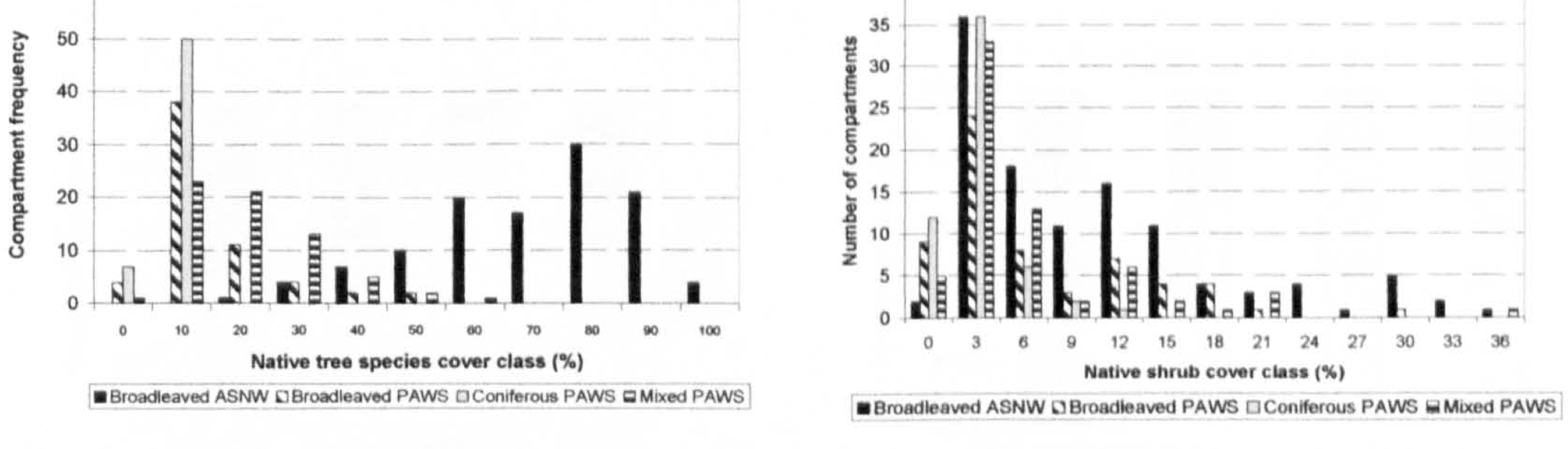


Figure 10.17
The frequency of occurrence of native tree species and native shrub cover per compartment between the habitats. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

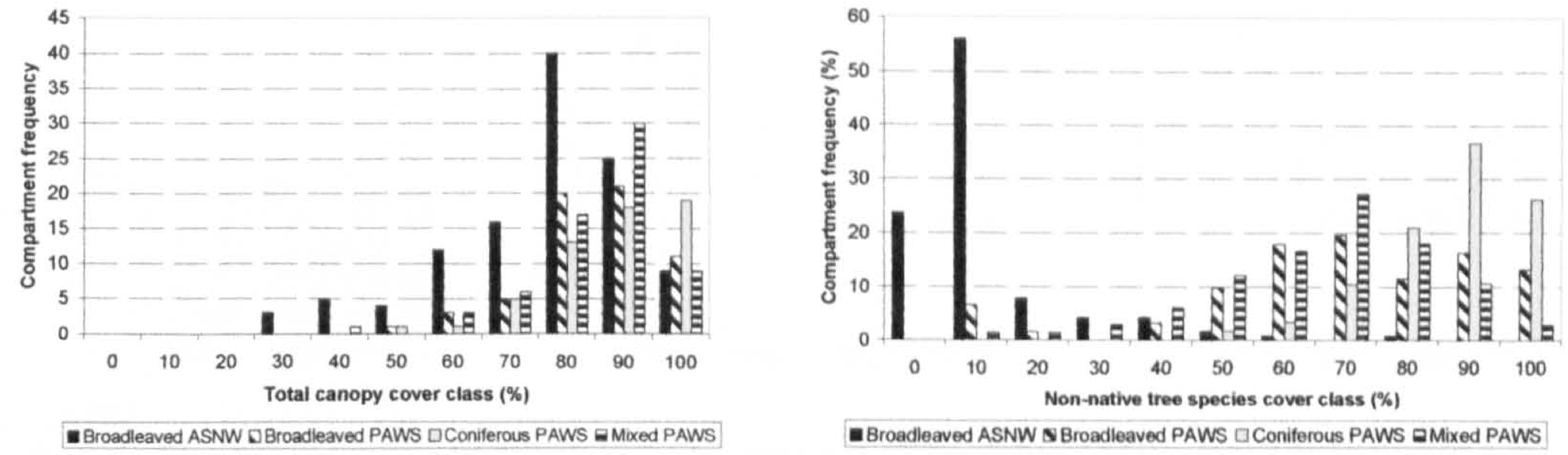


Figure 10.18
The frequency of occurrence of total canopy cover and non-native cover per compartment between the habitats. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

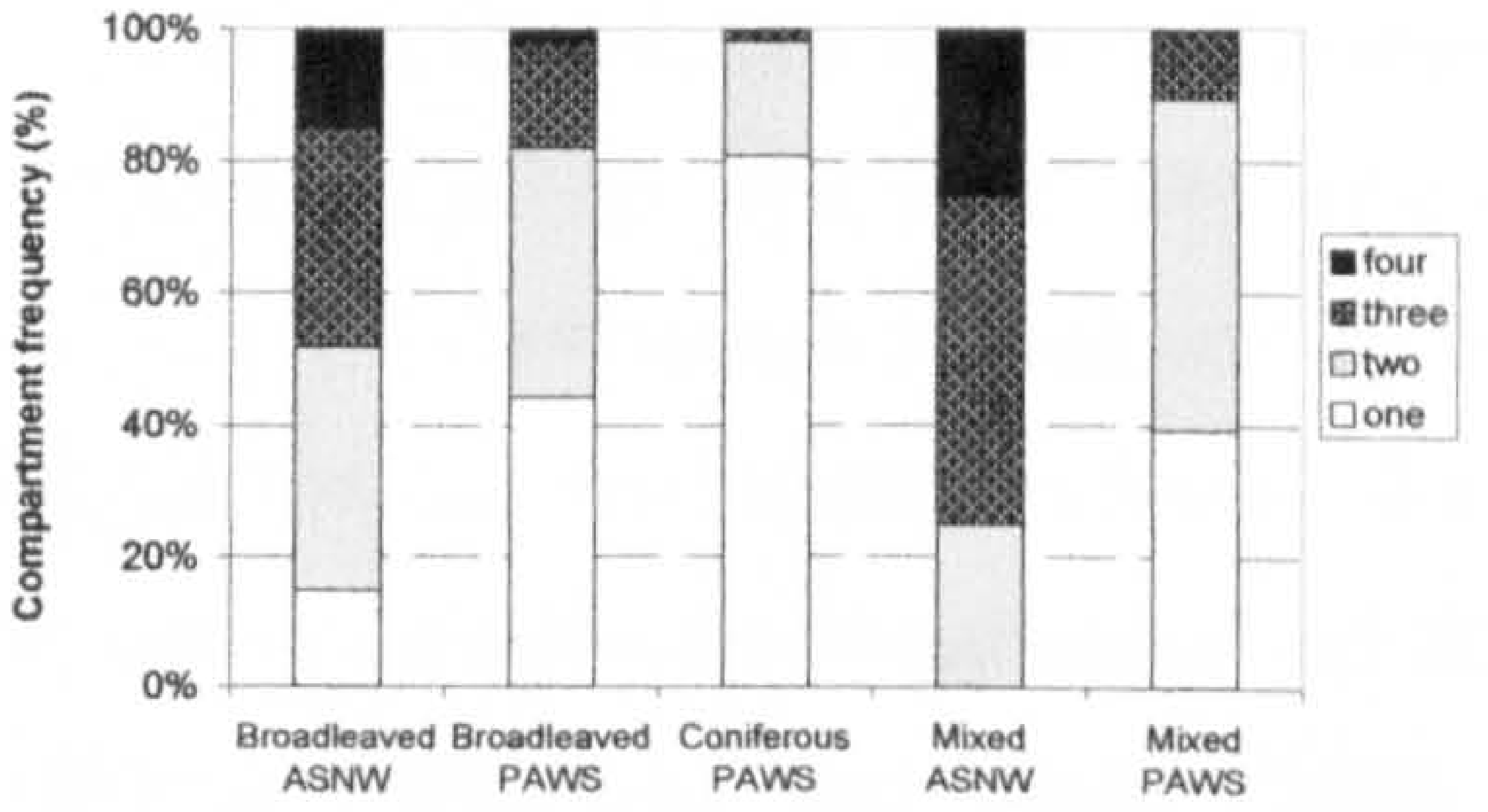


Figure 10.19
The % frequency occurrence of canopy structure layers among the different habitats. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

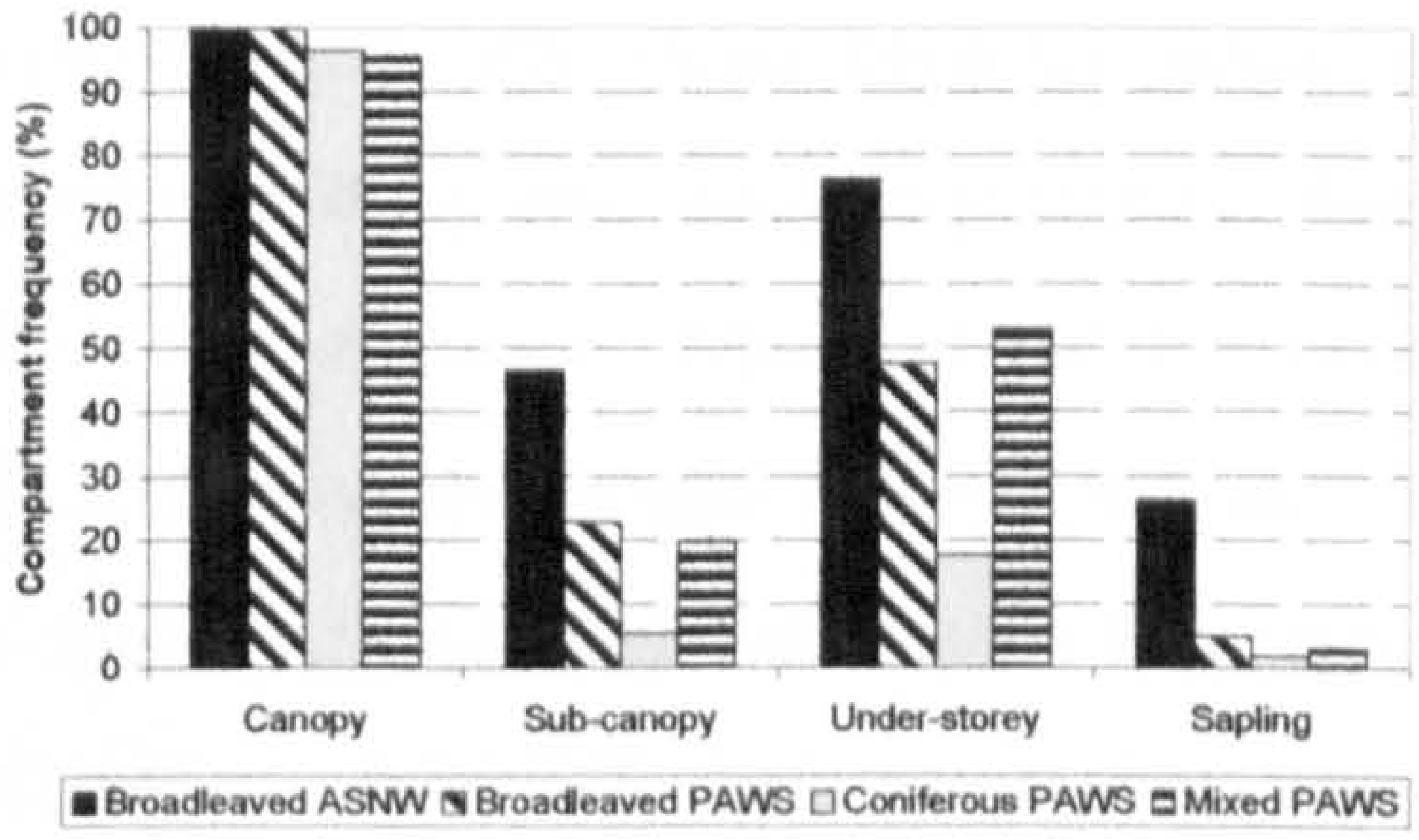


Figure 10.20
The % frequency of compartments within 4 canopy layer presence classes. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

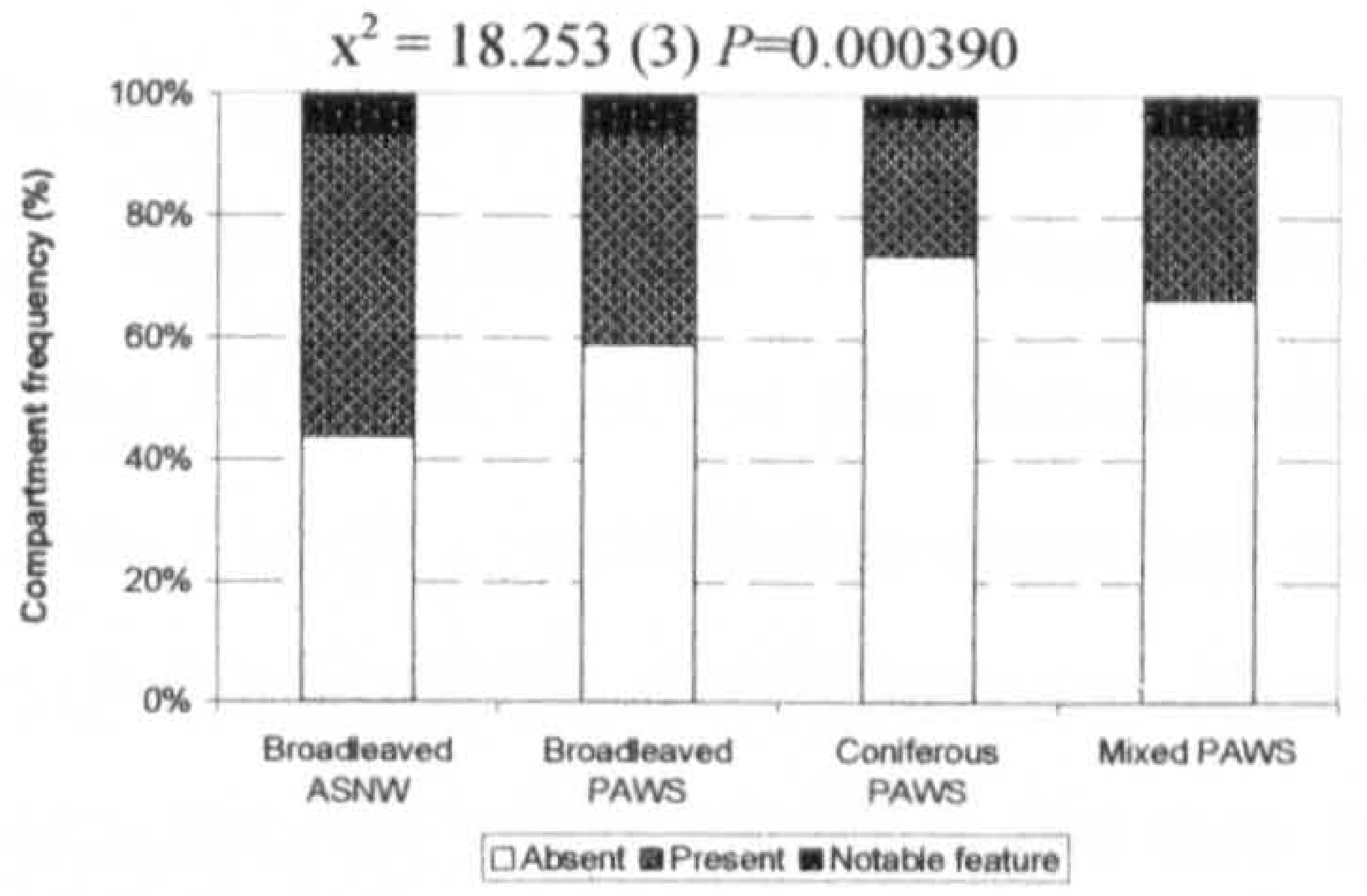


Figure 10.21
The % frequency of compartments classified into one of the three veteran tree presence categories. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

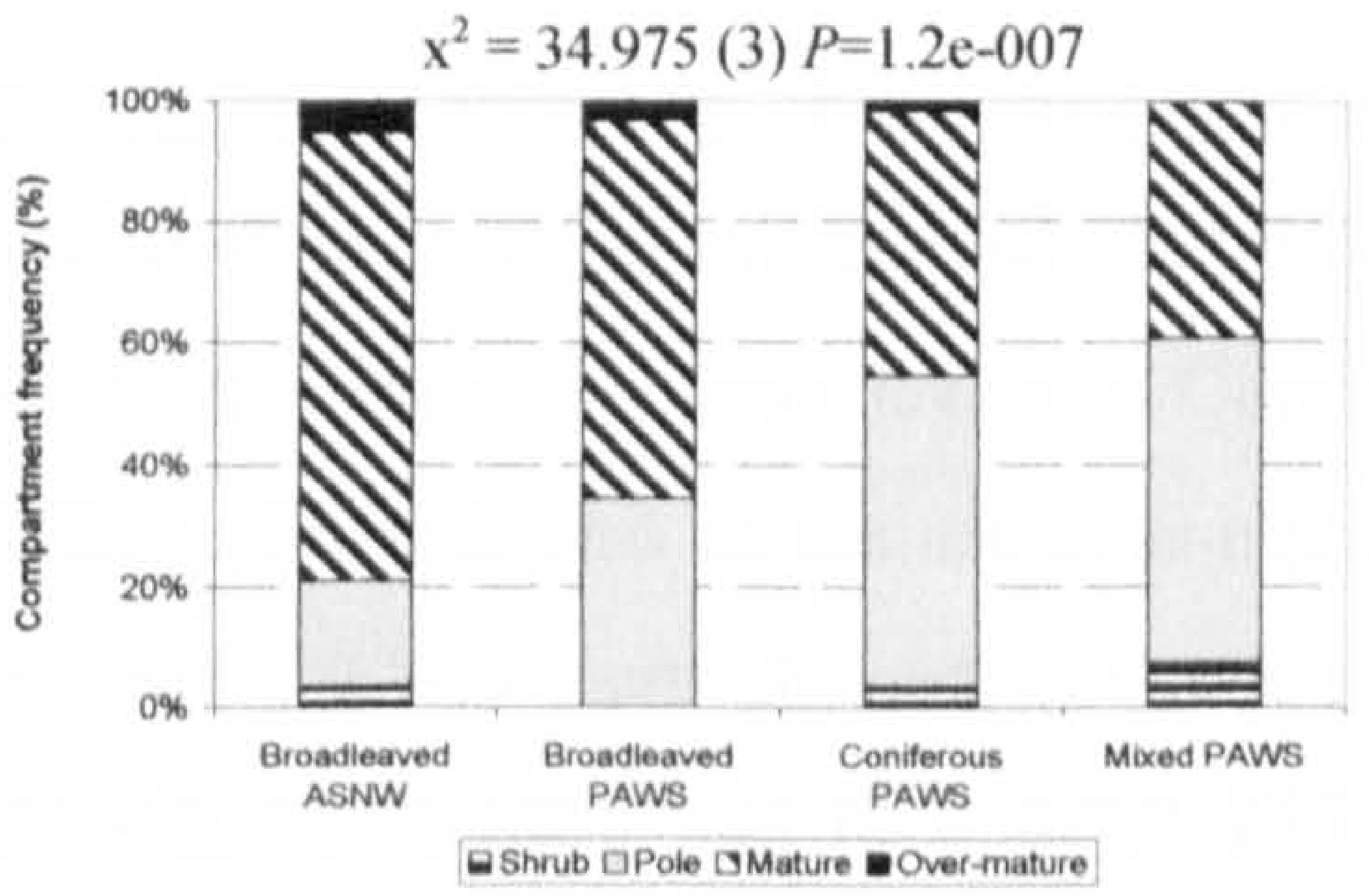


Figure 10.22
The % frequency of compartments classified into one of the four stand age categories for each habitat. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

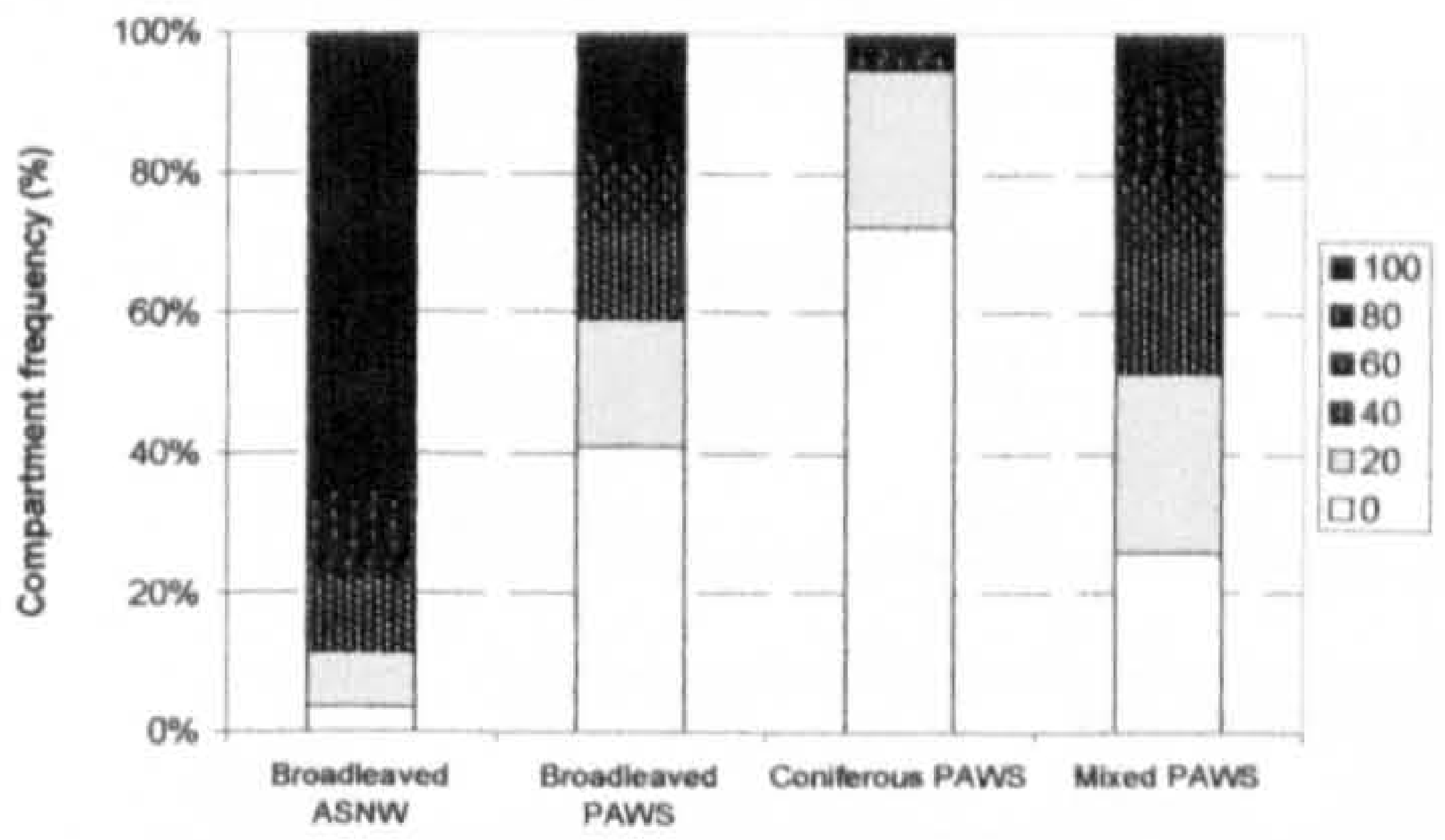


Figure 10.23
The % frequency of compartments classified into one of six NVC ground-flora cover classes. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66).

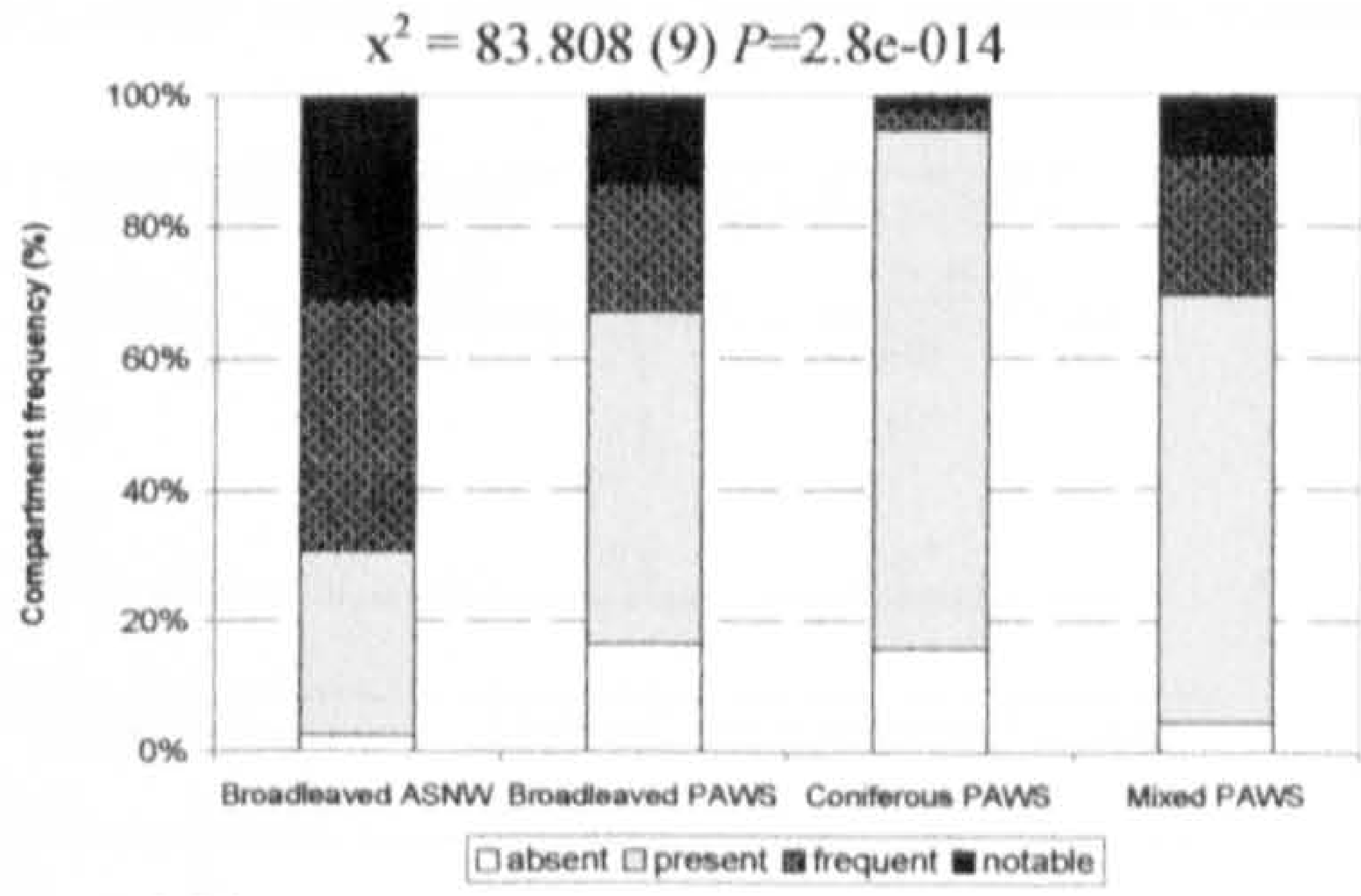


Figure 10.24
% frequency of compartments classified into one of four deadwood presence classes. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66).

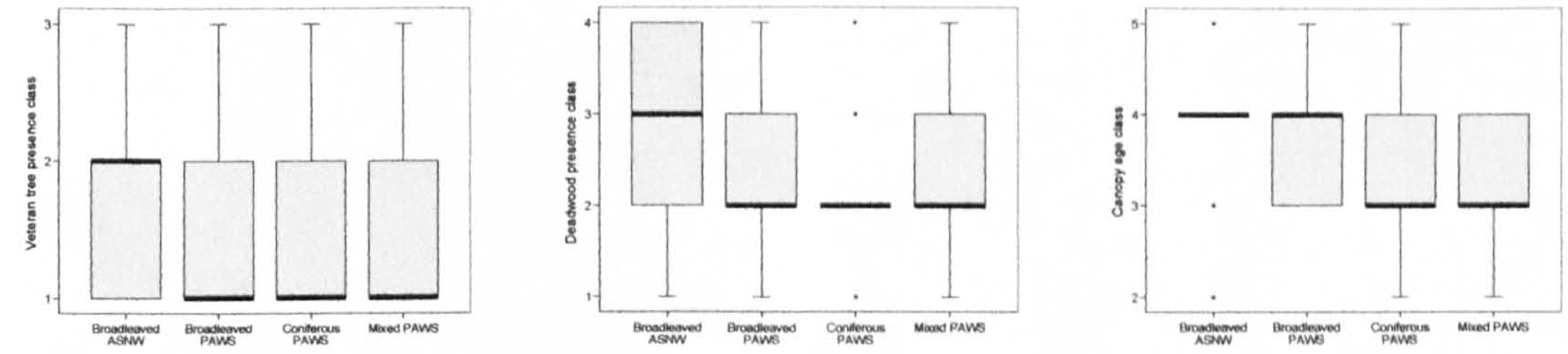


Figure 10.25
Boxplot of patch structural indicators, canopy age, deadwood and veteran tree presence. The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by points. (Populations: ASNW = 114, Broadleaved PAWS = 61, Coniferous PAWS = 57, Mixed PAWS = 66).

In summary, biodiversity structure indicators revealed clear differences between Broadleaved ASNW and Coniferous PAWS compartments, as predicted by the study hypothesis. Analysis also revealed differences among the three PAWS compartments. Many structural variables differed between the Coniferous PAWS and the Broadleaved and Mixed PAWS, but showed no differences between the Broadleaved and Mixed PAWS. Structural interest levels were typically higher in Broadleaved and Mixed PAWS than Coniferous PAWS. Indicators showing these trends included; cover of native tree and shrub species, total canopy cover, non-native canopy cover, number of canopy structure layers, ground-flora cover and presence and abundance of deadwood per compartment. Two further indicators showed subtly different trends. The presence of veteran trees within compartments was also typically more frequent within Broadleaved PAWS than Coniferous PAWS, and showed no differences between Broadleaved and Mixed PAWS, but in this indicator Mixed PAWS did not differ from levels in Coniferous PAWS. Finally compartment stand age was most frequently classed as mature/over-mature in Broadleaved ASNW compartments. More Broadleaved PAWS were classed as mature/over-mature than Coniferous PAWS and than Mixed PAWS, while there was no general difference between Mixed PAWS and Coniferous PAWS.

Table 10.7
Compartment structural indicators. Values with the same letter in their superscripts do not differ significantly according to pair-wise tests (Mann-Whitney tests with a Bonferroni correction with a .05 limit on familywise error rate). Note that only the four main habitats were compared in tests due to the small sample size of Mixed ASNW habitat ASNW = Ancient semi-natural woodland, PAWS = Plantation on Ancient woodland site.

		Native Tree cover		Native shrub cover		Ground-flora cover	
Habitat	N	Mean	Median	Mean	Median	Mean	Median
Broadleaved ASNW	114	70	70	15	10	78	100
Broadleaved PAWS	61	15	10	10	10^{A}	31	20^{A}
Coniferous PAWS	57	9	10	6	5	7	0
Mixed PAWS	66	21	20	11	10^{A}	33	20^{A}

		Total canopy cover		Canopy layers		Ground-flora potential cover	
Habitat	N	Mean	Median	Mean	Median	Mean	Median
Broadleaved ASNW	114	76	80	2.48	2	18	0
Broadleaved PAWS	61	85	90^{A}	1.75	2^{A}	42	40^{A}
Coniferous PAWS	57	88	90^{A}	1.21	1	38	30^{A}
Mixed PAWS	66	85	90^{A}	1.71	2^{A}	44	40^{A}

Figure 10.26
Veteran tree occurrence and re-growth from former coppice stool (A4 clipboard for scale) at semi-natural ancient woodland sites (ASNW)

Figure 10.27
Areas of remnant scrub and woodland cover at previous ancient or long established woodland sites where woodland cover has declined within the past century. Upper Derwent valley (left) and Woodlands Valley (right)

Figure 10.28
Densely shaded stream clough within a broadleaved sycamore and beech PAWS, Upper Derwent Valley (left) and over-shaded remnant oak tree occurring within a densely planted coniferous PAWS, Longdendale (right)

Figure 10.29
Areas of Oak dominated semi-natural ancient woodland (ASNW) cover on steep sloping ground with heath ground-flora

10.3.1.2 Biodiversity ordination: indicator inter-correlation and data reduction

Initial correlation analysis of the biodiversity indicators found redundancy in some variables (**Appendix 10.6**). A number of variables were combined or omitted where correlations were high, while some variables were found to be redundant within individual habitats, but not within all combined data. This resulted in a drop from 24 biodiversity variables to 17 (**Table 10.8**).

Table 10.8
Biodiversity indicators subject to ordination. AWIS = Ancient woodland indicator species, LBAP = local biodiversity action plan

Indicator group	Indicator variable	Transformation
Conservation interest	AWIS / patch	$(x+1)\log_{10}$
	AWIS / ha	$(x+1)\log_{10}$
Composition	Oak % cover	Arcsine
	Birch % cover	Arcsine
	NVC communities	Sq root
	Native tree and shrub richness	Sq root
	NVC communities / ha	$(x+1)\log_{10}$
	Native tree and shrub richness / ha	$(x+1)\log_{10}$
Structure	Native tree cover (%)	Arcsine
	Native shrub cover (%)	Arcsine
	Total canopy cover (%)	Arcsine
	Canopy structure layers	$(x+1)\log_{10}$
	Veteran tree presence score	$(x+1)\log_{10}$
	Canopy age score	None
	Ground-flora cover (%)	Arcsine
	Potential ground-flora cover (%)	Arcsine
	Deadwood presence score	$(x+1)\log_{10}$

The biodiversity indicators were subject to ordination which enabled a visual examination of the associations between the indicators and produced new variables with reduced dimensionality for use in subsequent analysis of biodiversity / abiotic interactions. Prior to the ordination a scatterplot matrix of variable distributions showed non-linear relationships between some variables. In addition there was a number of varying scales and the occurrence of ordinal variables. Therefore non-metric multidimensional scaling (hereafter NMS) (Mather, 1976, Kruskal, 1964, Prentice, 1977) was chosen as the most appropriate ordination and data reduction technique. This analysis is more readily able to handle non-linear response data and samples measured on varying scales than the more traditionally used PCA (McCune and Grace, 2002, Urban et al., 2002, Lichstein et al., 2002). The analysis was implemented in PC-Ord 5 (McCune and Jefford, 2006). Analysis was undertaken for all combined data (N=298), combined PAWS (N=184) and separately for each habitat: ASNW (N=114), broadleaved PAWS (N=61), coniferous PAWS (N=57) and mixed PAWS (N=66). NMS was conducted with Sorensen distance, thus minimising the effects of outliers and maximising the nonparametric potential of the method. Initial analysis was conducted with 50 runs of real data and 50 randomisations, at 500 maximum iterations, with an instability criteria of 0.0000001. Choice of dimensionality was made following examination of the scree plot, Monte Carlo results and the recommendations of the PC-Ord selection procedure. In all cases a 3D solution was selected. The final solution was selected from an analysis of 250 runs of data, selecting the solution with lowest stability. Stability was assessed by examination of the stress vs. iteration plot to ensure the number of iterations was sufficient to give a stable solution. McCune and Jefford (2006) recommend stability of less than 0.0001; all the solutions produced stability less than 0.000001. Final stress and variance explained by each axis are presented in **Table 10.10**.

The ordination plots, from the analysis of all compartment data, coded by habitat type, are presented in **Fig 10.30 and 10.31**. In the ordination (**Fig. 10.30**) Axis 1 represents a trend of increasing ground-flora cover, with high botanical and NVC community richness per ha. Axis 3 represents a general summary of biodiversity structural, compositional and richness interest (**Table 10.10**). This ordination shows separation of the ASNW and coniferous PAWS habitats with the other PAWS (mixed, broadleaved) occupying intermediate distributions. Indicators such as ground-flora cover and NVC communities per ha are associated with the ASNW habitat compartments. Axis 2 in the ordination shown in **Fig. 10.31** shows high ground-flora cover with high occurrence of several features of conservation interest (tree cover, deadwood, NVC communities, oak) but low richness of AWIS and tree and shrub species per ha. Axis 2 shows diverse and high quality sites that are not necessarily highly botanically diverse for their size. The ordination shows separation of the biodiversity values of the different habitats, again with most difference between ASNW and coniferous PAWS, with ASNW showing higher interest values. Mixed and broadleaved woods show intermediate distributions. However there is a larger degree of overlap between the compartments indicating a wide spread of biodiversity condition exist within compartments classified as any particular type. Of the biodiversity variables, several were clustered. The botanical richness per unit area indicators of AWI/ha and trees and shrub/ha occupy close positions as do deadwood, veterans and age, although this is not easily seen on the ordination plot due to overlap and scale. The ground-flora indicator can be seen to be associated with the area of the ordination space occupied by the ASNW habitat while similarly the potential / restorable ground-flora indicator and total canopy cover are located in the area of the ordination occupied primarily by PAWS habitats.

Table 10.9
Ordination score Pearson correlations with original biodiversity variables. Correlations $r^2 < 0.1$ are omitted for clarity

Variable	1	2	3
Stand age			
AWIS richness	.354		.536
AWIS richness / ha	.543	-.425	.360
Oak cover		.474	.579
Birch cover			.501
NVC richness		.479	.743
Tree + shrub richness			.729
NVC richness / ha	.443		.615
Tree + shrub richness / ha	.436	-.316	.381
Native tree cover	.325	.496	.767
Native shrub cover			.668
Total canopy cover			-.399
Ground-flora cover	.552	.636	.759
Ground-flora potential	-.672	-.691	-.322
Canopy layers			.705
Veteran trees	-.326		.343
Deadwood		.419	.350

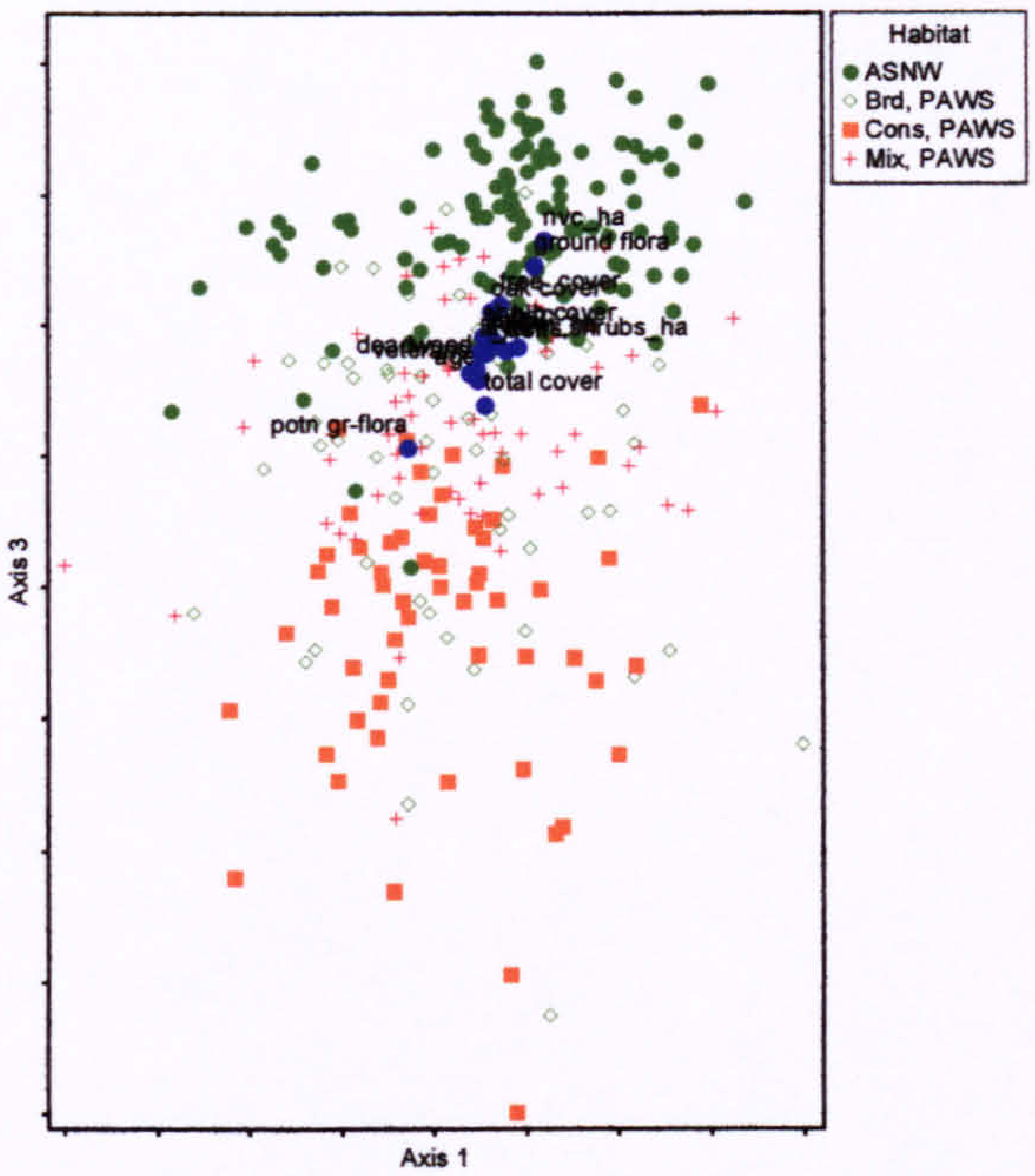


Figure 10.30
NMS ordination of biodiversity indicators for all combined compartment data (N=298): Axis 1 and 3, coded by habitat category. Axis 1: $r^2 = .12$, Axis 3: $r^2 = .61$. ASNW = ancient semi-natural woodland, brd = broadleaved, cons = coniferous, mix = mixed, PAWS = plantation on ancient woodland site. Blue circles indicate the projected location of the biodiversity indicators.

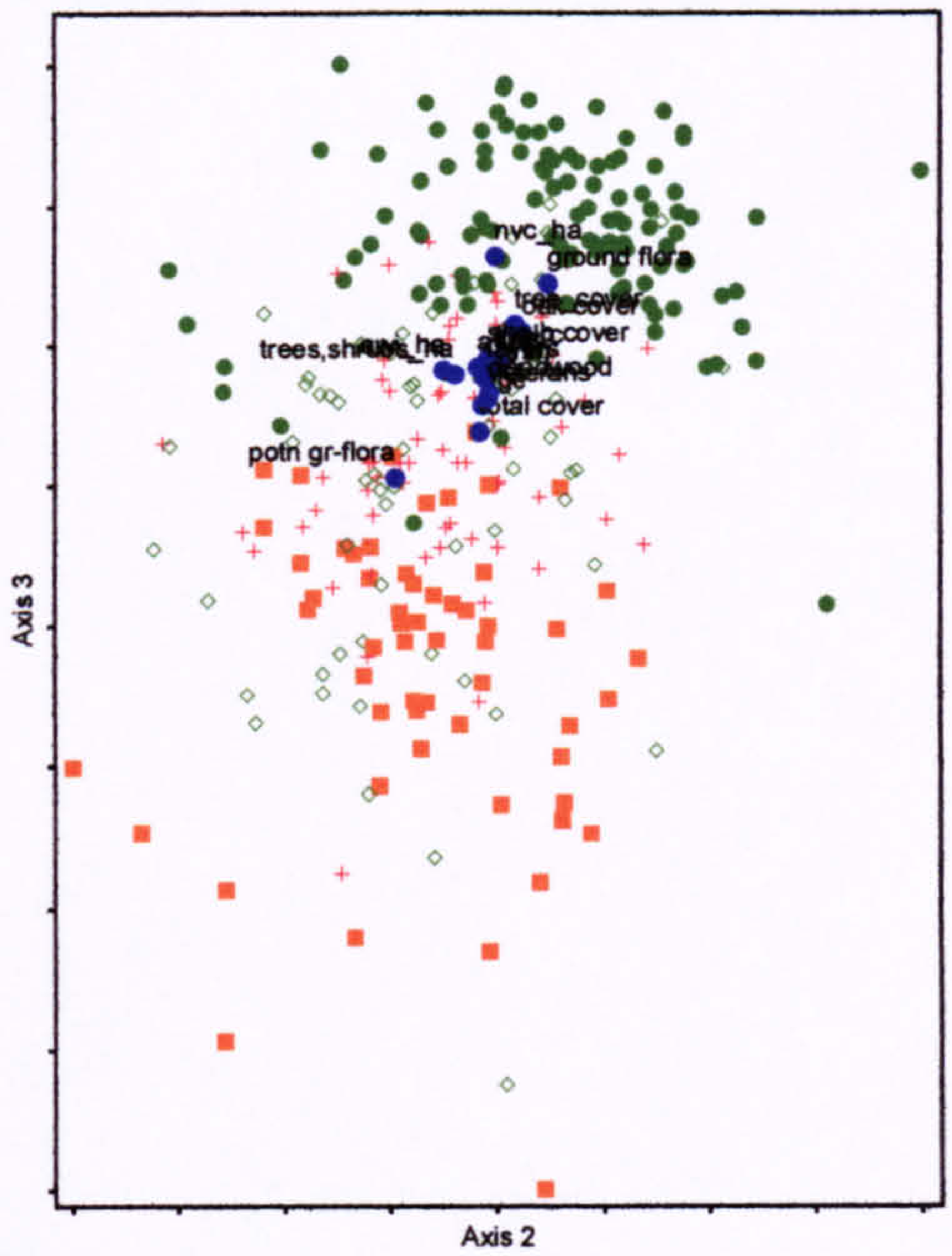


Figure 10.31
NMS ordination of biodiversity indicators for all combined compartment data: Axis 2 and 3, coded by habitat category. Axis 2: $r^2 = .18$, Axis 3: $r^2 = .61$. ASNW = ancient semi-natural woodland, brd = broadleaved, cons = coniferous, mix = mixed, PAWS = plantation on ancient woodland site. Blue circles indicate the projected location of the biodiversity indicators.

Table 10.10
Biodiversity indicator ordination / data reduction by non-metric multidimensional scaling (NMS). Each axis is interpreted resulting from visual examination of the ordination plot and assessment of the correlations between original biodiversity indicators and the reduced ordination axis scores. Solution r^2 is the result of an after the fact assessment of how well the distance in the ordination reflect the original distances in the untransformed biodiversity indicator space. This assessment of the variance represented by the ordination used Sorenson distance. Solutions were reached following varimax rotation.

Data	Stress + r^2	Axis	Axis biodiversity interpretation	Axis r^2	High axis scores indicate
All compartments	12.5	1	Ground-flora cover, and botanical richness per unit area: (AWIS / ha, NVC / ha, trees + shrubs / ha)	.12	High interest
N=298	r^2=.91	2	Ground-flora cover and structural diversity: (native tree cover, NVC, oak, deadwood)	.18	High interest
		3	Naturalness interest: (Tree cover, ground-flora cover, NVC, trees + shrubs, layers, shrubs, NVC /ha)	.61	High interest
All PAWS	14.3	1	AWI / ha, ground-flora potential / ground-flora cover, trees and shrub per / ha	.14	Low interest
N=184	r^2=.89	2	Trees and shrubs, shrub cover, AWI, tree cover, NVC, layers (oak, ground -flora, NVC / ha, deadwood)	.60	High interest
		3	Low ground-flora potential cover, ground -flora cover, NVC richness	.14	High interest
ASNW N=114	15.01	1	Oak, NVC / ha, low trees shrubs / ha, low shrub cover, low BAP, notable / ha	.09	Mixed interest
	r^2=.87	2	Trees and shrubs / ha, AWI / ha, BAP + notable / ha, NVC / ha, low oak cover	.38	High interest
		3	AWI, BAP, notable, AWI / ha, ground-flora, trees and shrubs, BAP, notable / ha, age	.40	Low interest

10.3.1.3 Biodiversity values, composite "Biodiversity score" and woodland habitat class

In addition to the quantitative, data-driven, analysis of compartment biodiversity a more qualitative approach was also undertaken. Each biodiversity indicator was given an interest value, producing a composite biodiversity score. This indicated biodiversity value for ancient semi-natural woodlands and remnant interest or "restoration potential" for PAWS woodlands. The scoring gave equal importance to each attribute and was based upon insights gained from the literature review (Chapters 4 and 5) and Forestry Commission PAWS restoration guidance (Thompson et al., 2003).

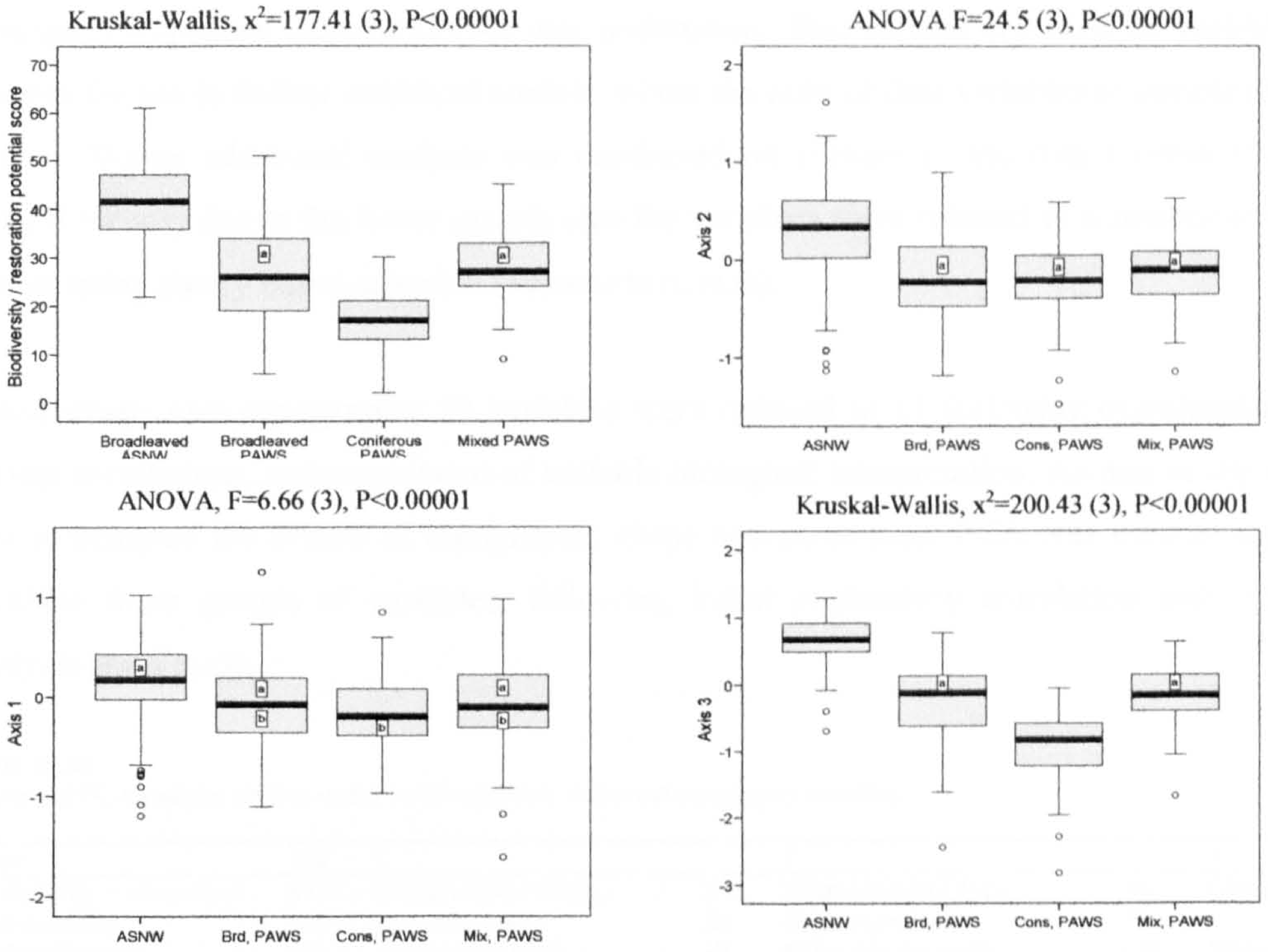
Table 10.11
Scoring of biodiversity indicators on a 1-5 scale prior to creation of compartment summary interest score.

Biodiversity indicator Derived score -	Absent 0	Very poor 1	Poor 2	Moderate 3	Good 4	Very good 5
Number of AWIS	0	1-3	4-8	9-13	14-18	19-24
BAP, BAP, notable sp.	0	1	2	3	4	5
No NVC communities	0	1	2	3	4	5
No of tree sp / patch	0	1	2	3	4-5	6-7
No of shrub sp / patch	0	1	2-3	4-5	6-7	8-10
Oak % cover class	0%	10%		20%		30%+
Birch % cover class	0%	10%		20%	30%+	
Ground-flora cover	0%	1-20%	21-40%	41-60%	61-80%	81-100%
Semi-natural tree cover	0%		10%	20%	30%	40%+
semi-natural shrub cover	0%		5%	10%		20%+
Canopy structure layers		1	2	3		4
Presence of veteran trees	Absent			Present		Notable
Canopy age	Shrub	Pole		mature		Over-mature
Presence of dead wood	Absent		Present		Frequent	Notable

Table 10.12
The predicted value of each indicator to potential target conservation organisms groups are indicated, *=important to ***= very important feature for that organisms group.

Biodiversity indicator	Birds	Inverts	Botany	Fungi	Mammals (bats)
Number of AWIS		**	***		
BAP, LBAP, notable			***		
NVC communities	**	**	***	**	**
No. of tree sp / patch	***	***	*	**	**
No. of shrub sp / patch	***	***	*	*	**
Oak % cover class	**	*		**	**
Birch % cover class	*	**		**	*
Ground-flora cover	*	**	***		
Semi-natural tree cover	***	**		*	**
Semi-natural shrub cover	***	**		*	**
Canopy structure layers	***	***		*	**
Presence of veteran trees	***	***		***	***
Canopy age	**	***		***	**
Presence of dead wood	***	***		***	**

Insight into differences between the biodiversity present within ancient woodland habitats can be gained by analysing the raw biodiversity variables or the summary values: biodiversity score and NMS ordination scores. Examination of the 4 summary scores (Fig. 10.32) shows that consistent differences exist between the biodiversity-rich ASNW habitat and biodiversity-poor coniferous PAWS. Among many of these measures however there is no difference between the intermediate mixed and broadleaved PAWS biodiversity levels, or in some cases as in Axis 2 score between any of the PAWS habitats. The relative values between habitat are such that overlap occurs and it is possible for poor quality compartments of ASNW to have similar interest levels to a high quality coniferous PAWS compartment.



Kruskal-Wallis, x^2=177.41 (3), P<0.00001

ANOVA F=24.5 (3), P<0.00001

ANOVA, F=6.66 (3), P<0.00001

Kruskal-Wallis, x^2=200.43 (3), P<0.00001

Figure 10.32

Boxplot of compartment biodiversity / restoration potential score and ordination scores. The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by a circle. (Populations: Broadleaved ASNW = 114, Broadleaved PAWS = 61, Coniferous plantation = 57, Mixed plantation = 66). Habitats with the same letter do not differ significantly following post hoc Mann-Whitney tests with Bonferroni correction to retain a familywise error rate of 0.05.

10.3.2 Abiotic data results

10.3.2.1 Abiotic indicator inter-correlation and data reduction

Data collection within ArcView GIS and Fragstats (McGarigal et al., 2002) allowed analysis of a wide range of abiotic data variables (**Table 10.2, Appendix 10.1**). With analysis occurring at patch scale and at 4 landscape scales, over 80 variables defining the abiotic characteristic within and around each woodland were collated. Following previous studies (Ritters et al., 1995, Neel et al., 2004, Calabrese and Fagan, 2004, Li et al., 2005) many of these patch and landscape variables were expected to be highly correlated. Data reduction was undertaken to produce a sub-set of variables efficiently representing the range of conditions occurring within and around the study woodlands. In order to allow appropriate testing of planned hypothesis the abiotic data were reduced within separate categories. These were "patch" features: area, shape, topography, and "landscape" measures characterising the nature of the woodland resource and matrix habitats surrounding the woodland sites, subdivided into functional and structural measures. The largest group prior to reduction was the landscape group. It was expected some potential for reduction may occur where data collection at certain spatial search scales was redundant, however prior to exploratory analysis it was unknown which scales were correlated.

Variables were examined using bivariate correlations and scatterplot matrices. Due to the linear relationships evident in the data, elimination of highly correlating variables, and reduction using principal component analysis (PCA) was undertaken. This refined selection of variables was suitable for use in further statistical models, where the ratio of data variables to sample sites was critical. Where additional analysis was conducted on subsets of the data (within PAWS or ASNW woods) due to the lower sample size the variables were reduced to a smaller number of factors using theory based selection (Appendix 10.11, 10.12).

Patch shape and topography 20 variables were reduced to 11 following examination of bi-variate correlations, and assessment of variable biological interpretation. An aim of the analysis was to compare the affects of topography, shape and patch area. PCA was used to separately combine these groups of variables, following initial exploratory correlation and ordination analysis (Table 10.13).

Table 10.13
Sequential PCA analysis used to create combined patch shape and topography variables

PCA factor	Var	1		2		3	
Shape complexity + elongation	88%	(Fractal index+1)$\log_{10}$	.96	(Shape index+1)$\log_{10}$	.95	Circle index	.89
Slope and elevation	73%	Elevation mean	.86	Slope mean	.86		
Topographic diversity	75%	Aspect variability	.91	Slope min (sq root)	-.89	Slope range	.78
Topographic diversity / ha	92%	((Aspect var / ha)+1)$\log_{10}$	.96	((Slope range / ha)+1)$\log_{10}$	.96		

Table 10.14
List of 33 abiotic variables recorded within each compartment, following initial data reduction and removal of high correlating variables

Landscape (structural)	Distance to stream (m)	(x+1)$\log_{10}$
	Distance to clough (m)	(x+1)$\log_{10}$
	Area of clough in 1km	None
	Area of contiguous ancient woodland site	(x+1)$\log_{10}$
	Number of ancient woodland sites in 20m, 1km	(x+1) sq root
	Total area of ancient woodland in 500m, 1km	(x+1) sq root
	Proximity score of ancient woodland in 1km	(x+1) sq root
	Area weighted isolation score of ancient woodland in 20m, 100m, 500m, 1km	Sq root arcsine
	Number of semi-natural woodland sites in 20m, 1km	(x+1) sq root
	Total area of semi-natural woodland in 500m, 1km	(x+1) sq root
	Proximity score of semi-natural woodland in 1km	(x+1) sq root
	Area weighted isolation score of semi-natural woodland in 20m, 100m, 500m, 1km	Sq root arcsine
Landscape (functional)	Compartment core area	(x+1)$\log_{10}$
	Core area index	Arcsine
	Contrast value (patch)	None
	Mean contrast value of landscape in 20m, 100m, 1km	(x+1)$\log_{10}$
	"least cost" proximity of ancient woodland in 500m, 1km	Log, log
	"least cost" proximity of semi-natural woodland in 500m, 1km	Log, log

Landscape / spatial The large range of landscape data were reduced to a refined list for inclusion in predictive analysis. Analysis of high correlations ($r>0.7$) and ecological interpretation produced an initial reduced list of 33 variables (Table 10.14). This resulted from variables being highly correlated between search distances, e.g. between 20m radius and 100m, or 500m and 1km. Some variables were correlated across all search ranges and were eliminated. Following initial reduction a further set of variables was produced for use in the multiple regression models where the number of input variables was strictly limited by relation to sample totals. Analysis of these 33 variables by correlation and exploratory PCA analysis showed there was insufficient structure in the entire set to allow PCA reduction, therefore the least correlated variables were retained in their original form and data reduction was applied in two stages to sets of functional isolation and structural isolation metrics (Table 10.16, 10.17). This resulted in a final reduced list of landscape variables (Tables 10.15).

Table 10.15
Reduced list of landscape variables resulting from variable elimination and PCA reduction

Landscape (structural)	Distance to stream (m)
	Distance to clough (m)
	Area of clough in 1km
	Area of contiguous ancient woodland site
	Number of ancient woodland sites in 20m, 1km
	Total area of ancient woodland in 500m, 1km
	Number of semi-natural woodland sites in 20m, 1km
	Total area of semi-natural woodland in 500m, 1km
	PCA S1= Area-weighted isolation of ancient woodland 500m and 1km
	PCA S2= Area-weighted isolation of ancient woodland and semi-natural woodland in 100m
	PCA S3= Area-weighted isolation of ancient woodland and semi-natural woodland in 20m
Landscape (functional)	Compartment core area and core area index
	PCA SF1 = Least cost proximity of Ancient woodland (500,1km) low habitat contrast in 1km
	PCA SF2 =Low contrast in 20m, high least cost proximity of semi-natural woodland in 500m
	PCA SF3 = High patch contrast, high contrast in 100m

10.3.2.2: Ancient woodland compartment abiotic conditions: differences between habitats

The group differences (and a rank order interpretation of pair wise differences) between the reduced list of abiotic variables are presented in Appendix 10.7. Multi-response permutation procedures (MRPP) (Mielke, 1984, McCune and Grace, 2002) was used to test the null hypothesis of no difference between groups, tested for all the abiotic variables together. MRPP is a suitable technique for use with the data due to being nonparametric and allowing the use of unequal sized groups. Analysis was undertaken in Pc-Ord 5 (McCune and Jefford, 2006), with Euclidean distances. MRPP returned $A = 0.067$, $P < 0.0001$ indicating the habitats differ significantly in abiotic conditions between the groups. However the rather low A value indicates the habitat groups are not particularly distinct in their abiotic conditions with a lot of overlap in variables values between habitats.

Pair-wise results indicate that the greatest difference occurs between the ancient semi-natural woods and the coniferous plantations, with the highest "A" value (Table 10.18). However this value, although significant remains rather low indicating that the abiotic conditions between these habitats are not particularly distinct. There is less, although still significant, difference as indicated by the lower A values between ASNW and the broadleaved and mixed PAWS and broadleaved PAWS and between broadleaved PAWS and coniferous PAWS. There was no significant difference between the conditions in the mixed and coniferous PAWS woods or between the mixed and broadleaved PAWS woods.

Table 10.16
PCA data reduction of functional isolation metrics. 3 PCA functions were extracted with 82% of variance. Correlations with scores shown with varimax rotation, Kaiser normalisation.
Input variables: AW = ancient woodland, SN = semi-natural woodland, LCProx = least cost proximity, Cont = contrast score.

PCA	Component variables															
	1		2		3		4		5		6		7		8	
PCASF1	LCProxAW1km	.91	LCProxAW500m	.80	Cont1km	-.74	Cont20m	.11	LCProxAW500m	.58	LCProxAW1km	.63	Cont	-.16	Cont 100m	-.29
PCASF2	LCProxAW1km		LCProxAW500m	.28	Cont1km		Cont20m	-.85	LCProxAW500m	.74	LCProxAW1km	.65	Cont		Cont 100m	-.57
PCASF3	LCProxAW1km		LCProxAW500m	-.24	Cont1km	.36	Cont20m	.31	LCProxAW500m		LCProxAW1km	.15	Cont	.88	Cont 100m	.70

Table 10.17
PCA data reduction of structural isolation metrics. 3 PCA functions were extracted with 60% of variance. Correlations with scores shown with varimax rotation, Kaiser normalisation.
Input variables: AW = ancient woodland, SN = semi-natural woodland, AIS = area weighted isolation score.

PCA	Component variables															
	1		2		3		4		5		6		7		8	
PCA S1	AW1kmAIS	.79	AW500mAIS	.72	SN1kmAIS	.64	SN500mAIS	.62	AW100mAIS		SN100mAIS		AW20mAIS	.14	SN20mAIS	-.20
PCA S2	AW1kmAIS	-.21	AW500mAIS		SN1kmAIS	-.12	SN500mAIS	.32	AW100mAIS	.83	SN100mAIS	.77	AW20mAIS	.11	SN20mAIS	
PCA S3	AW1kmAIS		AW500mAIS		SN1kmAIS		SN500mAIS	-.15	AW100mAIS	.10	SN100mAIS	.11	AW20mAIS	.81	SN20mAIS	.81

Table 10.18
Pair-wise MRPP tests with Sorensen distance. P values must be less than 0.008 to retain a 0.05 familywise error rate with Bonferonni adjustment.
N = ASNW:114, Brd PAWS: 61, Con PAWS: 57, Mix PAWS: 66.

Habitat	Habitat	T	A	P
ASNW	Con PAWS	-26.97	0.092	<0.0000
ASNW	Mix PAWS	-15.12	0.048	<0.0000
ASNW	Brd PAWS	-10.98	0.038	<0.0000
Con PAWS	Mix PAWS	-1.32	0.006	0.1017
Con PAWS	Brd PAWS	-5.49	0.028	0.0003
Mix PAWS	Brd PAWS	-0.66	0.003	0.2186

10.4 Analysis: site biodiversity and abiotic interactions

10.4.1 Predicting woodland biodiversity levels from abiotic conditions

Analysis was undertaken to examine the association between within-patch biodiversity levels (as summarised by the single composite biodiversity score and the 3 NMS ordination scores) and woodland within-patch abiotic condition and landscape context. Analysis was principally conducted on all combined data, although additional analysis examined relationships within the PAWS and ASNW data subsets (Table 10.26, 10.32, Appendix 10.12). Analysis examined the following postulates:

- Woodland patch biodiversity levels are associated with patch abiotic conditions
- A reduced number of abiotic variables can act as predictors of woodland patch biodiversity
- Within-patch abiotic conditions are more predictive than landscape context predictors
- Woodland habitat quality can be assessed using causal abiotic diversity variables e.g. topography, which are preferable to patch area or shape which are simply indicative of within-patch diversity in other abiotic conditions

10.4.2 Examining theory-based causal abiotic biodiversity predictors

Theory suggests a number of abiotic factors will be either causally related or associated with biodiversity values. Beyond habitat type, which is expected to be indicative of site value, strong evidence suggests within-patch habitat quality will affect biodiversity. Such factors include topography and hydrology. The effect of these indicators are due to their association with primary driving causes of diversity and / or management activity e.g. availability of microhabitats, soil chemistry, light levels and fertility. Additional patch variables such as area and shape may hold value themselves in being associated with biodiversity, or may simply be indicative of within-patch abiotic conditions. Beyond patches a range of landscape values may impact on site biodiversity levels either in causal or associative patterns. Causal influences of landscape context (isolation, woodland cover, urban area, disturbance) may result from landscape form directly influencing community dynamics. More isolated patches may show lower biodiversity levels due to effects of dispersal or extinction / colonisation dynamics, as predicted by landscape ecology and island biogeography theory, irrespective or in addition to the effects of within-patch quality measures. Landscape form may have a direct causal effect, especially when quantified with functional metrics such as landscape contrast, or least-cost connectivity. Conversely landscape factors may simply be associated with unmeasured factors or regional trends, which themselves may be the driving factors behind biodiversity levels.

The potential causality and predictive ability of measured abiotic factors on woodland biodiversity levels were assessed by constructing a sequential multiple regression model. The variables were entered in order of hypothesised importance (Table 10.19), allowing the impact of each block of variables to be assessed. Changes in significance and importance of individual variables as indicated by beta values and part, partial correlations were monitored during model progression. The effect of carrying out an NMS ordination followed by regressing the results on environmental variables is similar to carrying out a constrained CCA ordination (Urban et al., 2002). Data were transformed to reduce skewness, reduce the potential effects of outliers and improve the normality, linearity and homoscedasity of residuals (Table 10.19). The presence of outliers was assessed using SPSS casewise diagnostics and examination of the leverage statistic. Typically no outliers were indicated by leverage. In some data runs 3-4 potential outliers were indicated by standard deviation diagnostics. Running the final regression in the absence of these cases produced increases in the adjusted R achieved by the model, but did not qualitatively change model interpretation, therefore these cases were retained.

Variable order was based upon existing theory and current research hypothesis. It was hypothesised that patch area and shape are likely to be strongly associated with site biodiversity, but that they are themselves indicative of within-patch quality, which will better be predicted by directly measuring the likely causal within-patch factors: topographic diversity, slope mean, elevation, stream presence / distance, landscape topography class, clough presence and distance. Landscape variables were predicted to have lower impacts on the assessment of woodland biodiversity (richness, composition, structure) than within-patch variables. However potential associations of some diversity measures with landscape variables were expected. Of the landscape variables functional measures in particular were predicted to be associated with the biodiversity / botanical richness levels. It was expected several landscape variables would be more indicative of current or past management influences within woods, or of future potential dispersal / colonisation distances. However due to the broad assessment of total biodiversity interest captured by the summary biodiversity scores (including richness, composition and structural factors) it was unknown if landscape measures would prove predictive of biodiversity levels, or which landscape measure scales would most impact on biodiversity, therefore these later stages of the model analysis were acknowledged as exploratory.

The analysis was conducted with both the qualitative summary biodiversity score, and on each of the NMS axis scores, producing 4 regression models. Habitat class was indicated by dummy variables. Further models were also produced using the PAWS and ASNW data subsets, where these provided additional insight into whether effects were consistent within PAWS sites, and in order to examine associations within natural woodland sites. For these habitat groups with smaller samples, a reduced range of abiotic variables were used (Appendix 10.11). These additional models are referred to in the text below and are reproduced in Appendix 10.12.

10.4.3 Sequential variable addition and multiple regression model development

The models were constructed in the order of Table 10.19 and variables were added in blocks. The significance of each block was assessed using R^2 change and significant F change statistics, and the individual significance of each variable was monitored at each stage. Multiple regression tests assumptions were verified at appropriate stages. Due to the sequential methodology and incorporation of data within theory-selected blocks, multicollinearity was an issue following addition of the final landscape variables (block 7). Two methods were used to eliminate multicollinearity. Recommended assessment of VIF and tolerance levels (Tabachnick and Fidell, 2007) were used to identify problem variables. Where these were not individually significant in the model these were removed in order of VIF value from highest to lowest until a stable model was achieved. Additionally the effect of the removal of variables was monitored by observing the R adjusted change statistics. Only variables without significant affect on the model R were removed. In the cases when the variable indicated for removal (highest VIF) was itself individually significant, its removal was tested by observing the R^2 change statistic. Alternative variables, sharing the multicollinearity problem were removed instead and the R^2 change observed. This process was repeated until suitable multicollinearity diagnostic levels were achieved.

10.4.4 Addressing spatial autocorrelation

Spatial location and the autocorrelation of data are known potential confounding issues within landscape studies. The spatial aspects of landscape data may violate the assumptions of traditional statistics (Legendre, 1993, Wagner and Fortin, 2005, Haining, 2003, Legendre et al., 2002). Positive autocorrelation can lead to the inflation of r values in correlation (Liebhold and Sharov, 1998). Therefore means of addressing or confronting these limitations have been practised in a number of studies (Diniz-Filho et al., 2003, Liebhold and Sharov, 1998, Pandit and Laband, 2007, Lichstein et al., 2002). There is consensus that spatial autocorrelation should always be investigated in landscape ecology studies, although it need not always introduce bias (Diniz-Filho et al., 2003). Several studies have aimed to explicitly model or extract the effects of purely spatial effects by using variance partitioning (Meot et al., 1998, Borcard et al., 1992, Legendre, 1993). However a large number of past studies have ignored such potential effects leading some authors to criticize that few past studies have sufficiently addressed spatial autocorrelation in multiple regression (Lichstein et al., 2002).

Spatial autocorrelation of data need not be a problem when present in predictive data variables (Legendre et al., 2002), but is considered a problem when present in the residuals of regression models (Wagner and Fortin, 2005, Haining, 2003). When present the autocorrelation can indicate that important, key variables have not been included in the model (Haining, 2003, Lichstein et al., 2002). Within the current study it was hypothesised that all theory selected local scale (patch to 1km) spatial scales had adequately been incorporated within the model, due to the wide variety of landscape variables collected.

Of the available measures to quantify spatial structure of the model the residuals (Dale et al., 2002, Legendre, 1993), Moran's I was selected within ArcGIS 9.2 (ESRI, 2006) to assess spatial autocorrelation using inverse distances. When spatial auto-correlation was detected a procedure was undertaken to assess how reliable the models were and attempt to remove the autocorrelation by adding extra variables. Additional variables were only considered at scales beyond those already examined (Table 10.20). These broader scales, beyond 1km may hold predictive power, and could represent regional trends; such trends may also be reflected by association with site geographic co-ordinates. Visual plotting of model residuals in geographic space within ArcView suggested some possible spatial clustering at the 3–10km scale, where sites appeared to hold similar values. Additionally exploratory analysis using semi-variograms within the kriging routine in ArcGIS 9 suggested some evidence for significance at an 8 – 10km distance.

It is preferable to try and find additional explanatory variables in a model rather than just factor away the variance by using simple coordinate values, e.g. the "raw data" approach c.f (Legendre, 1993). Therefore additional variables of urban landcover and ancient woodland cover were generated at scales of 2km, 5km, 7.5km and 10km. Due to restrictions on the numbers of variables suitable for addition and testing within models all such variables could not be added to the model. Therefore simple pre-model correlation analysis between these additional potential explanatory variables and the dependant were undertaken and only significantly correlated variables were selected for entry. Where several variables were present backwards selection was used to produce a reduced model. Such pre-selection runs the risk of not including potential "suppressor" variables in the model. However since theoretically relevant variables have been selected *a priori*, this is not considered to be a significant problem. Following the addition of these extra variables the models were again tested for spatial autocorrelation. The use of a similar method, sequentially adding additional environmental variables, was successful in another study in reducing autocorrelation in residuals to undetectable levels (Diniz-Filho et al., 2003). In cases where these variables did not eliminate spatial autocorrelation then the "raw data" approach of Legendre (1993) was implemented and the polynomial XY coordinates were added to the model to assess if other unknown geographic / spatial trends existed. Assessment of XY co-ordinate effects are useful in a geographic model, as the comparison of individually significant variables in models with and without the XY coordinates allows assessment of whether the current significant variables are potentially casually significant or if they are merely correlated with some other more related geographic trend at a different scale (Legendre, 1993). Therefore if the model beta coefficients and the variance explained differed greatly when XY or spatial variables were added to the model, then the suggested influence of the theory defined variables would be put in question. However when addition of such extra variables was significant or was successful in eliminating spatial autocorrelation but did not significantly change the model beta values and model interpretation, then these variables can be attributed as soaking up environmental "noise" in the data. Models with significant spatial autocorrelation remaining, following this procedure, were therefore interpreted with caution.

10.4.5 Multiple regression models

The results of the final models are shown in **Tables 10.21-10.24**, (**Appendix 10.12**), indicating the unstandardised regression coefficients (B), intercept, standardised regression coefficients (β), semipartial correlations (sr^2) for the individual variables, and for the addition of variables in sequential blocks, and R, R^2 and R^2 adjusted for the final model.

Table 10.19
Sequential regression order of addition. All compartments, pooled data. N = 298. AW = ancient woodland, SN = semi-natural woodland

Block		Variables	Transformation
1	Habitat type	Presence / absence of each PAWS habitat	
		ASNW as the reference habitat	
2	Site quality	PCA A3 – topographic diversity	
		PCA A2 – elevation mean and slope mean	
		Grazing	
		Stream distance	$(x+1)\log_{10}$
		Clough distance	$(x+1)\log_{10}$
3	Area, Shape	Area	$(x+1)\log_{10}$
		PCA A1 – shape complexity and elongation	
4	Structural area	Core area index	Arcsine
5	Contiguous area	Ancient Woodland contiguous site area (semi-natural and plantation)	$(x+1)\log_{10}$
6	Functional connectivity	PCA1 SF =least cost proximity AW/ SN 1km, 500m and low contrast 1km	
		PCA2 SF=low contrast 20m 100m, and high least cost proximity SN500m, 1km	
		PCA3 SF =high contrast at patch and at 100m,	
7	Structural connectivity	Area of AW in 500m	(x+1) sq root
		Area of SN in 500m	(x+1) sq root
		No. of AW in 20m	(x+1) sq root
		No. of SN in 20m	$(x+1)\log_{10}$
		PCA3 S = high area weighted isolation, AW 20m, SN 20m	
		PCA2 S = high area weighted isolation, AW 100m, SN 100m	
		PCA1 S = high area weighted isolation, AW 1km,500m, SN 1km, 500m	
		Area of AW in 1km	(x+1) sq root
		Area of SN in 1km	(x+1) sq root
		Clough area in 1km	
		No. of AW in 1km	(x+1) sq root
		No. of SN in 1km	(x+1) sq root

Table 10.20
Spatial and co-ordinates data assessed for multiple regression models showing spatial auto-correlation in model residuals.

Block	Variables
Geographic co-ordinates	XY polynomial
Urban cover	Urban in 1km, 2km, 5km, 7.5km
Ancient woodland cover	Ancient woodland in 1km, 2km, 5km, 7.5km

10.4.5.1 NMS Ordination 1 (ground-flora potential, botanical and community richness per ha)

The final multiple regression model returned: $r^2 = .369$, $F_{(24, 273)} = 6.645$, $p < .0001$. The adjusted R^2 of .313 indicates that over a third of the variability in NMS1 biodiversity scores within compartments was predicted by the woodland habitat and abiotic conditions (Table 10.21). After the addition of habitat type, the addition of block 2 variables was significant. Individually slope and elevation mean, stream distance and topographic diversity were all significant. With the addition of area and shape in block 3, elevation, slope mean and topographic diversity were no longer significant, being replaced by a highly significant and high beta value for area. Stream distance remained significant. Addition of core area index and contiguous ancient woodland area in blocks 4 and 5 did not affect the results. With the addition of the functional isolation variables in block 6 one habitat became non-significant although beta levels remained similar. Area remained the highest effect but CAI also became significant with functional isolation 3. By blocks 7 and 8 the principal variables remained consistent (habitat types, area and stream distance), but additionally clough distance became significant along with the number of ancient woods in 20m, area of clough in 1km and the XY co-ordinates. Spatial variables provided additional explanatory power but did not change the order of effects between area and the within-patch quality variables (stream presence and topographic diversity).

Following the addition of all planned variables in block 7 considerable multicollinearity became evident in the model. Problem variables were functional isolation 1, 2, number of ancient woodland and semi-natural woodland in 500m and the area of ancient woodland and semi-natural woodland in 1km. None of the variables were individually significant in the model, however addition of both blocks of variables (functional and structural isolation) was significant. Consideration of the regression methodology was based upon an assumption that functional measures were preferable. Examination of the partial correlations revealed higher values for the functional measures. Therefore the structural measures showing multicollinearity were dropped and the model re-run, which resulted in acceptable multicollinearity levels. Model residuals were then assessed against test assumptions. The residuals proved to show significant spatial autocorrelation. Addition of the polynomial XY co-ordinates proved significant and did not qualitatively change the interpretation of the model, spatial autocorrelation was then absent from the residuals. Exploratory analysis of other potential explanatory variables failed to find any with better predictive power than XY variable to account for the autocorrelation.

In the final model higher NMS1 scores (associated with higher biodiversity interest) are promoted by several variables. Individually significant variables include, habitat type, stream distance, clough distance, patch area, number of ancient woodlands within 20m, area of clough in 1km and XY co-ordinates. In conjunction with the affects on individual variables seen during the sequential regression process it can be concluded that while some within patch-habitat quality variables have a positive effect on biodiversity scores (habitat type, stream presence / distance, clough presence / distance) there remains a significant affect of patch area, even when separated from quality variables. Therefore effects of area remain that are not accounted for by factors such as hydrology or topographic diversity. The dominant effects when individual sr^2 are examined are habitat type and area. Of the landscape variables that are significant low numbers of ancient woodland in 20m and low clough area in 1km are associated with higher scores. This indicates that sites that are particularly diverse for their unit area are small, isolated from other ancient woodland sites, and are more likely to exist in the more lowland or moorland fringe areas of the Dark Peak away from the core upland areas.

Table 10.21
Sequential multiple regression results of NMS Biodiversity ordination score 1 (ground-flora, botanical and community richness per ha), by habitat and abiotic values. Pooled data, $N = 298$.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	-.204	.087	-.183	-2.353*	.013	.064***
	Con, PAWS	N/A	-.253	.116	-.221	-2.174*	.011	
	Mix, PAWS	N/A	-.145	.092	-.134	-1.588	.005	
2	Grazed	N/A	-.063	.056	-.062	-1.118	.003	.054**
	Topo diversity	-.02	.032	.031	.070	1.021	.002	
	Elevation, slope	-.08	-.024	.030	-.053	-0.787	.001	
	Stream distance	-.18**	-.100	.027	-.222	-3.688***	.031	
	Clough distance	-.10	-.061	.024	-.134	-2.501*	.014	
3	Area	-.31***	-.262	.038	-.581	-6.811***	.14	.127***
	Shape	.07	.038	.027	.084	1.391	.004	
4	Core area index	-.20**	.060	.040	.133	1.514	.005	.001
5	AW site area	-.22***	.047	.033	.105	1.432	.005	.003
6	Functional isolation 1	-.08	.028	.034	.063	0.846	.002	.042**
	Functional isolation 2	.13*	.036	.055	.081	0.656	.001	
	Functional isolation 3	.15*	.068	.035	.150	1.922	.008	
7	No. of AW in 20m	-.20***	-.085	.032	-.189	-2.645**	.016	.057**
	No. of SN in 20m	.02	-.050	.035	-.110	-1.434	.005	
	No. of AW in 1km	.01	.019	.040	.042	0.471	.000	
	No. of SN in 1km	.18**	.003	.038	.008	0.092	.000	
	Clough area in 1km	-.01	-.062	.031	-.137	-1.979*	.009	
	Structural isolation 1	.19**	.051	.036	.114	1.425	.005	
	Structural isolation 2	.06	.008	.025	.018	0.316	.000	
	Structural isolation 3	.06	.044	.028	.097	1.592	.000	
8	XY co-ordinates	.17**	.081	.027	.166	3.033**	.021	.021**
	Residuals: Moran I =	0.02					R^2 =	.369
	Z score =	1.41 SD					Adj R^2 =	.313
	p =	> 0.1					R =	.607***

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$

10.4.5.2 NMS Ordination score 2 (ground-flora cover, tree cover, NVC richness, deadwood)

The final model returned $r^2 = .434$, $F_{(22, 275)} = 9.571$, $p < .0001$. The adjusted R^2 of .388 indicates that over a third of the variability in NMS2 biodiversity scores within compartments is predicted by woodland habitat type and abiotic conditions (Table 10.22). Only the addition of blocks 1 (habitat), 2 (habitat quality) and 3 (patch area + shape) were significant in the model ($p < .001$). In the first and second steps habitat type, grazing status and topographic diversity were all significant. With the addition of area and shape in block 3 grazing status and topographic diversity became non-significant and their beta values dropped significantly, leaving habitat type and area as the only individually significant and high beta value variables in the model.

There were no alterations to the model after addition of block 4 or 5. With the addition of the functional isolation variables in block 6 although not a significant addition, and with no individually significant variables, the habitat beta values dropped and two of the functional isolation variable had moderately high contributing beta value influence. With the addition of the block 7 variables the influence of area increased further, while functional isolation 3 became significant. Following the addition of all originally planned variables, considerable multicollinearity became evident. The problem variables were functional isolation 2 and 3, number of ancient and semi-natural woods within 500m, and area of ancient and semi-natural woodland in 1km. Of these only functional isolation 3 was individually significant. The regression methodology was based upon an assumption that functional measures were preferable. Examination of the partial correlations revealed high values for two structural measures and the SF3 functional measure. The structural measures were dropped and the model re-run. High multicollinearity remained on functional measure SF2, which was also dropped, which resulted in acceptable multicollinearity levels. None of these omissions was significant according to R change F stats. Model residuals were then assessed to see if they met model assumptions. The residuals proved not to be spatially autocorrelated.

Table 10.22
Sequential multiple regression results of NMS Biodiversity ordination score 2 (ground-flora cover, tree cover, NVC, deadwood), by habitat and abiotic values. Pooled data, N = 298.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	-.344	.068	-.291	-5.084***	.053	.200***
	Con, PAWS	N/A	-.342	.073	-.283	-4.691***	.045	
	Mix, PAWS	N/A	-.316	.065	-.276	-4.902***	.049	
2	Grazed	N/A	-.042	.056	-.040	-0.756	.001	.091***
	Topo diversity	.327***	.021	.031	.044	0.685	.000	
	Elevation, slope	.050	.008	.029	.016	0.255	.000	
	Stream distance	-.130*	.030	.027	.063	1.108	.002	
	Clough distance	-.106	-.041	.024	-.085	-1.172	.006	
3	Area	.471***	.196	.037	.410	5.328***	.058	.109***
	Shape	.171**	-.017	.027	-.036	-0.637	.000	
4	Core area index	.191**	-.016	.039	-.033	-0.403	.000	.002
5	AW site area	.217***	.021	.033	.044	0.648	.0008	.000
6	Functional isolation 1	.095	.011	.034	.022	0.316	.0002	.005
	Functional isolation 3	-.108	-.064	.035	-.134	-1.826	.0068	
7	No. of AW in 20m	-.067	-.061	.031	-.129	-1.964	.0079	.026
	No. of SN in 20m	.270***	.020	.033	.043	0.611	.0008	
	No. of AW in 1km	-.180**	-.021	.039	-.045	-0.546	.0006	
	No. of SN in 1km	.192**	.004	.035	.008	0.103	.0000	
	Clough area in 1km	-.028	.008	.031	.016	0.244	.0001	
	Structural isolation 1	-.220***	-.025	.036	-.053	-0.709	.0010	
	Structural isolation 2	.171***	.036	.025	.075	1.436	.0042	
	Structural isolation 3	.000	.030	.027	.064	1.106***	.0025	
	Residuals: Moran I =	0.01					R^2 =	.434
	Z score =	0.95					Adj R^2 =	.388
	p =	>0.1					R =	.659***

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$

In the final model higher NMS2 scores (associated with higher biodiversity interest) are promoted by several variables. Individually significant variables include: habitat type, area, and structural isolation metric S3. Within block 2 none of the within-patch habitat quality variables showed a strong effect. When area entered the regression in block 3 it was shown to be the dominant variable in promoting site biodiversity. In summary, from examining the beta scores it is apparent that higher biodiversity is promoted by larger compartment area, by ASNW habitat type and by low patch contrast around a site (SF1), and lower number of nearby ancient woods within 20m. In terms of the overall variance explained by the model (sr^2 incremental) much is accounted for by the habitat types in block 1, followed by patch quality in block 2, and area and shape in block 3.

10.4.5.3 NMS Ordination score 3: naturalness (ground-flora, tree cover, NVC, woody species richness)

The final model returned $r^2 = .707$, F (21, 276) = 31.767, $p < .0001$. The adjusted R^2 of .685 indicates that over two thirds of the variability in NMS3 biodiversity scores is predicted by woodland habitat type and abiotic conditions (Table 10.23). The addition of blocks 1 (habitat), 2 (habitat quality), 6 (functional isolation), 7 (structural), and 8 (spatial / co-ordinates) were each significant in the model ($p<.001$). In the second step of analysis stream distance, patch elevation and slope mean were individually significant, with habitat having the highest beta scores. With the addition of area and shape in block 3 these remained significant and with approximately similar order of beta values. Block 4 (CAI) was not significant and did not change the model. Block 5 was not significant but caused shape to become significant, although the order and beta values changed little and its beta effect was small. Addition of block 6 (functional isolation) was significant and caused shape to no longer be significant and SF2 and CAI to become significant. SF2 had a moderately high beta value and partial correlation. With the addition of the block 7 variables (structural isolation) the core variables of habitat type and stream distance remained unchanged, but elevation and slope mean were no longer significant, SF2 and CAI were still significant and clough in 1km and PCA S3 were also significant. Following the addition of all originally planned variables considerable multicollinearity became evident in the model. The problem variables were identified from VIF and tolerance values as functional isolation 2, number of ancient and semi-natural woodland in 500m, and area of ancient and semi-natural woodland in 1km. Of these functional isolation 2 was individually significant when the whole block was first added. The original regression methodology was based upon an assumption that functional measures were preferable. Examination of the partial correlations revealed higher values for the functional measures. Although there was a presumption against removal of the functional variables, the addition of the structural variable had been significant. Therefore a form of backwards selection was undertaken on the correlated variables within block 7, proceeding in the order of the highest VIF and monitoring the R change F stats. Removal of all the problem variables did not detrimentally affect the model. However removal of these problem variables did not fully remove the multicollinearity on the SF 2 variable. Therefore removal of other structural variables continued. In the final model only the area of clough habitat within 1km and three summary isolation variables were added. The model was then re-run with only this single variable in block 7 added.

Following resolution of multicollinearity the model residuals were assessed against model assumptions, and were found to be spatially autocorrelated. New ancient woodland and urban variables were entered and the block subject to backward elimination. Only urban area in 5km proved to be individually significant. Inclusion of this variable resulted in model residuals no longer being spatially autocorrelated and did not appreciably change the order or significance of the other model variables in the stage prior to investigation of the spatial issues.

Table 10.23
Sequential multiple regression results of NMS Biodiversity ordination score 3: Naturalness (tree cover, NVC, layers, woody species richness), by habitat and abiotic values. Pooled data, N = 298.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	-1.125	.097	-.601	-11.597***	.142	.620***
	Con, PAWS	N/A	-1.782	.125	-.927	-14.209***	.214	
	Mix, PAWS	N/A	-.966	.100	-.530	-0.9626***	.097	
2	Grazed	N/A	-.067	.063	-.040	-1.054	.001	.044***
	Topo diversity	.327***	.036	.035	.047	1.024	.001	
	Elevation, slope	.050	-.014	.034	-.019	-0.421	.0001	
	Stream distance	-.130*	-.124	.031	-.164	-4.042***	.017	
	Clough distance	-.106	-.050	.027	-.066	-1.858	.003	
3	Area	.471***	-.002	.043	-.002	-0.037	.0000	.003
	Shape	.171**	.031	.031	.041	1.018	.001	
4	Core area index	.191**	.089	.045	.118	1.979*	.004	.001
5	AW site area	.217***	-.025	.034	-.033	-0.738	.0005	.001
6	Functional isolation 1	.095	-.014	.033	-.019	-0.434	.0001	.018**
	Functional isolation 2	.566***	-.172	.050	-.228	-3.420**	.012	
	Functional isolation 3	-.108	.052	.038	.068	1.367	.002	
7	Clough area in 1km	-.028	-.095	.035	-.125	-2.672**	.007	.015**
	Structural isolation 1	-.220***	.019	.029	.025	0.655	.0004	
	Structural isolation 2	.171***	.019	.027	.025	0.704	.0005	
	Structural isolation 3	.000	-.049	.026	-.065	-1.875	.0038	
8	XY co-ordinates	.005	.058	.034	.071	1.687	.003	.001
	Urban area in 5km	.211***	.00004	.000	.097	2.027*	.004	.004*
	Residuals: Moran I =	0.02					R^2 =	.707
	Z score =	1.58					Adj R^2 =	.685
	p =	>0.1					R =	.841***

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$

In the final model higher NMS3 scores (associated with higher biodiversity interest) are promoted by several variables. Individually significant variables are: habitat type, stream distance, core area index, functional isolation metric SF2, area of clough in 1km and urban area within 5km. Interestingly area was not significant and did not have high beta score. The dominant effects when individual sr^2 are examined are habitat type, habitat quality and functional isolation SF2. In summary, higher compartment biodiversity is promoted by ASNW habitat type while there is some evidence for regional trends and isolation effects. Additionally the presence of a stream / watercourse or close proximity to one favours biodiversity. Although area per se does not significantly impact on the model the regression indicates that compartments with high core area index hold higher biodiversity. Higher interest sites tend to occur in areas of high local landscape contrast and further away from other semi-natural wood sites. Higher interest sites also occur in areas with lower areas of clough within 1km, e.g. in the moorland fringe rather than near the moorland core where cloughs are most common.

Although the model required addition of extra geographic / spatial variables to account for spatial autocorrelation effects, the original levels of autocorrelation were low and the additions showed relatively little account of the total variance. Little can be interpreted from these variables save to say that the addition did not significantly affect the order or rank of other variables in the model suggesting they mainly account for residual spatial "noise" in the model. However it is possible that the urban area indicator, suggesting that biodiversity is higher in sites closer to urban areas, may be indicative of past or current management levels, or of sites that may have been protected from grazing in the recent historic past. Such affects would require further investigation.

10.4.5.4 Biodiversity summary score

The final model returned $r^2 = .721$, $F_{(25, 272)} = 28.148$, $p < .0001$. The adjusted R^2 of .696 indicates that over two thirds of the variability in biodiversity scores within compartments is predicted by woodland habitat type and abiotic conditions. The addition of blocks 1 (habitat), 2 (habitat quality), 3 (area and shape), and block 7 (structural isolation) were significant in the model ($p < .001$) (Table 10.24). In the second step of analysis stream distance, grazing, and topographic diversity were individually significant. With the addition of area and shape in block 3, area became significant in the model, grazing was no longer significant and the others stayed significant. The addition of area caused the topographic diversity variable beta score to drop but it remained significant, although the beta score of area was higher. Block 4 (CAI) was not significant and did not appreciably affect the model. At block 5, addition of ancient woodland site area, topographic diversity became non-significant, the pattern of other variables remained similar. Addition of block 6 (functional isolation) was not significant but caused topographic diversity to become individually significant again, the rest of the variables rank order did not appreciably change. Following the addition of all originally planned variables in block 7, considerable multicollinearity became evident in the model. Variables were deleted to retain functional in preference to structural variables, and to retain variables that were significant upon addition. The problem variables were identified from VIF and tolerance values as: functional isolation 1, number of ancient and semi-natural woodland in 500m, and area of ancient and semi-natural woodland in 1km. Of these, area of semi-natural woodland in 1km, number of woods in 500m, and area of ancient woodland in 1km were each significant. The addition of the structural variables had been significant to the model, therefore a form of backwards selection was undertaken on the problem individual ancient and semi-natural area and number variables within block 6, proceeding in the order of the highest VIF and monitoring the r change F stats. Removal of all the problem variables did not significantly detrimentally affect the model.

However removal of these variables did not fully remove the multicollinearity on the SF1 variable. Therefore removal continued of additional structural variables known to share multicollinearity with SF1 and semi-natural woods within 500m. Following elimination of multicollinearity the model was re-run with this limited selection of variables added at block 7 Addition of block 7 was then significant but the rank order of existing model variables did not change. The model residuals were assessed against model assumptions, and were found to be spatially autocorrelated. Addition of urban area in 5km and 1km, and of XY co-ordinates improved the assessment, but autocorrelation remained.

Table 10.24
Sequential multiple regression results of summary Biodiversity score by habitat and abiotic values. Pooled data, N = 298.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	-15.783	1.622	-.523	-9.731***	.0973	.578***
	Con, PAWS	N/A	-24.220	2.183	-.783	-11.097***	.1260	
	Mix, PAWS	N/A	-13.937	1.703	-.475	-8.183***	.0686	
2	Grazed	N/A	-1.043	1.009	-.038	-1.034	.0010	.090***
	Topo diversity	.390***	1.170	.559	.096	2.093*	.0044	
	Elevation, slope	-.056	.252	.552	.021	.457	.0002	
	Stream distance	-.375**	-1.900	.495	-.156	-3.837***	.0151	
	Clough distance	-.081	-.766	.438	-.063	-1.747	.0031	
3	Area	.349***	2.058	.734	.169	2.804**	.0081	.017***
	Shape	.310***	.118	.492	.010	.239	.0000	
4	Core area index	.034	.835	.740	.068	1.128	.0012	.001
5	AW site area	.071	-.269	.590	-.022	-.456	.0002	.002
6	Functional isolation 1	-.099	-.147	.654	-.12	-.224	.0000	.004
	Functional isolation 2	.645***	-1.954	1.125	-.160	-1.737	.0031	
	Functional isolation 3	.033***	.163	.654	.013	.249	.0000	
7	Clough area in 1km	-.164**	-1.510	.567	-.124	-2.663**	.0072	.021**
	AW in 20m	-.117*	-.463	.552	-.038	-.839	.0007	
	SN in 20m	.305***	.709	.601	.058	1.179	.0014	
	SN area in 500m	.266***	.245	.827	.020	.296	.0000	
	Structural isolation 1	-.125*	.652	.468	.053	1.394	.0020	
	Structural isolation 2	.163**	.364	.450	.030	.808	.0006	
	Structural isolation 3	-.062	-.707	.506	-.058	-1.396	.0020	
8	XY co-ordinates	.049	1.296	.566	.098	2.289*	.0053	.008
	Urban area in 5km	.198**	.001	.000	.117	2.458*	.0062	
	Urban area in 1km	.109	.014	.071	.008	.194	.0000	
	Residuals: Moran I =	0.06					R^2 =	.721
	Z score =	3.55 SD					Adj R^2 =	.696
	p =	< 0.001					R =	.849***

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$

In the final model higher woodland biodiversity was promoted by several variables. Individually significant variables include, habitat type, stream distance, topographic diversity, patch area, area of clough in 1km, urban area within 5km and XY co-ordinates. The dominant effect was habitat type, as evidenced by the high beta scores, however significant effects remained from stream distance, topographic diversity and compartment area.

Higher biodiversity occurs in ASNW sites compared to PAWS woods, and is promoted by larger compartment size, low SF isolation (high contrast and low semi-natural wood occurrence) low stream distance / presence of streams, and low occurrence of cloughs in 1km. When incremental sr^2 is examined it is clear that most of the variance in the data is accounted for by block 1, habitat type, followed by habitat quality (topographic diversity and stream distance /

presence), the addition of patch area and functional and structural isolation measures then accounted for additionally explanatory power, although small amounts of variance were able to be explained following the addition of these previous variables..

The occurrence of significant landscape variables: isolation, XY and urban area in addition to spatial autocorrelation remaining in the model indicates the model must be interpreted with caution. However it may be assessed with regard to the previous NMS ordination where autocorrelation was accounted for. It may be that further spatial variables could be found that would improve model accuracy and could affect the order of variables; however the Moran index, although significant, at 0.06 was very low. This is considerably lower than levels considered to represent "weak" spatial autocorrelation and dismissed in previous studies (0.27-0.51) (Bailey et al., 2002).

10.4.6 Important abiotic variables in predicting woodland biodiversity interest

The multiple regression models have examined the effect of abiotic variables in providing explanatory power of site biodiversity levels. The variable order was theory selected to allow comparison of the use of different sets of variables for biodiversity prediction, with reference to potential use in conservation planning studies. Of particular interest was the comparison of whether patch area and shape provided additional predictive value once the variance explained by a range of within-patch abiotic diversity factors had already been included to the model. Theory suggests patch area and shape may be associated with biodiversity levels because they themselves are indicative of a broader range of within-patch abiotic diversity measures, which in this study were also measured directly. Having developed the regression models they were available for consideration and discussion against previous research and theory. However it is advantageous to examine how robust the models are and whether the results are falsifiable (Ford, 2000). An advantage of multiple regression models is the ease with which model structure can be altered to test the effects between different sets of variables. Because the models show the variance that addition of variables adds to the models at the point of addition, the order can be changed to test effects. With reference to the key relationships between habitat type, habitat patch area and shape, within-patch habitat quality and the remaining effect of the landscape variables the model were repeated, with variable order altered, and with selected subsets of data, as follows (Table 10.25):

- Patch area and shape were entered ahead of within-patch diversity to examine the relationship between the two groups of variables, and the relative levels of variance uniquely explained each group
- PAWS and ASNW only sub-sets of data were examined to test if the observed relationships persisted within these subsets, in particular to examine the effect of habitat between the

different PAWS groups and of within-patch quality within the semi-natural broadleaved wood sites

Patch area, shape and within-patch habitat quality are known to be associated. The analysis in Table 10.25 shows the relative variance of within-patch quality and patch area and shape. By examining the variance accounted for after altering sequential variable addition order the relative importance of each can be assessed. If a block of variables provides independent and unique variance the level explained by the block will not change with order of addition. However where interactions and shared variance occur, the variance explained will change with point of entry in the model. The two most important summary scores defining compartment biodiversity interest, the summary biodiversity interest score, and NMS3 ordination score show a higher predictive interest of within-patch quality than patch area and shape. Within the regression of these scores, when the order is altered, the interaction of the two blocks of variables can be seen (Table 10.25, 10.26).

In the models of summary biodiversity score in isolation the within-patch quality variables were most affective at explaining the most unique variance but when added first area and shape explained more variance than left to be explained by within-patch quality when added next in the model. This shows a mixed effect between these indicators. A relatively small but significant amount of variance is able to be explained by area once habitat quality is added but larger amount of variance is left to be explained by habitat quality when area is first entered into the model. Both groups thus add to models explanatory power, but if one group had to be chosen in preference for its overall predictive power within-patch quality would be more effective than just area and shape.

In the NMS3 ordination score model when the effect of adding area and shape to the model ahead of patch quality was examined, sequential variance explained by area and shape increased slightly and that by patch quality decreased slightly when added after area but the rank order remained. This interpretation confirmed that within-patch quality is the most useful additional predictive factors after habitat type, albeit explaining only relatively small additional variance levels.

The NMS1 and NMS2 scores represent less of the ordination explanation of compartment biodiversity interest and had less successful multiple regression models. In these models area was more important than within-patch quality, and this relationship was retained when the order of variable addition was altered. This reflects the extraction in these NMS ordination scores of the biodiversity per unit area measures, where small sites held relatively diverse features for their size. Indeed in the altered NMS2 model the altered order with the addition of area and shape to the model ahead of within-patch quality resulted in patch area and shape accounting for a higher incremental explanation of variance, and the within-patch habitat quality block no longer being significant, when added after area (Table 10.25, 10.26).

The comparison of the single model based upon the collated summary biodiversity score and the 3 models based upon the NMS ordination is useful. The single summary biodiversity score indicates that generally there is a mixed effect of both compartment area and shape and compartment within-patch quality on biodiversity interest. The two groups are associated and each provides a level of prediction independent from the other. Of the two groups within-patch quality is able to explain a larger amount of variation independently. The NMS ordinations show that when the different elements of compartment biodiversity interest are extracted that most (NMS3) are successfully able to be predicted by habitat type with some additional explanation by patch quality, while an element of ancient woodland biodiversity interest is associated with compartments where patch area is an important predictor, as shown by the models based on NMS1, and NMS2 ordinations.

An examination of the success of models based on the summary score and ordination within subsets of the data provides further insight (Table 10.26, 10.27). Habitat type remains a strong predictor of biodiversity interest within the PAWS woodland types for the ordination score capturing the most of the ordination variation (NMS2). Additionally for this model patch quality shows higher explanatory power than patch area and shape, and shows higher levels of variation explained within these PAWS sites than within the combined data set. Within PAWS the models based upon ordination that capture compartment based biodiversity levels and naturalness have within-patch variables holding higher predictive power than patch area, while the ordination expressing biodiversity interest per unit area, shows strong influence of patch area in addition to patch quality (Table 10.10, 10.26, 10.27, Appendix 10.12).

The ordination of the ASNW subset data (Table 10.10, 10.26, 10.27, Appendix 10.12) showed a mixed interpretation of axis with a mixture of biodiversity measures per compartment and per unit area. The regression models showed effects of both within-patch diversity and patch area and shape. The most successful regression model showed the strong influence of patch area on the biodiversity measure which summarised botanical and community richness per unit area. Area diverse ASNW sites are often small.

When the biodiversity score regressions were examined among the PAWS and ASNW subsets (Table 10.10, 10.26, 10.27, Appendix 10.12) the models showed strong prediction from within-patch quality of the summary biodiversity score. Although interaction with the effects of patch area occurred the independent prediction from within-patch habitat quality was higher.

Comparison of the different models confirmed the use of habitat type, within-patch quality in biodiversity prediction but showed the strong effect of the different measures of compartment biodiversity interest in effecting dominant predictors. When single assessment of biodiversity are made strong effects relate to within-patch quality, while when biodiversity levels per unit area are extracted the link between small and highly area-diverse woodland sites become apparent. The importance of these findings are further discussed in Section 10.5 and Chapter 11.

Table 10.25
Comparison of variance attributed to each block of variables, comparing different model order, examining effects of habitat type, area, within-patch quality and isolation factors in their explanatory power of biodiversity (All data, N=298).

Block^	Variable block, in order	NMS1	NMS2	NMS3*	Bio
1	Habitat type	06	20	62	58
2	Patch quality / diversity	05	09	04	09
3	Area, shape	13	11		02
6	Functional isolation	04		02	
7	Structural isolation	06	03	01	02
8	Spatial	02			
Block^	Variable block, in order	NMS1	NMS2	NMS3*	Bio
1	Habitat type	06	20	62	58
3	Area, shape	12	19	01	07
2	Patch quality / diversity	06	02	04	04
6	Functional isolation	04		02	
7	Structural isolation	06	03	01	02
8	Spatial	02			
	Total variance	37%	43%	71%	72%

^Only significant blocks shown for clarity *=score representing the largest % of variance of the ordination

Table 10.26
Comparison of variance attributed to groups of variables within NMS ordination score regression, comparing habitat type, area, within-patch quality and isolation factors in their explanatory power of biodiversity.

		All data			PAWS			ASNW		
		NMS1	NMS2	NMS3*	NMS1	NMS2*	NMS3	NMS1	NMS2*	NMS3*
Block	Ordination r	.12	.18	.61	.14	.60	.14	.09	.38	.40
1	Habitat type	06	20	62	02	29	02	N/A	N/A	N/A
2	Patch quality / diversity	05	09	04	10	12	10	17	16	06
3	Area, shape	13	11		16	02	03	10	38	05
4	AW site area					02		03		
5	Clough in 1km					02				
6	Functional isolation	04		02	03	02	01			16
7	Structural isolation	06	03	01					04	
8	Spatial	02						03	04	
	Total % variance	37%	43%	71%	32%	49%	17%	33%	62%	27%

* = score representing the largest % of variance of the ordination

Table 10.27
Comparison of variance attributed to broad groups of variables, within Biodiversity composite score regressions, comparing habitat type, area, within-patch quality and isolation factors in their explanatory power of biodiversity

Block		All data	PAWS	ASNW
1	Habitat type	58	27	N/A
2	Patch quality / diversity	09	18	18
3	Area, shape	02	04	03
4	AW site area		01	
5	Clough in 1km		02	03
6	Functional isolation			
7	Structural isolation	02		
8	Spatial		01	02
	Total % variance	72%	53%	26%

10.5 Discussion - Woodland biodiversity value: current interest, association between surrogates and potential abiotic causal factors

10.5.1 Introduction

Woodland conservation has often been based on the results of site surveys, highlighting diverse, rare or interesting communities to be promoted for conservation. Several studies have indicated the importance of ancient woodland communities as locations (and potential sources) of biodiversity (Rackham, 2003, Thomas et al., 1997, Peterken, 1996, Peterken, 2000b). There is increasing interest in the planning of woodland networks and the restoration of woodland cover to landscapes in a manor that maximises resultant biodiversity (Peterken, 2000b, Hampson and Peterken, 1998). Past studies have suggested internal woodland features that may promote biodiversity, such as size, topography, soil chemistry, hydrology, (Brunet, 1993, Thompson, 2005, Peterken, 1974), while recent work has also examined external landscape factors which may be indicative of woodland biodiversity (Thompson et al., 2001b, Lee et al., 2002, Lee et al., 2001b). These are especially relevant to landscape strategy development. There is always a trade off between expensive field data and more rapidly collated remote sensed or GIS data. Enhanced knowledge of factors associated with woodland biodiversity that are able to rapidly, and cheaply, modelled are of benefit to conservation planning.

Within GIS, woodland habitat characteristics, abiotic variables (extracted from DTM), and patch-scale variables, such as landform class and hydrology presence, can be rapidly collated. In contrast the collection of site biodiversity assessments, such as species census, or structural assessments are expensive and slow to produce. Much interest exists therefore in the potential use of abiotic factors for conservation planning. Several previous studies have shown positive links of these factors to biodiversity (Kirby, 1988b, Luoto et al., 2002, Honnay et al., 1999a, Honnay et al., 1999b, Dumortier et al., 2002, Peterken and Game, 1984, Peterken and Francis, 1999, Lee et al., 2002, Lee et al., 2001b, Thompson et al., 2001b). However the majority of these studies focused purely on broad species richness, often botanical, and few took a structural approach. There is current interest in assessment of woodland biodiversity by multiple indicators, including richness, composition and structure, allowing assessment of multiple species groups, rather than an overly botanical focussed approach (Ferris and Humphrey, 1999, Lindenmayer, 1999, Lindenmayer et al., 2000).

The purpose of this study was to investigate the potential of abiotic, GIS and remote sensed data for predicting a broad assessment of woodland site biodiversity. Site biodiversity was measured using multiple assessments, beyond simple botanical species richness, using presence of structural features to indicate current or potential value for a range of species groups. The research also provides quantitative values for the conservation interest of ancient woodland sites across an entire Natural Area, and details the differences in remnant interest levels within PAWS woodland sites.

10.5.2 Ancient woodland cover and composition

The Dark Peak Ancient Woodland resource covers 1,269ha, with 1,123ha of established woodland. Ancient woodland sites occupy approximately 1.5% of the Dark Peak. The resource was evenly split between Ancient Semi Natural Woodland Sites (ASNW) and Plantations on Ancient Woodland Sites (PAWS). The PAWS sites comprised significant contributions of each of the three plantation types. 35% was broadleaved, 23% coniferous and 35% mixed PAWS. This compares to a study of sample areas within England which found PAWS comprised 34% broadleaved, 37% coniferous and 21% mixed (Pryor and Smith, 2002). Although significant areas were classified as PAWS, analysis showed considerable retention of native tree interest. Over a third of the area of Broadleaved PAWS habitat was either dominated by site-native species or by combinations of site-natives and non-natives. Similarly over 50% of the area of Mixed PAWS was dominated by a mixture of both site-natives and non-natives. These figures indicated the inherent potential for restoration within many sites.

Dark Peak ancient woodland cover compares to an English average of 2.6% (Pryor, 2003, Peterken, 2000b), and reported figures of 2% in the Clyde valley area (Peterken, 1999), 2.7% in the North York Moors (Peterken, 2002a), and 1.4% cover of PAWS in Snowdonia National Park (Gkaraveli et al., 2004). The area converted to PAWS at 50% is higher than the national average of 39–42% conversion (Pryor and Smith, 2002, Pryor, 2003), and supports the views that even within National Parks the conservation of ancient woodland has been no better, and in this case worse, than in the general undesignated countryside (Thomas et al., 1997). Derbyshire, as a county, is considered to have above average conversion rates (Pryor and Smith, 2002). Ownership based studies however, have found conversion rates of up to 70% when examining sites on the Forestry Commission estate across England (Spencer, 2002).

10.5.3 Compartment biodiversity levels, conservation interest and habitat type

Clear differences were found in biodiversity interest between the high levels within ASNW and low levels in coniferous PAWS, which typically scored half the values of ASNW. No significant differences existed between the mixed and broadleaved PAWS, which held intermediate biodiversity levels between coniferous PAWS and ASNW. Canopy naturalness was a therefore a reliable indicator of biodiversity. In the uplands conifer cover on ancient woodland sites should be strongly resisted and a rapid partial conversion to intermediate mixed or broadleaved plantations during restoration may enable biodiversity levels to recover.

While the composite biodiversity score summarised interest within a single score, the NMS ordinations allowed different strands of interest to be examined separately. Tests comparing all 3 axis scores between groups found the same habitat associations as the biodiversity score, but showed mixed and broadleaved PAWS to have a greater affinity to the conifer PAWS than to ASNW (Fig 10.28), a pattern reflected in the differences between habitats in many of the individual biodiversity indicators (Fig 10.10, 10.16. 10.25, Appendix 10.7). Remnant interest levels suggest that in some compartments replanting of conifers was not wholly successful or that within some Mixed and Broadleaved PAWS conditions continued from previous native broadleaved plantations or semi-natural woodland, allowing the persistence of semi-natural indicators. It was interesting that across the individual indicators several variables showed higher levels within mixed than broadleaved PAWS compartments. These included AWIS richness (conservation interest), % cover of birch species (composition indicators) and % cover of native tree species (structural indicators). This suggests that perhaps contrary to initial expectations that, for some indicators, there are higher remnant interest levels in many Mixed PAWS compartments than Broadleaved PAWS, and additionally provides encouraging support to the idea that gradual conversion of conifer PAWS, perhaps through a stage as Mixed PAWS could lead to increases in general woodland ecological interest.

No previous studies have directly compared ASNW and PAWS sites and quantified biodiversity levels within a single Natural Area. However several studies provide insight into habitat–biodiversity associations. Although some woodland studies have failed to find a link between woodland canopy type and biodiversity levels in lowland English woods (Usher and al, 1992), much research reflects the current results, and suggest strong links between canopy type and biodiversity levels, especially in ancient wood sites (Spencer, 2002, Pryor et al., 2002, Skov, 1997, Kirby, 1988b). This study confirms also past research that survival of at last some of the key components of the ancient woodland community within PAWS sites is expected to be the norm (Pryor et al., 2002). Additionally the work confirms research that higher interest exists within semi-natural sites than plantations (Coroi et al., 2004), and that within PAWS, interest levels can be linked to canopy type such that mixed or broadleaved stands will hold higher interest levels than coniferous stands (Skov, 1997, Kirby, 1988b, Pryor et al., 2002).

A study of ancient woodland sites by the Woodland Trust found ground-flora levels in PAWS to vary with canopy shading and density. Survival was lowest under heavy shading species and greatest under light shading canopy species (Pryor et al., 2002), broadly reflecting the distinction between coniferous, mixed and broadleaved stands in the current study. However these results reflected not only differences by canopy type, but also by species. Pryor et al examined a wider range of canopy species than the current study. It is possible that some of the effects seen here in the strong contrast between conifer and other PAWS are due to different conifer species being planted within mixed compartments than in conifer compartments. Some heavily shading species such as *Picea spp* were more likely to be present as pure stands in the study area with lighter shading species such as *Larix spp* and *Pinus spp* more likely to be present in mixed stands. The Woodland Trust work confirmed that mixed plantations, where broadleaves were originally planted with conifers, or where birch had subsequently invaded, resulted in higher survival than pure coniferous PAWS (Pryor et al., 2002). In their study 41% of PAWS had retained surviving ground-flora and veterans with only 16% of stands having no flora or veterans (Pryor et al., 2002). However only 7% of stands were considered to have frequent / distinctly valuable veterans (Pryor et al., 2002), a figure closely fitting the range of PAWS compartments with notable veterans of 3.5%-6.6 % in the current study. Further research in Ireland, of non-ancient sites, also found higher ground-flora richness and cover values in semi-natural broadleaved stands compared to conifer plantations (Coroi et al., 2004). Interestingly the analysis only found consistent differences between the two extremes of semi-natural woodland to coniferous plantation, as in the current study. No differences were found among richness / area levels or ground-flora cover levels between the different plantation habitat types (mixed, broadleaved, coniferous) (Coroi et al., 2004).

10.5.4 Associations between biodiversity surrogates

The project results can be used to infer if a limited range of the collected biodiversity surrogates could be used to allow more rapid assessment of compartment interest. This can be gauged by examining the indicator correlations and ordinations (Fig 10.26, 10.27, Appendix 10.6). The study found a number of correlations suggesting affinity between different measures of biodiversity within existing high quality (ASNW) or replanted sites (PAWS). However few indicators were deemed redundant, all being capable of adding to recorded biodiversity, except shrub and tree species richness which were found to be sufficiently correlated that use of a combined woody species richness variable captured the variation between sites, and could be used in further studies rather than examining the two groups. Features of general association were the affinity of ground-flora measures (cover, richness) with NVC community richness and some structure measures (shrub, tree cover). Additionally the negative effects of shading and high cover were confirmed. A number of positive associations occurred with native canopy cover features and woody species richness. Implications for future recording studies include the high value of native shrub cover as an indicator in these upland woods. The presence and extent of a shrub layer is a good indicator because it was correlated with a number of groups and it is known that detrimental affects such as high grazing and high non-native canopy cover will cause the loss of this group, therefore its presence can be indicative of current, and likely past, high biodiversity levels. Additionally the consistent link between ground-flora cover and NVC community richness may have potential to be explored through development of a combined ground cover and richness scale. There was similar, although reduced potential, to combine a broader botanical diversity index from the AWIS and trees and shrub richness, although many sites occurred where richness was not entirely correlated in the two groups. There may also be scope for combined assessment of woodland canopy / structural naturalness and deadwood / veteran features interest. Deadwood presence was correlated to canopy layers and canopy age, which itself was associated with presence of veterans. The different area corrected indicators were all found to be relatively highly correlated (tree and shrub species / ha, AWIS / ha and BAP and notable / ha), indicating that area diverse compartments are rich in several groups, although the presence of common species may have inflated the correlation coefficients.

While the scope for reduced collection of individual biodiversity indicators was limited, the associations provided insight into the types of biodiversity present and remnant interest levels in replanted sites. Several associations confirmed that biodiversity interest features often occur in "hotspots", where a number of interest features are present (Pryor et al., 2002). The correlations of indicators were strong within the PAWS habitats when examined individually, especially in broadleaved PAWS, but less so in coniferous PAWS where remaining interest levels were so low that few hotspot associations remained (Appendix 10.6). Bivariate correlations were also lower in ASNW sites where occurrence of distinct woodland types may have different combinations of characteristics not easily picked up when examining all stands together. Further associations may exist if analysis were conducted separately, for example by NVC type within ASNW sites.

Studies in non-ancient plantations have shown that older stands tended to have more diverse ground-flora than younger stands. In the current study canopy age was not strongly correlated with tree and shrub richness or AWIS richness (Table 10.9, Appendix 10.6). This indicates the difference between effects in ancient versus recent woods. In recent woods which may have originated on non woodland land older stands have time to acquire more species, effectively canopy age is associated with woodland presence longevity, while in ancient woods richness may be more related to stand condition such as canopy type, density and past management rather than canopy age. However it is notable that stand age was related to some other naturalness features such as canopy layers and veterans (Appendix 10.6.

Table 10.28
Biodiversity associations in the current research confirming relationships found in previous studies (also see Chapter 5)

Biodiversity	Association recorded	Relationships confirmed from previous research
Ground flora cover	Ground flora richness	(Kirby, 1988b)
Ground flora richness	Canopy layers	(Dumortier et al., 2002, Skov, 1997)
Ground flora richness	Native tree + shrub sp. richness	(Dumortier et al., 2002, Neumann and Starlinger, 2001)
Native tree + shrub richness	Canopy layers	(Dumortier et al., 2002)
Birch species cover	ground-flora cover	(Pryor et al., 2002)
Native tree cover	Stand structural complexity	(Neumann and Starlinger, 2001)
Native tree cover	Native tree + shrub sp. Richness	(Dzwonko and Loster, 1997)
Stand age	Stand structural complexity	(Humphrey et al., 2003)
Stand age	Deadwood	(Humphrey and Peace, 2003)
Ground flora survival / cover	Canopy total cover / density	(Pryor et al., 2002, Kirby, 1988b)

The ordinations show that biodiversity interest can be summarised but that different clusters of interest features may be found in different woodland sites, or in different habitat data subsets. If site based biodiversity assessment is practiced the current range of recorded variables are recommended and prove useful. Analysis showed the single composite summary biodiversity score was similar, and showed similar abiotic relationships to the principal axis representing most of the variance from the NMS ordination. Therefore if rapid scoring is required the use of a composite score from this range of biodiversity indicators proves useful, but it should be noted further insight may gained by more detailed analysis, as with the NMS ordinations, to examine groupings and extractions within the biodiversity data, which can reveal distinct sets of associations with abiotic variables.

10.5.5 Predicting woodland site conservation interest

10.5.5.1 Introduction

Ancient woodland site location, habitat type and species composition are affected by abiotic conditions. Sites often occur in areas of steep or inaccessible topography, such as valleysides, especially in the uplands (Peterken, 1999). Similarly, a study in the Snowdonia National Park found all large patches of native scrub occurred on steeply sloping banks (Good et al., 1990), away from accessible areas of cultivation and less affected by high grazing levels. Abiotic condition may therefore influence woodland location, management intensity and habitat type. Abiotic conditions influence management through associations with relative site accessibility in addition to deterministically affecting biodiversity through association with resource availability and microhabitat occurrence. Using the results of the site based biodiversity assessment and the GIS collated abiotic woodland conditions the project examined the following postulates:

- Biodiversity values differ between ASNW and PAWS
- Biodiversity values are associated with abiotic variables
- Biodiversity values can be predicted from abiotic values
- Patch area and shape are redundant indicators as they are simply indicative of within-patch habitat diversity, which can be directly measured
- Effective woodland conservation strategies cannot be designed unless they sufficiently account for within-patch habitat quality / diversity in assessing multiple woodland sites across landscapes

10.5.5.2 Confirming associations in previous research

The research results confirm a number of studies where woodland patch abiotic indicators have been shown to be associated with measures of woodland biodiversity (Thompson et al., 2001b, Luoto et al., 2002, Honnay et al., 1999b). Patch area is a well known biodiversity surrogate. A number of woodland studies have recorded patch area / biodiversity associations: with vascular plant richness (Dumortier et al., 2002, Peterken and Game, 1984), number of canopy layers, and tree species richness (Dumortier et al., 2002). Patch area has also been widely found to be related to the number of other habitats present in a wood (Dumortier et al., 2002, Bastin and Thomas, 1999, Bellamy et al., 1996a), and to woodland structural complexity (Watson et al., 2001), canopy density (Bellamy et al., 1996a) and to density of large / veteran trees in woodland reserves (Gotmark and Thorell, 2003). Topographic diversity (measured as elevation range) was also correlated with number of canopy layers and tree species richness (Dumortier et al., 2002). It can be seen therefore that area is a rather complicated biodiversity surrogate in that itself it is correlated with many other measures which may themselves be causally correlated with biodiversity levels.

Patch shape has also been linked to woodland biodiversity, although the results are rather contrasting depending on the study focus. In several studies shape has been considered indicative of the potential range of microhabitats or environments within a wood, with more variable shaped woods more likely to cover several habitats and thus hold higher biodiversity. Studies have shown botanical diversity to be linked to complex woodland shape (Honnay et al., 1999b, Thompson et al., 2001b). However in some studies, especially plantation woods in hostile landscape complex patch shape has been shown to be associated with high edge effects and thus potentially with lower richness of core woodland species (**Chapter 5: Woodland ecology**).

The current study found that woodland patch abiotic variables were strongly correlated (area, shape, topographic diversity, stream presence / distance) (**Appendix 10.6**). Therefore the analysis methods were required to separate which abiotic factors were most associated, or most usefully predictive of woodland biodiversity.

10.5.5.3 Predictive success within different woodland habitat types (all woods, PAWS, ASNW)

The multiple regression models examined the NMS ordination scores and the summary biodiversity score. This allowed an examination of the interactions of the abiotic factors on site biodiversity and analysis of the unique variance contributions. Good model fits were achieved. The NMS 3 ordination (all data, N=298) representing overall woodland naturalness and biodiversity achieved adj R^2 = .685 and the summary compartment biodiversity score model achieved adj R^2 = .696. In NMS 3 ordination the majority of the variance was explained by habitat type (62%), beyond which smaller amounts were explained by within-patch habitat quality variables (4%), functional isolation (2%) and structural isolation (2%). A similar pattern was shown by the regression of summary biodiversity score. The main effect was by habitat type (58%) with further variance added by within-patch habitat quality variables (1%), patch area and shape (2%), and structural isolation (2%). When all Dark Peak ancient woods are compared the best and most reliable overall predictor of biodiversity is habitat type. ASNW have higher biodiversity levels than PAWS and within PAWS mixed and broadleaved PAWS have higher biodiversity levels than coniferous PAWS. The models of the other NMS scores (NMS1, NMS2) performed less well (Tables 10.22, 10.23). These scores accounted for less of the ordination variation. NMS 1 (botanical and NVC community richness per ha) was most predicted by area while NMS 2 (woodland naturalness and diversity) was most predicted by habitat type (20%) with additional unique contributions from within-patch habitat quality (9%) (mostly clough presence / distance), and patch area and shape (11%).

The regression models developed from all compartment data were also examined by varying the order of variable addition, and were compared to models developed using subsets of the data, for PAWS and ASNW datasets. The PAWS models performed less well than the all data models (Table 10.26, 10.27, Appendix 10.12). Interpretation of the models (biodiversity score and the principal NMS ordination axis) revealed habitat type was still an important predictor (27-29%), with strong additional variance explained by within-patch habitat quality (12-18%). Within PAWS prediction of biodiversity interest is effective using habitat type, accounting for almost a third of the variance in biodiversity levels. Additional predictive power can be gained by considering stream presence, and to a lesser extent area. Compartments will hold higher biodiversity levels, irrespective of habitat type when they have streams present or close by and when the compartments are larger. Although the other NMS score models performed less well, NMS 1 representing botanical richness / ha and ground-flora cover showed interesting results. The model indicated that sites that were comparatively rich for their area were most predicted by compartment size, and not by habitat type. Smaller compartments tended to have higher richness per ha levels than larger sites, additionally richness was also favoured by stream presence / distance.

Of the models developed from the data subsets (Table 10.26, 10.27, Appendix 10.12) the ASNW performed most poorly, indicating there was less of a connection between compartment biodiversity levels and abiotic conditions in ASNW woods, or that multiple sets of interest exist that were not sufficiently captured by the ordination or the biodiversity summary score. Future cluster analysis and examination of each ASNW cluster may yield interesting results. The ASNW models revealed that for area-diverse sites (high richness per unit area) were predicted by area in addition to within-patch quality. Smaller compartments had higher richness / ha and topographically diverse sites had higher values while compartments without stream presence or with streams further away had lower values. Importantly this shows that even within this subset of sites, captured by the ordination where small diverse sites area, predicted by low compartment area, high topographic diversity / within-patch quality remains an important positive factor. Therefore while compartments with rich values / ha can largely be predicted by their size stream presence and topographic diversity also have important effects. Although the ordination score model for NMS3 (botanical richness and ground-flora interest) returned a model with low adj $R^2 = .200$, the results were interesting. Most variance was predicted by isolation measures (16%) with minor effects of area (5%) and within-patch diversity (6%). Richer sites occurred in areas of low cloughs in 1km, high local patch contrast, with streams present / low distance, small compartment area and high shape complexity. Therefore in ASNW botanically diverse sites showed elements of a regional trend and high interest sites tended to be relatively isolated. The ASNW summary biodiversity score achieved a poor model of only adj $R^2 = .194$. The largest predictive power came from within-patch habitat diversity, explaining 18% of variance (topographic diversity and stream distance). Small additional unique variance was explained by area and shape (3%) and area of clough in 1km (3%). From comparing these regressions it can be concluded that in ASNW there was a less strong link with abiotic factors than in PAWS, but this comparison is affected by the fact that within PAWS habitat type was always a strong predictor. In ASNW except for the botanical and NVC community richness / ha values the biodiversity interest was typically predicted more by within-patch quality measures or isolation measures than patch area. These models show the additional interpretation when the subsets of models are examined.

10.5.5.4 Model comparison with previous research

Previous research has also used multiple regression or variance partitioning to examine the relative effects of abiotic factors on woodland biodiversity. Theory suggests that patch area, shape, habitat quality/diversity and woodland isolation will be strong factors associated with biodiversity levels. Past models have achieved varying prediction success, while the main limiting factor in direct comparison is the wide range of abiotic variables previously examined and the unique feature of the current study in assessing broad biodiversity value from a range of biodiversity indicators across woodland composition, structure and richness. Previous studies have concentrated on assessment of biodiversity within single groups, such as ground-flora diversity or avian communities. While many have compared effects of patch area and shape on biodiversity rather fewer have examined detailed within-patch habitat quality measures. Within those that have, widely differing quality / topography or diversity measures have been used. Some studies however have taken a similar approach comparing data able to be collected purely from fieldwork to GIS collected data to predict biodiversity. Several projects incorporated field collected patch composition or structure indicators (e.g. canopy diversity or density) as predictive variables within their models, limiting their comparison in the current context.

A number of studies have examined woodland ground-flora richness prediction. Models have achieved R^2 of .14 (lowland woods) (Petit et al., 2004a), .22 (Thompson et al., 2001b), .393 (Bastin and Thomas, 1999), .48 (upland woods) (Petit et al., 2004a), .57 (Usher and al, 1992) and .586 for AWIS richness in English woods (Peterken and Game, 1984), and between .518

(Dumortier et al., 2002) and .708 (Luoto et al., 2002) for general flora richness in European studies. Research has also examined the predictive power of the classic abiotic variables patch area, shape and isolation on botanical richness without examination of within-patch habitat quality measures (Dzwonko and Loster, 1992, Thompson et al., 2001b, Usher and al, 1992). Usher et al compared models and found using patch area alone gave the best prediction. Another study found a dominant effect of patch area on flora species richness during succession in secondary woods, but did not examine within-patch habitat quality features (Dzwonko and Loster, 1992). The low variance explained by Thompson et al (2001) may result from the lack of inclusion of within-patch habitat quality variables as examined in the current study, or the potential presence of different distinct communities in different woods responding separately to different driving forces. In contrast, several papers have included the potential effects of within-patch diversity or quality, variously measured by soil chemistry, hydrology or topography indicators. These provide insight into how patch area may be linked to other variables or may itself be indicative of within-patch quality features. Although Peterken found that prediction of AWIS richness was most effective by patch log area alone (59%), using abiotic variables instead of area, including internal patch features such as number of soil types and occurrence of rides allowed 45% of variance to be explained (Peterken and Game, 1984). The research did not include GIS collated within-patch hydrology or topography values and relied on fieldwork for several within-patch abiotic variables such as presence of soil types. In another study achieving total variance explained of 38%, the researchers found that addition of the number of habitats within a patch first in the model explained 29% of the variance, acknowledging a link between area and number of habitats (Bastin and Thomas, 1999). Therefore although area was important it did not explain the largest variance, but just contributed to the total. In Belgium analysis found that area itself played only a minor role in driving plant diversity, being correlated with a number of other more individually important variables (Honnay et al., 1999b). A number of studies therefore, highlighted in (Honnay et al., 1999b), indicate plant diversity may be deterministically driven by habitat diversity, of which area is simply indicative. Peterken found that the number of open space species present in woods increased with wood size, suggesting a greater range and diversity of habitats present in larger woods allowed the increased range of species to exist (Peterken and Francis, 1999). One forest herb study found that in an agricultural setting refuge areas including areas of topographic diversity such as bedrock outcrops in addition to hedges and other refuges, allowed forest species to be retained during periods of conversion (Bellemare et al., 2002). A study within a broadleaved ancient woodland found that understorey flora was related to topography, soil, edge-effects and unknown boarder scale (e.g. location / co-ordinates) factors (Thomsen et al., 2005). This range of research suggests that, where possible, if the driving forces can be measured instead of area they would more usefully be used in conservation prediction / practice. However the relative link between patch area and habitat quality measures needs to be assessed and this may vary between habitats and landscapes. Indeed in one landscape analysis found that specialist forest species decreased with patch size, the explanation being that larger woods were more intensively managed, and thus subject to increased disturbance, detrimentally affecting biodiversity (Lawesson et al., 1998).

Botanical research have also found varying effects of isolation, ranging from no effects of isolation (Honnay et al., 1999b, Thompson et al., 2001b), to strong isolation effects (Jacquemyn et al., 2003), although the analysis examined new woodlands being actively colonised, rather than established woods. A study in Belgium of non-ancient woodlands returned a model of R^2 .738 with important predictors being longevity of woodland development at the site, soil chemistry factors, number of habitats in the woodland and tree richness, and negatively by isolation from nearby old woodlands (Dumortier et al., 2002). Interestingly the work compared prediction ability from within-site survey data to GIS collected data. Using GIS data a prediction of only R^2 .518 was possible with the main predictors being area, length of woodland development at the site, length of previous pasture use and distance to older woodland patches (Dumortier et al., 2002). The authors noted that topographic diversity did not add any additional information to the model even though it correlated well with species richness in bivariate correlations. This is most likely due to their use of simple elevation range as the topographic diversity measure. This variable is very highly correlated with patch area as large patches have higher potential to cross higher elevation ranges. In contract the current analysis used aspect variability and slope range as measures of topographic diversity which are superior. Although these are also correlated with patch area they provide further diversity information due to capturing information on within-patch extremes in conditions.

An interesting study of AWIS flora in non-ancient woods across great Britain examined a range of patch and landscape variables on AWIS richness, providing useful comparison with the current analysis (Petit et al., 2004a). Variables included area, shape, number and area of woodland within 500m, length of hedges in 500m, and several soil chemistry within-patch measures. No hydrology or topography variables were recorded, presumably the study assuming that soil chemistry variables would accurately model variations in fertility or presence of micro-habitats. The research recorded distinct associations of factors between upland versus lowland woods. In lowland woods only 14% of AWIS variance was explained and this was predicted by patch area, length of hedges and area of woodland in 500m. In contrast in the uplands 48% of the variance was explained, mainly by soil chemistry and light availability indicators (Petit et al., 2004a). This indicates in the uplands that within-patch habitat quality / diversity will strongly the influence the species present. These results compare interestingly with the current study, however direct comparison is difficult. The study located woods randomly and did not include information on woodland habitat or age. Therefore results may reflect difference in woodland age or habitat type between the uplands and lowlands. Due to the range of conditions present there could be expected to be higher variability in soil chemistry and exposure in the uplands, such that woods created on moorland or low fertility soils, or predominantly conifer woods as in the uplands, may be expected to be more affected by chemistry factors. Additionally lowland woods may generally show higher longevity than uplands woods. Therefore the association of area and isolation found in lowland woods may reflect some island biogeography dynamics. Additionally in many areas of the uplands woodland area is so low and isolation so high that area and isolation effects may not be picked up by the isolation measures used in that study. However the study does agree with current project results in that within-patch conditions were found to be more important in these upland sites than landscape-level factors in explaining site biodiversity. At a broader landscape-scale analysis has shown local botanical richness levels, measured through grid square "landscapes" to be predicted by abiotic factors returning a model of R^2 .708 (Luoto et al., 2002). The study utilized grid sample data, rather than patch samples and found species richness was predicted by habitat diversity, abundance of forest types, wetness index variation and negatively by urban and agricultural land-use cover.

A number of studies have examined woodland avian richness. These tend to utilise abiotic patch criteria from GIS in addition to field collected woodland structure and composition values. Model success includes R^2 of .70 (Bellamy et al., 1996a) and .704 (Bennett et al., 2004). Forest bird richness in English lowland woods was predicted by patch habitat type, habitat quality, woodland structure and composition (Bellamy et al., 1996a). Another study developed a model explaining woodland dependant richness from patch area, and the length of hedges and area of woodland cover within 1km of a patch (Bennett et al., 2004). This research did not examine within-patch quality measures. Several studies however have collected information on woodland habitat structure/quality allowing an assessment of the relative impacts of patch area and structure/quality on species richness. Importantly in England research examined the relative effects of within-patch quality and area by varying the regression model (Bellamy et al., 1996a). Although area provided a high predictive ability of avian richness, it was partly due to correlation with within-patch quality features. When patch quality was entered first in the model it accounted for 27-34% of the variance with additional explanation of 36-42% provided by area. Habitat diversity has an affect on richness but is masked by its association with area. In their work, for purely predictive purposes, area was a superior predictor as it already cover the habitat quality associations. However the study illustrates the association of the two measures suggesting that in certain situations where patch area is less correlated with patch quality, that patch quality could be a more effective predictor. The analysis illustrates the importance of assessing the relative value of predictors using sequential regression methods which may be hidden or lost when using simple statistical stepwise regression. For example while analysis can show woodland area to have a high predictive and unique / independent power of variance in multiple regression models of bird species richness,, e.g. (Bennett et al., 2004), this research although testing was undertaken to find unique variance, model parsimony was assessed statistically rather than theoretically. Therefore there remains the danger that causal within-patch variables for which area was indicative were dropped in preference for patch area, limiting the potential interpretation of the model.

10.5.6 Predictive models summary and implications for conservation planning

A variety of researches have linked patch abiotic conditions to woodland biodiversity, with varying levels of predictive success. The current model predictions lie within this predictive range, with the most effective models being as successful as those from previous studies. Past work shows that both patch area and within-patch quality features can be important for botanical richness, although much research suggests that area is simply indicative of within-patch variation. Faunal studies have measured both abiotic features and biotic woodland structure. These works have found that even when variation in woodland features are measured, that patch area may remain important in predicting avian biodiversity. This is presumably due to the increased abundance of resources within larger woods, home-range size effects of individual species, and the fact that even when some structure measures are measured, it is impossible to capture all aspects of woodland structural / compositional diversity, and patch area remains an important surrogate for those range of individual within-patch affects left unmeasured within studies. Rather fewer studies have found no affect of area, while some studies examining management influence suggest possible extreme relationships with area such as where larger woods may in fact be subject to more frequent or more intensive management than smaller, natural woods, such that biodiversity declines with wood size. These studies show the importance of aiming to examine causal factors, rather than over-arching indicators which may just be correlated themselves with causal factors. By analysing these effects of different factors on woodland biodiversity sequentially, using theory driven regression, the current project provides insight into important factors in predicting woodland value in upland areas from readily available abiotic data. The current project results show a strong association of biodiversity indicators with habitat type, within-patch habitat quality and patch area. Additionally the strong associations between remnant biodiversity interest features in PAWS sites compliments previous work, finding that hotspots of remnant interest occur and that these may be associated with watercourses, rides or damp / wetland areas (Pryor et al., 2002). The project results suggest a distinction between stronger abiotic influence in PAWS as compared to the ASNW sites. The project analysis showed that their were associations between the predictive effects of site area and within-patch habitat quality. The comparison of the analysis between the single biodiversity summary score and the three NMS ordination scores allowed the relative importance of the two groups of abiotic predictors to be assessed. The detailed analysis showed that elements of biodiversity assessment could be extracted that were strongly related to patch area. Small but area-diverse (rich in diversity per unit area) sites existed where their small size was a strong indicator of the biodiversity present. In these sites within-patch habitat quality, e.g. topographic diversity and the presence of watercourses still retained a positive predictive influence. When the overall, broader summary of biodiversity interest as examined among all compartments strong indicators were habitat type, patch area and within-patch quality. From the examination of previous research and investigating the relative effects shared between the patch area and within-patch indicators several sights can be gained to the use of such variables for conservation planning. Woodland habitat type is consistently a strong predictor of biodiversity presence. Beyond habitat type, abiotic factors were also found to have predictive value, and are particularly useful in PAWS sites. Because sites exist that are small yet relatively diverse for their area the relationship of biodiversity interest to woodland area for conservation planning is not straightforward. Sites exist where high biodiversity may be predicted by either low area or high compartment area. Both types of sites may be considered valuable for conservation purposes. Their is a known association between patch area and within-patch diversity, from previous research and in the analysis presented here. In considering the use of predictor variables it is notable that even in the sites where low site area is predictive of high biodiversity levels, within-patch quality is also predictive, as it is in larger sites. Therefore as within-patch quality measures (topographic diversity and stream presence) show value in the full range of sites, when compartment area shows mixed effects, these within-patch quality measures are generally recommended for use in conservation planning in addition to habitat type, with which to predict woodland value across networks. The use of such abiotic variables in conjunction with remote sensing classifications, such as woodland habitat type, is discussed in the final chapter, where the detailed selection of predictive variables is discussed in relation to the case study of upland Oakwood conservation within the Dark Peak Natural Area.

10.6 Chapter Summary

Ancient woodland resource

- The Dark Peak ancient woodland resource was surveyed, and a range of site based biodiversity indicators collected, together with a range of within-patch and landscape scale abiotic data variables
- Dark Peak Ancient woods were evenly split between ASNW (632ha) and PAWS (637ha)

Ancient woodland biodiversity indicators

- A wide range of biodiversity interest, as measured by the richness, composition and structure variables was recorded within both ASNW and PAWS woods
- Biodiversity values differed between ASNW and PAWS
- Few differences existed between mixed and broadleaved PAWS
- NMS Ordination revealed associations between biodiversity indicators
- A composite summary biodiversity score was developed to summarise compartment interest

Ancient woodland abiotic indicators

- A wide range of abiotic indicators, collected within-patch and at landscape scales of 20m, 100m, 500m and 1km were analysed and reduced using correlations and PCA scores to variables indicative of woodland patch abiotic conditions
- Abiotic conditions differed, although not strongly, between the woodland habitats, overlap in conditions between habitat types occurred

Predicting woodland biodiversity from patch abiotic conditions

- Biodiversity values were associated with abiotic values
- Biodiversity was able to be predicted from abiotic variables with varying success.
- NMS regressions returned R^2: .313 to 685
- Biodiversity composite summary score models showed R^2: all data .696
- Habitat type was the best and consistent predictor of biodiversity value
- Patch variables proved most predictive with minor input from landscape level variables
- The regression model for the main NMS score (NMS3) was broadly comparable to the regression model of the site summary biodiversity score
- Multiple regression models were altered to examine the predictive relationship between patch area and within-patch abiotic variables
- Models derived from all compartment data (N=298) were compared with predictive models based on all PAWS data (N=184) and ASNW data (114)
- Biodiversity interest was most predicted by habitat type, beyond which habitat quality provided useful additional predictive ability
- Interaction occurred between the within-patch diversity and patch area/shape indicators, when examined together area showed some additional positive effects, especially with the summary biodiversity score
- Models revealed that sites existed that were highly diverse for their area, where small patch size and high patch topographic diversity were both predictive of biodiversity interest
- Interest within ASNW woods as a single class was less successfully predicted using abiotic criteria than PAWS sites or examining all woodland habitats together

- Additional spatial variable and geographic co-ordinates were used to deal with spatial autocorrelation model residuals and these generally resulted in autocorrelation being removed and the variance being accounted for as noise in the data, as main model effect remained unchanged

Implications for landscape- scale woodland conservation

- The modelling confirmed previous research that woodland site biodiversity could be predicted from abiotic variables
- Patch area was associated with within-patch quality: topographic diversity, watercourses
- Both patch area and within-patch quality were significant in predicting woodland biodiversity
- Complex interactions occur with biodiversity and patch area because some small site are highly diverse for their size
- Comparison of models revealed the most useful predictors were habitat type and within-patch quality in addition to potential landscape and isolation measure or regional trends
- Within-patch abiotic variables were particularly useful in predicting biodiversity within PAWS
- ASNW models showed poorer prediction levels and less association with within-patch habitat quality, possibly because they all occur within sites with high habitat diversity / quality, and different clusters of woodland types may occur
- Due to associations of biodiversity within small ASNW sites, patch area should not be used to score ASNW or semi-natural sites
- Regional trends / undetermined local factors influenced woodland biodiversity in the models, as shown by remaining spatial autocorrelation or the significance of the clough and urban landscape measures
- Summarising model interpretations a conservation planning system can be devised that uses:
    - habitat type indicative of patch quality
        - broadleaved semi-natural > mixed + broadleaved > coniferous
    - stream presence or proximity is favourable compared to absence
    - clough landform preferable to non-clough landform
    - topographic diversity preferable to uniform topography

Part V:
Conclusion

Chapter 11
A Natural Area woodland conservation strategy
The conservation of Upland Oakwoods and clough woodlands in the Dark Peak Natural Area

11.1 Introduction

This chapter illustrates how the research results were combined to produce an integrated woodland conservation strategy using the separate elements of landscape assessment, and woodland habitat quality modelling, using multiple indicators of woodland biodiversity and abiotic predictors. The links between woodland habitat type, habitat variability / quality and features indicative of broader woodland conservation interest were examined and modelled. This chapter therefore details:

- The use of a mixed methodology applied to the formulation of a woodland conservation strategy, at the Natural Area scale
- The examination of the Ancient Woodland resource as a study model for woodland ecology within the Natural Area
- How the results of the landscape assessment, woodland habitat mapping and woodland abiotic conditions / biodiversity association were used in formulating the conservation strategy
- How results of the strategy were applied and how these relate to current plans for the Natural Area within the Peak District LBAP

The project literature review found a range of woodland conservation activity that was classified into three principal strategy formulation areas and three implementation processes, a mixture of which have been practised by a variety of conservation organisations. Strategies were: landscape based, habitat/community based, or species based, while implementation methods included: landscape design guidance, conservation zone mapping and land parcel prioritisation / scoring. The combination of strategy formulation and implementation method was determined by the range of information available to the conservation organisations / researchers, the levels of ecological realism attempting to be modelled and the desired levels of prescription / detail within the final strategy.

The current study examined the potential for woodland conservation strategy development at a Natural Area scale (86,800ha) utilising widely available woodland habitat classification data and data created from GIS DTM. Conservation at such scales relies heavily on surrogacy, either environmental surrogacy or the use of biological surrogates. All surrogate data, representing other unmeasured biodiversity elements, of which the surrogates are representative, have some cost to collect but are generally less expensive to collect than the many factors for which they are indicative. The current study pursued two areas of research extracted from the current woodland conservation debate: the use of multiple structural and compositional indicators within woods as indicative of broader conservation value and habitat "quality", and the use of environmental diversity surrogate information instead of such biological indicators. The study was therefore formulated using a combination of the landscape assessment approach and the woodland habitat / community modelling approach (Chapter 6) with which to assess and define existing and potential woodland sites. The strategy was then implemented using conservation zone mapping and land parcel prioritisation / scoring approaches rather than broad landscape design guidance.

When dealing with conservation initiatives at the landscape-scale multiple species and species groups are involved and potentially long timescales may be required for results to be achieved. When conservation, restoration and creation strategies are integrated key issues emerge as the most appropriate way in which to focus activities to benefit the broader "pool" of woodland specialist species which may variously occur in existing, converted and plantation woodland sites. Issues arising here may then be the representation of such species pools by landscape ecology theory and island biogeography, both of which has much influenced such planning strategies. Key sources of such species are remnant native semi-natural woodland sites and high quality areas within converted sites. The relative pool of such species in different areas of the landscape will affect conservation activities aimed at conservation, restoration and creation of woods.

11.2 Strategy insights from current Dark Peak research

11.2.1 Landscape assessment

The results of the Natural Area landscape and landform assessment (Chapter 8) concentrating on clough sites and topography produced a GIS assessment showing the current land-use across the area in relation to topography, and its potential for development of native woodland. Analysis of the clough topography zones and existing land-use allowed identification of areas of woodland outside clough zones where conversion to other semi-natural land-use may be desirable, identification of plantation woodland within cloughs where conversion to native wood would be desirable, and identification of suitable non-woodland habitats where encouraging woodland cover may be beneficial. Potential woodland creation or woodland conversion areas covered approximately 16% of the Natural Area.

11.2.2 Phase 1 woodland habitat survey

The Dark Peak is a relatively scarcely wooded area at 9% total and 2% semi-natural cover. Plantation woods are split between coniferous, mixed and broadleaved types. A range of typical woodland sizes occur, with plantations often being bigger than semi-natural woods. Important implications for conservation planning suggested by the Phase 1 woods analysis were that current semi-natural woods are typically small, complexly shaped, occur in cloughs and are topographically variable. Due to their sizes and shapes semi-natural and broadleaved plantation woods suffered more from modelled "edge-effects" than conifer and mixed woods. Semi-natural woods sites only typically began to achieve up to 75% of their area as core area when they were more than 8-10ha in size. Semi-natural woods often occur relatively close to other such sites, with median distance of 50m, although wide ranges of isolation values were seen. The picture therefore is of a scattered resource of often small sites rather than totally isolated larger woodland sites.

When typical abiotic conditions of the wood groups were examined there was an association between mixed and conifer plantation conditions and between semi-natural woods and broadleaved plantations. However a wide range of values were seen within woods of each type, woods of a particular habitat do not entirely have a set character. Semi-natural woods differ in topography, size and shape from plantation woods, reflecting both the character but also the influence of management over the years. Pockets of more clustered semi-natural woodland occur in the more lowland valley areas of the Dark Peak while native woods at higher altitudes in the moorland fringe tend to be more isolated and remote. Research suggests, due to difference in landscape position and character that broadleaved woods may be older and longer established than mixed and conifer sites. The analysis also suggests that topographic position and variability can itself be indicative / associated with woodland type and management history.

The analysis noted that the high occurrence of scattered tree habitats represents potential for conversion to native woodland sites. Of the existing woodland types research suggested that broadleaved woods may have high potential for conversion / restoration to native wood cover due to their similarity to the native woodland conditions, although the often larger size and relatively higher core area of some mixed plantation can also make those favourable conservation sites. Due to the strongly contrasting conditions / locations of most conifer woods these were not considered likely to offer much scope for conversion or creation to native woodland cover.

Analysis of the existing semi-natural woods showed increasing topographic diversity (habitat quality) with patch size. Approximate thresholds exist at 2ha, 10ha and 20ha which could be used as minimum targets with which to aim to increase existing woodland sizes. A maximum size of approx 50–100 ha could be set for combined / created patches based on current analysis of landscapes as woods bigger than this would begin to affect current landscape character and could not easily be accommodated in the area. The results of the Phase 1 analysis therefore suggest several areas useful for strategy formulation:

- Where core area is a concern for semi-natural woods then woodland size needs to be increased or sites need to be buffered by similar habitat types such as scrub or scattered trees
- Reduction of semi-natural woodland isolation is required more in the upland and moorland fringe areas than the more lowland areas of the Dark Peak
- Broadleaved and mixed plantation sites should be preferred for conversion to native woodland cover compared to conifer plantations, the preference between the two plantation types depends on site topography and character
- Conifer and mixed woodlands outside cloughs are unlikely to hold conservation interest for native woodland communities, are likely to be recent and should not be prioritised for conversion, they may however be appropriate for reversion to other habitat types
- The present woodland distribution within the riparian clough network means that woodland creation or conversion within this zone will lead directly to reduced isolation
- Thresholds of 2, 10, 20ha could be used as targets for woodland creation / expansion while upper limits of 50-100ha would be suitable to ensure landscape character is not compromised

11.2.3 Woodland biodiversity–abiotic conditions associations

Analysis showed that abiotic conditions differed between ancient woodland habitat types and that biodiversity levels were associated with, and could be successfully predicted from, site abiotic conditions (Chapter 10). One summary score and one ordination score (NMS 3) can be used to summarise conservation interest. The sequential multiple regression models were theory driven and analysis of the model results, examining the impact of variables, in conjunction with the models derived from a single biodiversity summary score, and from biodiversity variables derived from ordination, allowed insights to be gained into the predictor variables that can be suitable for use in a conservation strategy model.

The model predicting woodland biodiversity value based on the single summary biodiversity score had significant individual predictors as: habitat type, habitat quality (topographic diversity, stream distance), compartment area, clough area in 1km, geographic co-ordinates and urban area in 5km. These returned a model of $R^2 = .72$ (R^2 adj = .70). Of the ordination scores NMS3 showed the highest representation of biodiversity variation. This NMS3 ordination score model was similar to that based on the single biodiversity score, although with a higher effect of habitat type. Individually significant variables were habitat type, habitat quality (stream distance), core area index, functional isolation 2, clough area in 1km and urban area in 5km. These returned a model of R^2 .71 (R^2 adj .69).

The range of significant variables within the models was considered for their predictive potential based upon consideration of their likely potential causal influences on biodiversity from these examinations and comparison with previous research. The single biodiversity summary score model was followed and used as the source of individually significant variables to use in the subsequent predictive planning model. However input was also included from the ordination models, particularly NMS3. Habitat type has a clear influence and is shown to reflect differing biodiversity levels, not only between semi-natural and plantation sites, but also within different types of plantation woodland. This variable was interpreted as reflecting naturalness levels and also the influence of management intensity and canopy cover conditions such as shading. Habitat quality, defined as comprising site topographic diversity and the presence or distance to streams showed an influence on biodiversity and was interpreted as being indicative of the variability and availability of micro-habitat conditions and resources. Sites with diverse topography and with stream presence have higher variation in soil types, soil chemistry and hydrology conditions offering more niches for plant and fauna species. These variables are also interpreted as influencing the likelihood of past or current conversion of native woodland to plantations, with areas of diversity e.g. steep slopes and cloughs being less likely to have been converted, or where present within larger plantation sites, to be more likely to have retained native woodland conditions.

Within both models, although not always individually significant, interactions were found between the effects of area and habitat quality (topographic variability, stream distance) on biodiversity. For both models, when considered separately, habitat quality showed most explanation of variance of the two sets of variables, but levels of variance remained that were explained by both variables. Within the single summary biodiversity score model when the model was examined without the habitat predictor the variance explained by habitat quality variables increased, suggesting that habitat type was indicative of, and accounting for, some of the range in habitat quality between habitats. When the relative influence of habitat quality and area was examined in the absence of habitat type habitat quality was again shown to explain the most individual variance of the two sets (.217 out of .257) although shared variance remained.

Generally habitat quality was considered more deterministic of biodiversity than area, with area itself often simply being indicative of habitat quality levels. Area was indeed not individually significant in the all data NMS3 model. Some NMS models (all data, NMS1) revealed biodiversity richness per unit area were higher in small sites, that small sites could hold proportionally high biodiversity levels for their size. Other NMS results revealed a strong importance of area in predicting certain biodiversity features but that overall model results were low (all data, NMS 2). Certain NMS models such as the ASNW model showed that biodiversity interest per unit area were promoted by stream presence and topographic diversity but were also promoted by smaller site area. Smaller ASNW tended to have higher interest levels per unit area. Therefore the interpretation was followed that habitat quality was consistently predictive of biodiversity among models and that the effect of area may be variable, but was itself often merely indicative of habitat quality. To avoid the problems of topographically diverse, but small, woodland sites being considered to be biodiversity poor, area was not considered further as an individual predictor. Therefore habitat quality measures were preferred over simple use of area. An additional factor in using predictive regression is that it is important not to apply predictive models to data that vary significantly beyond the range of data values used to derive the model. While habitat quality levels were comparable the area of surveyed ancient woodland compartments used to derive the models were relatively small compared to some of the large plantation woodland sites present within the Dark Peak, therefore use of area could be considered unwise, attempting to predict values beyond the known variable reaction range.

It is notable that no direct or composite woodland isolation variables were found to be significant in the model after accounting for site effects, despite many being individually significant in simple bi-variate correlations (Chapter 10). Individual woodland isolation variables were not consistently selected as significant within models and therefore were not interpreted for use in the predictive models. The relationship with the isolation variables is interpreted as being related to past management and landscape-scale management trends, rather than causal effects. It is likely that this relationship is affected by the fact that high quality sites may often occur in cloughs and be isolated from other high interest woods. The relationship is not interpreted as being causal therefore but is deemed to reflect the past isolation of higher interest sites. Lower interest plantation woods are more likely to occur in clusters and to be near other woodland sites due to management planting decisions and their locations in often more accessible areas of the Dark Peak.

Two landscape variables were interpreted as representing broad environmental trends from the central moorland plateau towards the marginal moorland fringe areas – a trend of woodland site occurrence not picked up by simple elevation. These variables were area of clough area in 1km and urban area in 5km. Initially the amount of clough area in 1km was included as a potential surrogate for past levels of woodland cover, where it was expected to be positively associated with biodiversity levels. However it was negatively associated with biodiversity and is interpreted as being associated with a range of conditions in the moorland fringe and uplands of the Dark Peak, where cloughs are frequent compared to the richer conditions in lowland woods, where large areas of clough are scarce. In areas with more cloughs, grazing levels are likely to be higher, woods smaller, more exposed, and on poorer soils, leading to comparably lower biodiversity levels compared to the slightly more lowland, better-connected woods likely to occur on an increased range of soils. Urban area in 5km was selected for inclusion in the predictive model and was interpreted as representing a trend from lowland to upland areas, in combination with area of clough in 1km, helping to define local landscape types along a gradient from moorland to lowland fringe, that is not accurately represented by simple elevation. The positive association with urban area in 5km may also result from associations with woodland management levels, being higher near to urban areas where woods may be more likely to be stock-proof and managed, or may result from a co-correlation of less urban areas and the moorland core where conditions are associated with low interest woodland sites, poor soils and potentially higher grazing levels

Following the consideration of potential predictive patch and landscape factors in the Ancient Woodland sites the research model was applied that theoretical deterministic, site based, variables linked to biodiversity would be similar within the broader, non-ancient woodland cover of the Dark Peak. Additionally landscape trends in woodland biodiversity across the Dark Peak are expected to be comparable. Therefore the following predictors were selected for use in woodland biodiversity planning:

- Habitat type: semi-natural broadleaved and broadleaved, conifer and mixed plantation
- Habitat quality: stream distance, topographic diversity (slope minimum, slope range, aspect variability)
- Landscape-scale trends: area of clough within 1km radius, urban area in 5km radius

11.3 Woodland conservation strategy methods

11.3.1 Introduction

The woodland conservation strategy methodology was developed by combining the landscape assessment / landform analysis, Phase 1 habitat woodland analysis and ancient woodland analysis to develop a predictive GIS model to map woodland biodiversity across the Natural Area, using abiotic variables, landform occurrence and habitat type. The mapped biodiversity was then used together with focal neighbourhood analysis at four spatial scales to map strategies for conservation, restoration and creation. Prioritisation scores were given to woods and land areas illustrating areas required to meet Local Biodiversity Action Plan (LBAP) area targets. The strategy was devised and implemented with the intent that a system based on woodland quality and multi-scale implementation assessment would allow a more effective and valuable conservation network system than one developed from random or landowner focussed uptake of conservation schemes. The methodology involved the following stages:

- Prediction of *site* woodland biodiversity based on multiple regression using habitat type, topography, stream presence / distance, area of cloughs in 1km and urban area in 5km
- Calculation of the biodiversity levels of woodland within surrounding "*landscapes*" at, 20m, 100m, 500m, and 1km. These scores were scaled and converted to log value to account for the extreme range of values returned using circular search area extent

- Creation of a *combined* score, derived from *site* and *landscape* scores, each given equal weighting, allowing identification of priority sites with both high site and landscape based biodiversity levels

11.3.2 Predictive regression model development and GIS refinement

The strategy was implemented using the "Grid and Theme regression" extension to ArcView 3.2 (Jenness, 2006). Using the insights gained from the analysis of ancient woodland sites (Chapter 10), the relationship of woodland biodiversity value / quality to abiotic factors and landscape form was implemented within a predictive GIS model to map woodland biodiversity across un-surveyed areas. The predictors for the model were chosen as in Section 11.2. The regression model was developed using the surveyed ancient woodland sites and was then applied to a GIS theme detailing all classified woodland and semi-woodland habitats within the Natural Area, within which the full range of predictor data had been collected within the GIS for each site / polygon. The analysis was run on woodland polygons for existing woodland areas and for amalgamated and mapped potential woodland creation sites in open ground habitats. The prediction model was applied within ArcView 3.2 GIS and gave a model of $R^2 = 0.71$ using the selected predictors. The model regression equation was:

> Y-hat = 21.6385979 - 13.5652251*[Broadleaved plantation presence] - 20.4120276*[Coniferous woodland presence] - 11.5158446*[Mixed plantation presence] + 0.1964873*[Slope range] + 0.7012832*[Aspect variability] - 0.0153959*[Area of clough within 1km radius] - 2.5947794*[Stream distance ($\log_{10}$)] + 4.0884544*[Area of urban area in 5k radius ($\log_{10}$)] + 2.0577173*[Slope minimum ($\log_{10}$)]

Within this analysis and prior to the final woodland biodiversity scoring four modifications were made to the GIS to allow this model to run. These were: modification of the classified woodland sites GIS to detail areas relevant to clough landscape areas, identification of a minimum standard to identify woodland considered to be in "favourable condition", the identification and mapping of polygons to represent potential woodland creation sites, and the identification of areas of non-ancient plantation for creation of new semi-natural native woodland.

11.3.2.1 Amending the woodland GIS by woodland clough landscape character assessment

Prior to final biodiversity prediction analysis the woodland sites GIS, detailed in Chapter 9, was altered using the clough landscape assessment. All occurrences of semi-natural woodland habitats were retained, but the areas of plantation woodland and semi-woodland habitat such as scrub and scattered trees were altered such that only the areas that occurred within the clough landscape zone were retained (Fig 11.1). This resulted in a GIS layer where plantation woodland boundaries had been altered by their presence within the clough landscape zone. Plantations occurring outside the clough zones were omitted. The premises for this methodology was: the identification of the clough landscape zone was significant to the Upland Oakwood habitat, the model had been developed on sites that were largely within the cloughs zone and plantation woods occurring within the cloughs were more likely to have developed on previous semi-natural woodland or semi-woodland habitats. Only plantation woods or semi-woodland habitats within the cloughs zone were considered suitable for woodland conservation management.

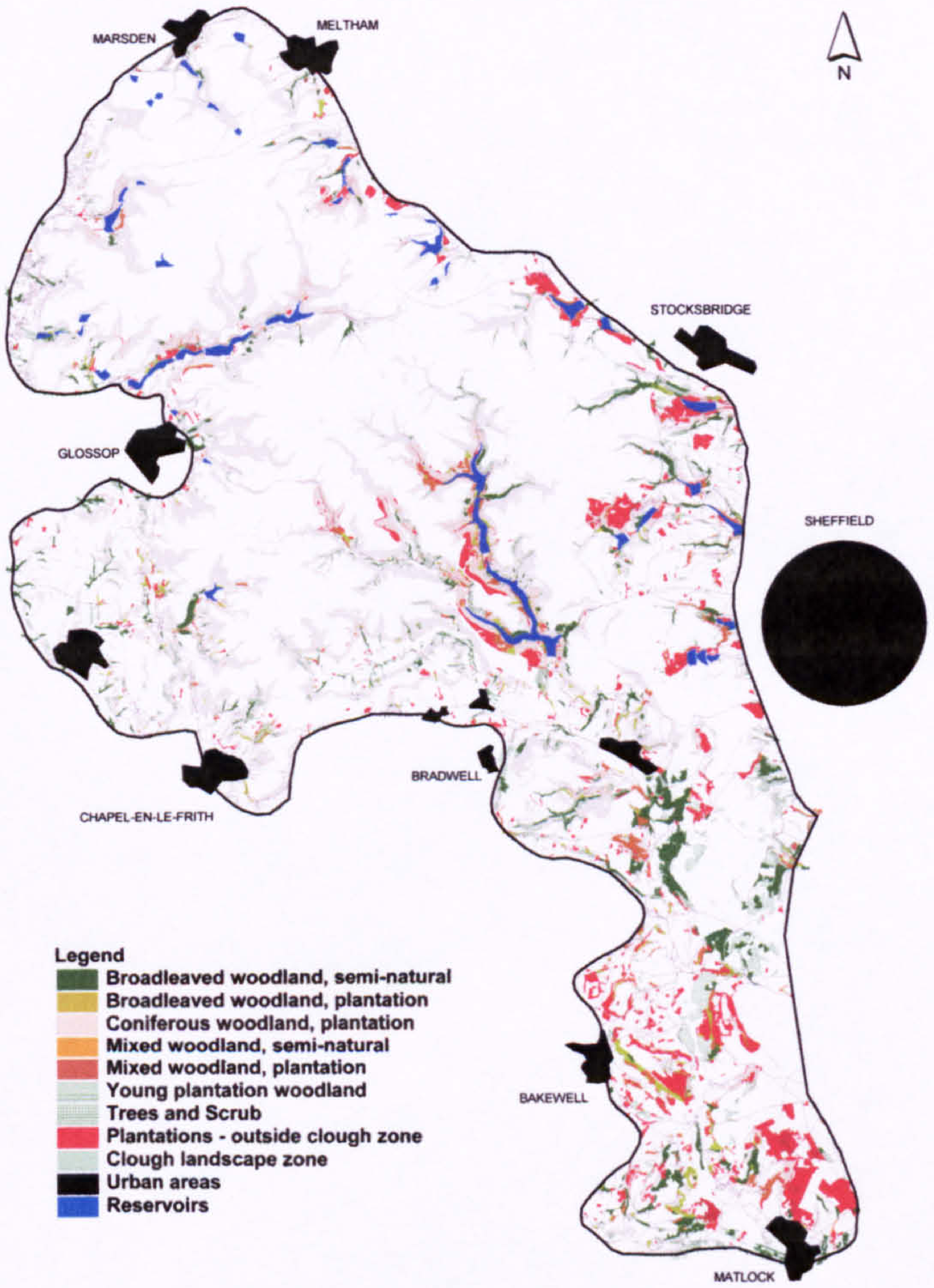


Figure 11.1
Dark Peak woodland resource, clough conservation potential, plantation woodlands occurring in non-clough zones (with potential for conversion to open habitats) and geographic context. (See GIS CD for full scale GIS files and images).

11.3.2.2 Identifying ancient woodland sites in favourable condition

One of the LBAP objectives required information on the current "favourable condition" status of the ancient woodland sites. Therefore for the sites that were surveyed a minimum standard was developed from a combination of the current Natural England (English Nature) guidance on SAC status mapping and from an examination of the relative level of different biological indicators record within Dark Peak ancient Woodland sites (**See Chapter 10**). These guidelines were then applied to the survey results to classify sites reaching these minimum standards as being in favourable condition (**Table 11.1**).

Table 11.1

Favourable condition status classification, adapted and expanded from English Nature SAC / SSSI assessment advice. Sites are classified as in favourable condition when all conditions in the compulsory column are met and 4 out of the 5 optional diversity measures are met in a compartment. (AW = ancient woodland).

Compulsory:			Diversity:		
Oak % cover class	>=	30%	Number of AWIS	>=	8
Canopy structure layers	>=	3	No of tree sp / patch	>=	3
Ground flora cover	>=	50%	No of shrub sp / patch	>=	3
Presence of dead wood	>=	Frequent	Birch % cover class	>=	10%
No NVC communities	>=	1	Canopy age	>=	Mature
Semi-natural tree cover	>=	30%			
Semi-natural shrub cover	>=	10%			
Invasive species presence	<	Frequent			

11.3.2.3 Mapping of potential woodland creation sites

The project methodology and GIS analysis resulted in individual woodland polygons available for scoring and prioritisation. However, for the woodland creation LBAP objective site polygons did not exist. In Chapter 8 broad areas within the clough landscape zone were identified that were suitable for woodland creation or conversion. A further stage of methodology was applied to these sites in order to prepare the data for scoring. While individual habitats were mapped and the boundaries of these polygons could be used directly for scoring an alternative approach was taken. The composite GIS (Chapter 7, 8) was the result of amalgamation of datasets involving both ground based and aerial photograph based habitat mapping. Within the upland and upland fringe areas the mapping of certain habitats such as woodland, scrub and bracken can be considered reliable. However the exact boundaries between different "open ground" habitats such as grassland and heathland, and in particular mosaics of different habitats may be much more reliant on individual surveyor experience and style. Therefore the use of individual polygons may be less appropriate for open ground habitats. Additionally it was felt that successful and high quality potential woodland creation sites would most suitably consist of several pre-cursor habitats, rather than one habitat type, allowing the presence of more variable conditions and soil features in the potential creation site. These facts, in addition to a desire to map broader / larger potential woodland creation sites, led to a pre-processing stage for this LBAP objective. This involved analysis of the potentially suitable areas identified in Chapter 8 within Spatial Analyst in ArcView 3.2 to derive amalgamated potential priority areas using a neighbourhood mean analysis, based on conversion values of the different habitat types. The analysis is detailed in Appendix 11.1 but essentially resulted in mapped polygon representing areas where high priority creation areas occurred, resulting from merged pockets of high priority habitats buffered across potential conversion habitat, so larger sites were formed and lower priority conversion areas were avoided. Scrub and scattered tree sites were buffered and enlarged. Additionally the process favoured areas near to existing semi-natural woodland habitats. Although the project planning methodology broadly aimed to avoid using patch area for planning the creation of small woodland areas has particular practical limitations in fencing and woodland creation costs, therefore a comprise value of 4ha was selected. Only potential creation sites of 4ha and larger were selected for subsequent scoring and prioritisation.

11.3.2.4 Identification of plantation sites suitable for semi-natural native woodland creation

During methodology development an omission in the LBAP targets development was noticed. A strict interpretation of LBAP objective 4, relating to native wood creation, would involve only prioritisation of currently open ground habitats. Analysing the GIS and considering the potential conversion value of habitats occurring within the clough landscape zone it was clear that in many areas existing plantation woods were suitable for conversion to native woods, and were not explicitly covered by the current LBAP objectives. Therefore the objective was run twice, once using open ground habitats, and once using areas of current non-ancient plantation woods within cloughs, for comparison.

11.3.3 Priority scoring methods

The LBAP prioritisation strategy was based upon calculation and mapping of 4 biodiversity targeting scores: "*site*", "*landscape*", "*combined*" and "*effects*" (**Table 11.2**). These represented different factors useful in conservation planning and were derived from the combination of the site based predictive analysis detailed in the section above and landscape analysis conducted in the GIS. The 4 scales used within the GIS analysis to represent different woodland species movement / colonisation scales were: 20m, 100m, 500m and 1km. These were the same scales identified in the literature review (**Chapter 5**) for collection of data around woodland sites during analysis in **Chapter 10**. The results presented here concentrate on the "*combined*" scores resulting from the *site* and *landscape* based analysis. Priority area mapping was also undertaken using each of the separate scores in sequence, and are available in the accompanying GIS CD.

Table 11.2
Woodland site and landscape biodiversity summary scores: definition and calculation

	Woodland biodiversity score	Source data and Calculations
Site Biodiversity	Score indicating predicted current or future potential site biodiversity value	Calculated from site collected survey data for Ancient Woodland sites, and predicted from abiotic data for non-AW sites*
Landscape Buffer Biodiversity (individual)	Landscape buffer score representing the site biodiversity interest of the woods within 1km, 500m, 100m, 20m.	Calculated from the cover weighted sum of the total value of site based woodland biodiversity within each buffer, multiplied by the mean landscape contrast within the buffer. Relativised by Dark Peak maximum to give a score out of 100.
Landscape Biodiversity (total)	Score representing the biodiversity interest of the surrounding woods, combined from scores from the separate buffer zones	Calculated by detailing the site biodiversity value of woods surrounding a site at 4 buffer scales and then summing each separate buffer zone score, with equal weighting. Relativised by Dark Peak maximum to give a score out of 100.
Combined Biodiversity	Score indicating the combined influence of site and landscape score, with equal weighting	Calculated from the addition of the site biodiversity score and the landscape biodiversity score. Relativised by Dark Peak maximum to give a score out of 100.
Effects Biodiversity	Score representing the effect of the surrounding landscape woodland value on mapped combined biodiversity scores	Calculated from combined biodiversity score (scaled) minus site biodiversity score (scaled). Strong negative values allow identification of high interest sites with very low landscape scores

*small numbers of AW sites were not surveyed e.g. where permission was not received and sites along the DP boundary, these were therefore predicted from abiotic data.

The methodology used to create these 4 scores combines the predictive GIS model with methods aimed to provide a functional connectivity representation of the woodland habitat quality / biodiversity value present in the local landscape. The predictive GIS model was used to derive the "site" scores, indicative of biodiversity values for all woodland and semi-woodland habitats within the Dark Peak. In order to account for the known history of ancient woodland sites the value of mapped ancient woodland site scores were increased by x1.3 when relative scores were examined and calculated. Therefore site scores comprise direct surveyed biodiversity summary scores for the majority of ancient woodland sites and predicted scores for un-surveyed ancient woodland sites and all non-ancient woods. For semi-woodland habitats scores, dense scrub and scattered trees were assumed to be similar to mixed plantation habitat, while open scrub and scattered trees were assumed to be similar to broadleaved plantation values. Young plantations were assumed to hold similar biodiversity levels to coniferous plantation sites for predictive purposes. For the amalgamated woodland creation sites (Section 11.3.2.3), the regression prediction was run with these areas classed as semi-natural broadleaved woodland. Thus for LBAP Objective 4 creation sites the site scores presents predicted future biodiversity value if semi-natural woodland cover were to develop at the site.

"Landscape" scores provide a functional connectivity representation of the surrounding woodland landscape biodiversity levels. These scores were calculated using buffers created around polygons at 20m, 100m, 500m and 1km. Each buffer was used to calculate the total "site" biodiversity scores of all woodland (Table 11.2). The resulting scores incorporated functional connectivity assessment by modifying the site score total by the mean contrast value within the buffer zone (Table 11.2, Appendix 10.3). At a particular buffer scale the landscape score represented the cover weighted sum site biodiversity score of all woodlands within the buffer multiplied by the mean inverse contrast within the buffer. The final score was log transformed for each buffer scale in order to provide a linear scale for buffer scale amalgamation. Each score were relativised by maximum to give a score out of 100, and the 4 scores from each buffer were then combined and relativised by maximum to give a score out of 100. This "landscape" score increases in value with three factors of the local woodland landscape: the level of site biodiversity present in the woodlands occurring within the buffer, the proportion of the buffer comprising these woodlands, and with the similarity of the landscape within the buffer. Therefore woodlands with larger areas of high quality woodland nearby and with low contrast habitats in the buffer, such as semi-woodland habitats, scrub, scattered trees or bracken would return the highest scores. Total "landscape" score reflects such woodland values across each of the scales and provides a general picture of nearby woodland value and connectivity across several scales. Woodland sites with high scores within more than one individual buffer scale will score highly on total "landscape" score. The incorporation of the modification of each landscape score by the contrast value of the buffer ensures the functional connectivity of the landscape is incorporated into the scoring. This ensures that sites which may hold relatively high areas of high quality woodland nearby but which are surrounded by highly contrasting habitats such as urban areas or improved grassland are not given high landscape scores. This is considered justified because the biodiversity scoring will be utilised to examine future woodland restoration and creation areas, for which species colonisation will be required to allow the biodiversity potential of new site to be realised. Although the current modelling of existing woodland sites found little direct evidence for the effect of such spatial factors on the range of biodiversity indicators currently measured, it is acknowledge from the literature that spatial connectivity will be important for future colonisation and conservation of population so particular species groups, in addition to the actual quality of individual sites. At each stage relativisation by the maximum of each buffer zone, and scaling 0-100 allowed comparison and addition of the 4 buffer zones. This does determine that the values of each zone are not directly comparable, each being the maximum recorded under the current Dark Peak woodland configuration, rather than being interpreted in relation to a particular level of score achievable within a particular zone. These scores were designed for comparative examination within each scale. This methodology was implemented within the GIS by using a grid theme of predicted site scores of woodland biodiversity value, of which woodland buffers (with attribute values of each woodland polygon ID retained), were used to summarize the zones of the grid site biodiversity value theme. The sum value within each polygon was divided by the total buffer area and multiplied by the mean inverse contrast level within the buffer, before scaling (Table 11.2).

The "combined" scores were created from the addition of the "site" and total "landscape" scores, after each was relativised by maximum and scaled to 0–100. This combines values indicating the current biodiversity of each site with values indicative of the surrounding woodland landscape quality. Woods scoring highly for "combined" scores have a high combination of site biodiversity and surrounding landscape interest. The "effects" scores were then created from the calculation of the "combined" score minus the "site" score, following scaling, which illustrates the difference in priority of a wood from examination of only the site value to the combined effect of site and landscape. This allows identification of high interest sites which have very low landscape interest, and are thus have low functional connectivity (Table 11.2).

11.3.4 LBAP targets and prioritisation of woodland conservation, restoration and creation

Current LBAP targets give greatest priority to conservation of existing ASNW (30%), restoration of PAWS (15%), followed by conservation of existing non-ancient sites (10%) and lastly creation of new woods (7%). Calculation of Dark Peak Natural Area targets are indicated in Table 11.3.

Table 11.3
Peak District Local Biodiversity Action Plan: Upland Oakwoods Action Plan targets (Peak District National Park Authority, 2002). Dark Peak estimates / targets have been extracted by basing calculation on the relative areas of the Dark Peak and South West Peak, the two Peak District Natural Areas in which the plan will be implemented.

Objective	Target	Dark Peak	
		Resource	Target
Maintain extent of upland oak/birchwoods and bring all existing ancient semi-natural woodland on the Ancient Woodland Inventory (AWI) into favourable condition	Initiate measures by 2005 to bring 300 ha (approximately 30 %) of oak/birchwoods on the AWI into favourable condition, and the remainder by 2015.	632 ha of ASNW	189 ha
Bring priority examples of non-ancient semi-natural oak/birchwoods into favourable management.	Introduce appropriate management regimes by 2010 to bring 100 ha (approximately 10 %) of oak/birchwoods which are not on the AWI into favourable condition.	Non ancient semi-natural Woodland = 1,324 ha	132 ha
Convert Plantations on Ancient Woodland sites (PAWS) back to oak/birchwoods where this is a priority	Introduce appropriate management regimes over 80 ha (15 %) of relevant PAWS by 2005, to restore site-native species over appropriate time spans. Review and set a new target for 2005 - 2010.	637 ha of PAWS	96 ha
Reverse woodland fragmentation by creation of new woodland, particularly by natural regeneration. Prioritize the extension/linking of existing ancient woodlands and relic clough woodland	Initiate measures by 2005 to create 200 ha of new oak/birchwood, including at least 100 ha of clough woodland in relic sites adjacent to existing ancient woodland, following current best practice. Review and set a new target for 2005 - 2010	1,832 ha existing woodland	134 ha

11.3.5 Derivation of priority sites for each LBAP objective

Within the project methodology relativisation by maximum and scaling was used to allow comparison of values for the different scores and different buffer sizes. The scores are of principal use when comparing between similar sites and are not illustrating any intrinsic value. When the LBAP targets were addressed the broad method was applied as described in Section 11.3.3, but only to the selection of sites to which each LBAP objective applied. The GIS was analysed to identify sites that were relevant to each of the LBAP objectives. Subsequently all calculations, scoring, relativisation and scaling by maximum were carried within selections of sites for each objective. For example within LBAP objective 1, examining sites classed as ASNW with Upland Oakwood present, and which were not already in favourable condition, were classed as suitable for this objective and were subjected to scoring. Therefore the "landscape" results and priority "sites" at each scale and are interpretable only within each individual LBAP objective. In order to select priority areas to meet each LBAP target all sites relevant to a particular objective were selected and ranked by the "combined" scores. Woods were selected in order of these scores until the LBAP target area had been allocated.

Table 11.4
Woodland site and landscape biodiversity summary scores: interpretation and conservation usage

	Biodiversity score	Conservation use
Site Biodiversity	Score indicating broad site biodiversity value	Score which can be used to rank woodlands / compartments by individual site biodiversity interest. Of use in ranking interest within woods of the same habitat type, such as existing ASNW or PAWS, or of non ancient plantation woods.
Landscape Biodiversity	Score representing the biodiversity interest of the surrounding woods, combined from scores from the separate buffer zones	Score which can be used to indicate the broad woodland biodiversity interest which is present in the surrounding landscape (combined from a number of focal scales). This has several potential uses. Sites with higher landscape biodiversity scores can be expected to have higher functional woodland species connectivity, at a number of scales. Existing semi-natural sites have an importance as sources of native woodland species. For plantations (e.g. potential restoration) the score can represent the ease with which sites may be colonised by native woodland species / and / or the size of the local native woodland species populations likely to be able to colonise a restored site. Sites with low landscape scores have low functional connectivity of woodland at the scales examined. The score can be examined separately from current site score to examine the potential interest of sites, especially useful when examining sites within a particular habitat type.
Landscape buffer biodiversity	Score representing the biodiversity interest in a single buffer	The separate landscape buffer biodiversity scores can be used in preference to the landscape biodiversity score when particular buffer landscape-scales are of interest. Buffers were calculated at: 1km, 500m, 100m, 20m.
Combined biodiversity	Combined site and total landscape score, with equal weighting	This score shows both the current site value, and the value derived from site context. Sites with high scores have high current site based biodiversity interest and are also highly functionally connected at the scales examined, and therefore are most likely to be able to exchange species / allow species to colonise new sites, or be colonised by additional native species if restored. Examination of sites importance on this score in addition to the separate site and landscape based scores allows the relative importance of site or landscape based conservation priorities to be examined.

11.4 Strategy results

The results of the identification of priority Dark Peak woodland conservation areas, for each of the four LBAP objectives, are illustrated in Fig 11.3–11.8. These illustrate priority woods identified using the "combined" biodiversity scores. Priority areas identified using the individual scores (site, landscape) and the "effects" scores are also illustrated within layouts and the GIS files on the accompanying GIS CD. The model results have potential to be utilised in different ways, depending on the perceived importance of colonisation versus existence of existing species interest within woodlands, and of likely target species groups. If woodland species interest is assumed already to occur within established woodland sites, or planning aims to examine particular woodland species which are able to disperse widely then the site scores alone could be used to indicate potential site interest. Where particular species groups are the focus of conservation then one of the scores developed from the most similar focal groups from the landscape buffers could be used for scoring to examine potential colonisation processes. The results of the combined site and landscape scoring are presented here to illustrate the method, with reference to a strategy where biodiversity planning is based on an assessment of current and potential future woodland biodiversity site levels, including assessment of relative species connectivity levels across a range of species movement and dispersal abilities.

11.4.1 LBAP Objective 1: conservation of ASNW sites

The Peak District target was to initiate measures to bring 30% (189ha) of the ASNW resource into favourable condition. Of the 1,124ha of ancient woodland, 780ha held Upland Oakwood habitat, of which 144ha was ASNW in favourable condition (Table 11.5, Fig 11.3). Depending on how the total resource is considered, between 15% and 34% of the potential Upland Oakwood resource is currently in favourable condition (Table 11.6). Following scoring 193ha of priority ASNW at 50 sites was identified that are currently not in favourable condition, and are priority areas for conservation (Fig 11.4).

Table 11.5
Habitat occurrence and favourable condition status of established woodland on Dark Peak ancient woodland sites. (AW = ancient woodland, ASNW = ancient semi-natural woodland, PAWS = plantation on ancient woodland site).

Compartment	Total		ASNW		PAWS	
	N	Area (ha)	N	Area (ha)	N	Area (ha)
Total AW habitat	308	1,124	122	531	186	593
AW Surveyed	302	1,098	118	512	184	586
Upland Oakwood present	178	780	108	490	70	290
Upland Oakwood as dominant habitat	106	478	94	429	12	49
Upland Oakwood, dominant habitat: favourable condition	20	164	19	144	1	20

Footnote = no sites occurred that were in favourable condition but had UO as present, but not as the main habitat.

Table 11.6
Upland Oakwood ancient woodland in favourable condition (164 ha) as % of available resources. (AW = ancient woodland).

Favourable condition %	N	Area (ha)	%
Total AW habitat	308	1,124	15%
AW Surveyed	302	1,098	15%
Upland Oakwood present	178	780	21%
Upland Oakwood as dominant habitat	106	478	34%

11.4.2 LBAP objective 2: conservation of existing non-ancient semi-natural woodland

Out of the 1,324ha of existing semi-natural woodland to which the LBAP Objective applied, 133ha at 28 sites were identified for priority conservation action (Fig 11.5).

11.4.3 LBAP objective 3: restoration of PAWS sites to native woodland

The Dark Peak has a resource of approximately 637ha of PAWS sites. Implementation of the scoring strategy identified 100ha of priority woods at 18 sites (Fig 11.6).

11.4.4 LBAP Objective 4: creation of new native woodland

The broader areas suitable for native woodland creation or conversion occupy almost 14,000ha (Table 11.7). Splitting the objective identified initial opportunity areas for creation sites of 3,124ha and for conversion sites of 2,933ha (Table 11.7) (Fig 11.2). Implementation of the scoring strategy identified 134ha at 44 sites for woodland conversion and 173ha at 10 sites for creation sites (Fig 11.7, Fig 11.8).

Table 11.7
Dark Peak wood creation / conversion opportunities. LBAP Objective 4, a: open ground, b: plantations in clough landscape zones.

Conversion / creation sites within cloughs	Area (ha)	% Dark Peak
Total potential suitable creation / conversion habitats within cloughs (open ground and plantation)	13,888	16%
Total LBAP Objective 4a: woodland creation sites (semi-woodland and open ground habitats)	10,949	13%
Potential priority (4ha+) LBAP Objective 4a: woodland creation sites	3,124	04%
LBAP Objective 4b: woodland conversion sites (plantations in cloughs)	2,933	03%

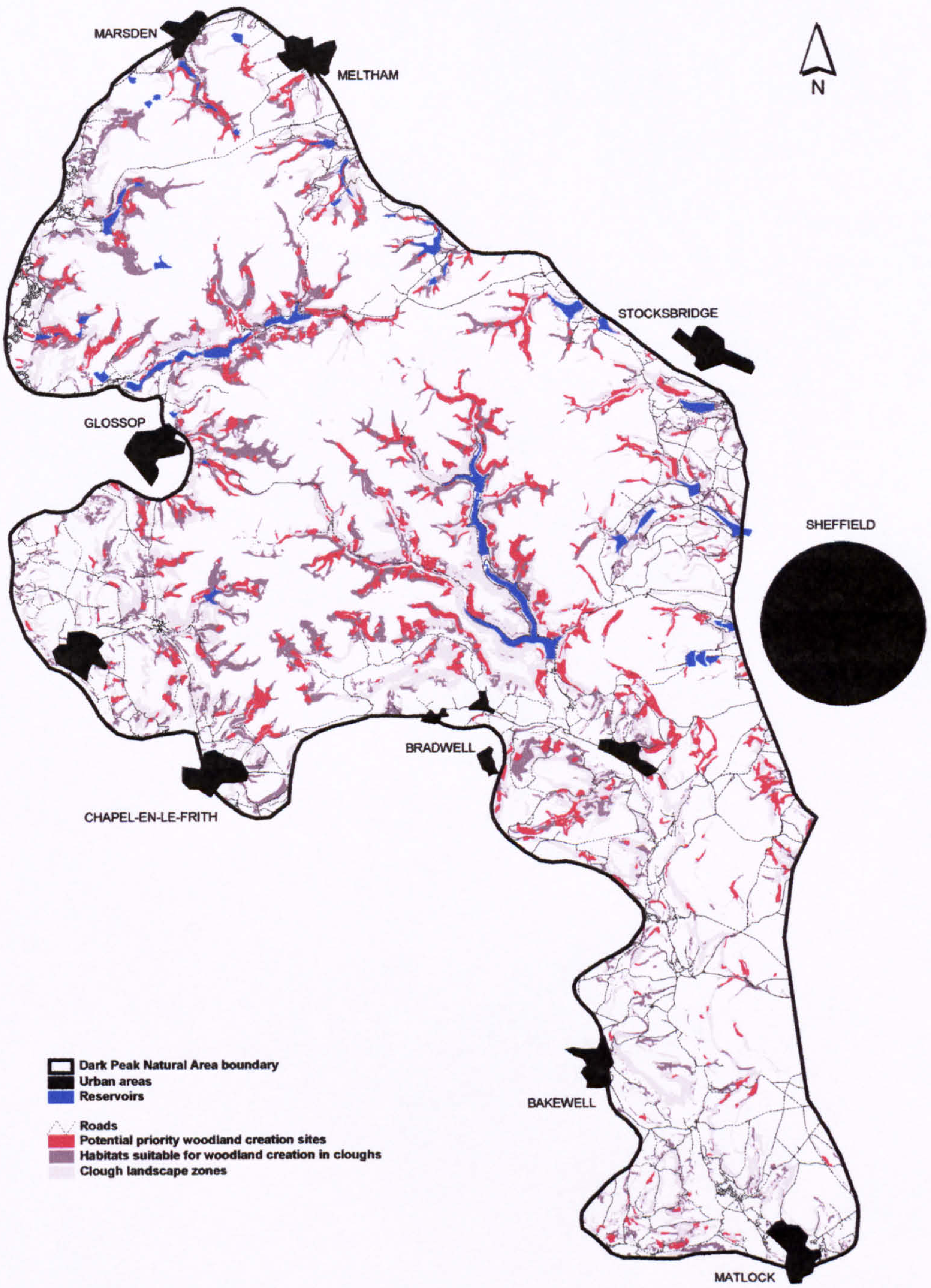


Figure 11.2
LBAP Objective 4 areas
(See GIS CD for full scale GIS files and images).

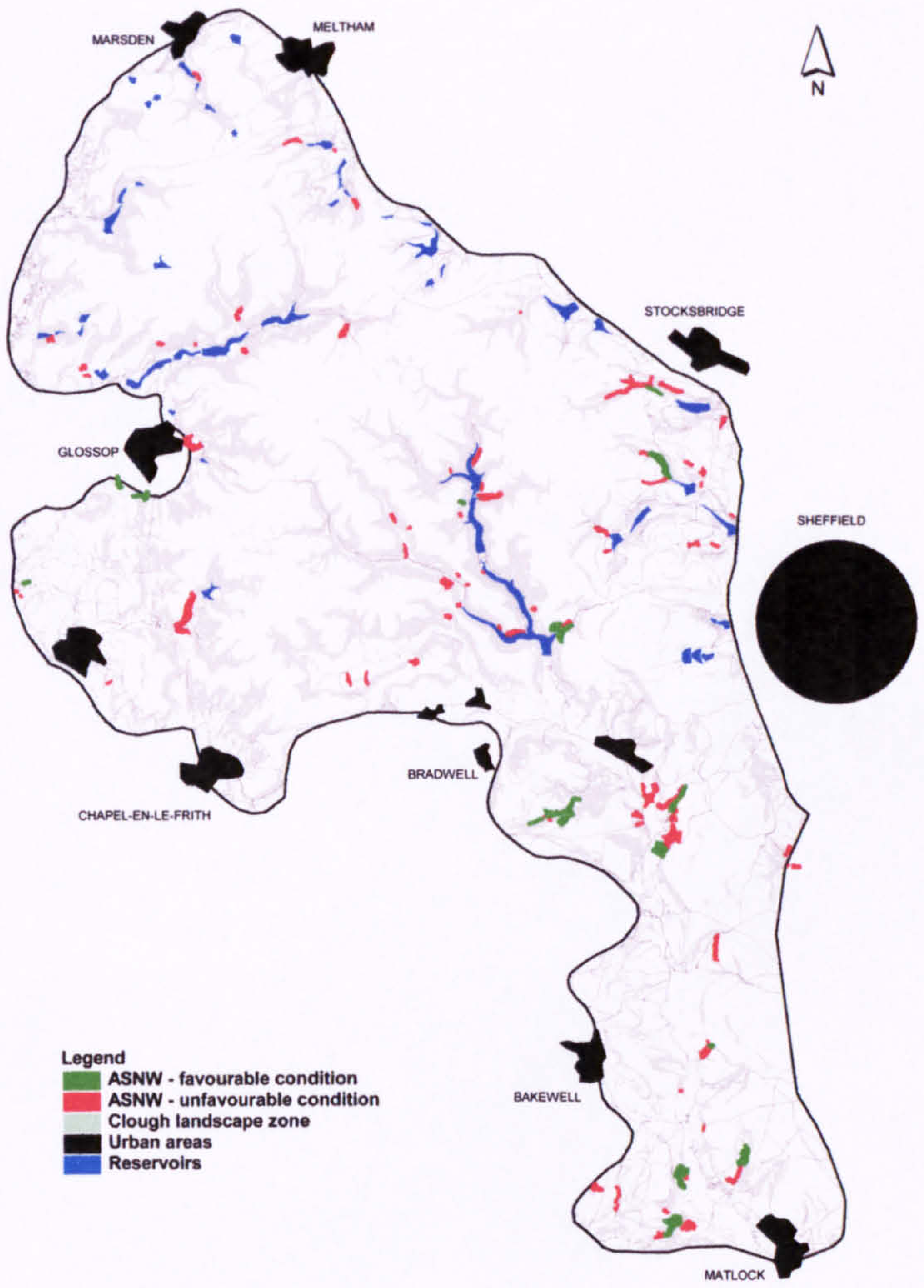


Figure 11.3
LBAP Objective 1: Dark Peak Ancient Semi-Natural Woodland (ASNW) sites in favourable condition. (See GIS CD for full scale GIS files and images).

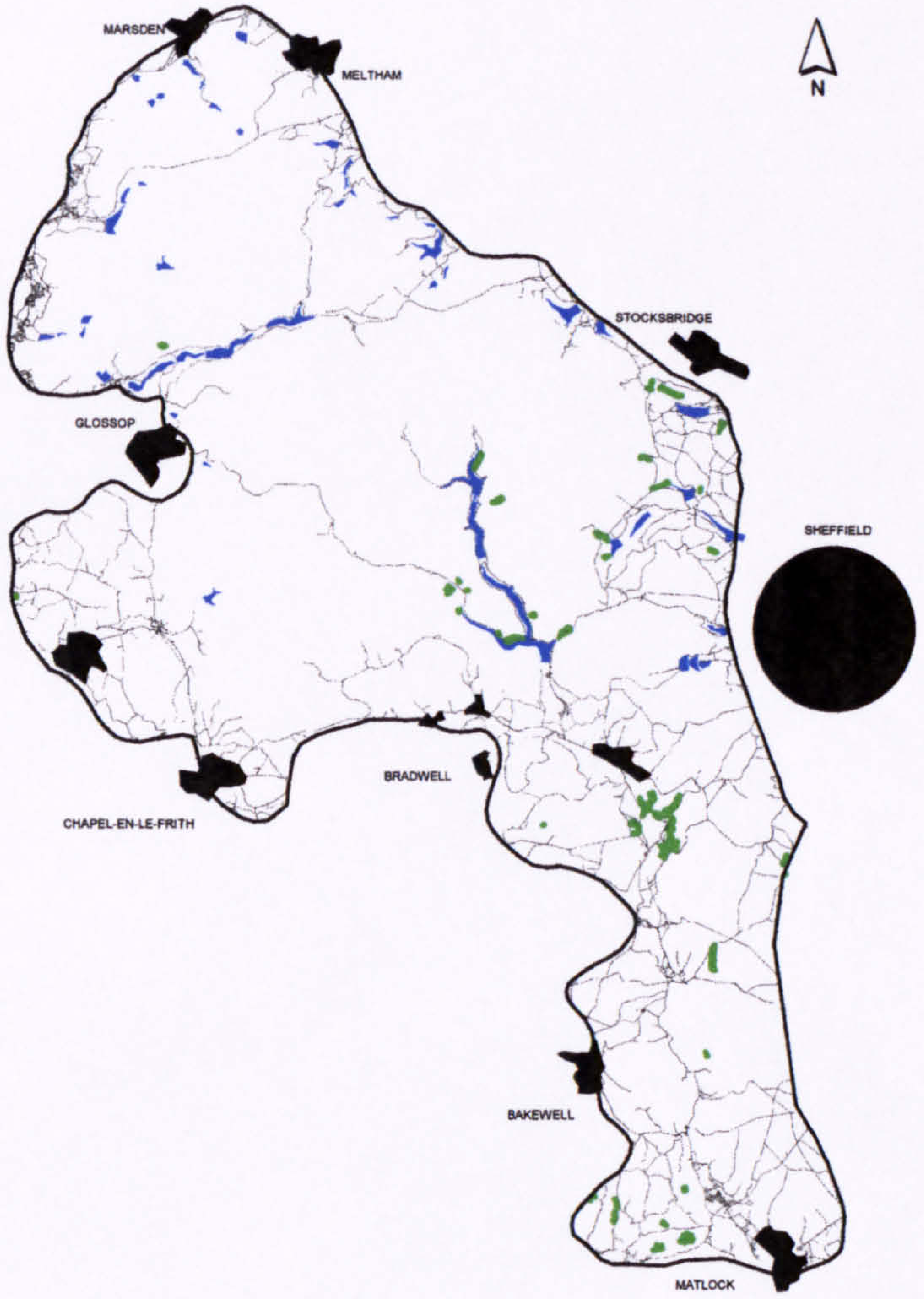


Figure 11.4
LBAP Objective 1: Undertaking conservation to bring ASNW into favourable condition. Priority Dark Peak sites (193 ha at 50 sites), based upon biodiversity combined "site" and "landscape" scores. (See GIS CD for full scale GIS files and images).

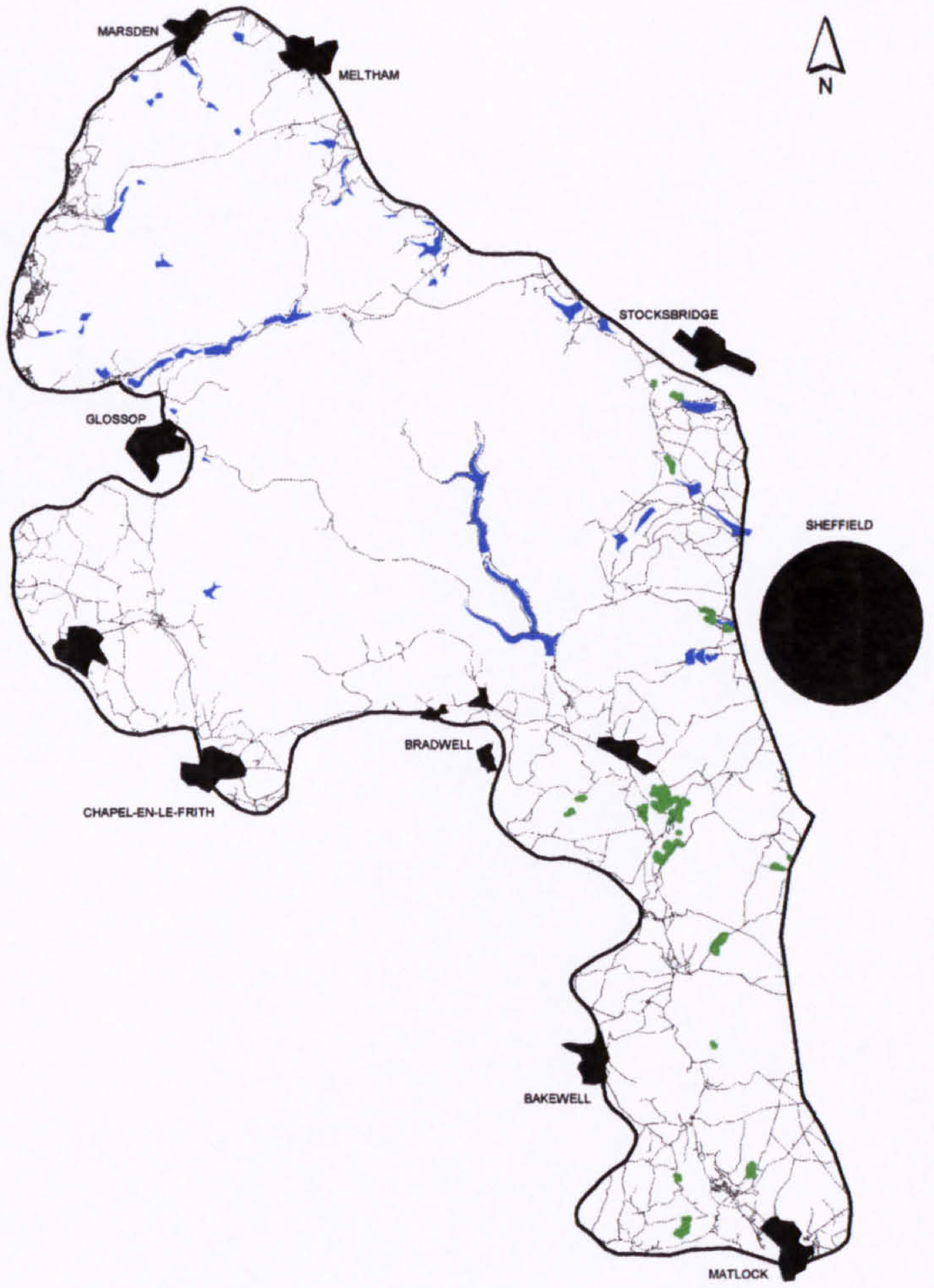


Figure 11.5
LBAP Objective 2: Bringing non-ancient semi-natural woodland into favourable management. Priority Dark Peak sites (133 ha at 28 sites), based upon combined biodiversity "site" and "landscape" scores. (See GIS CD for full scale GIS files and images).

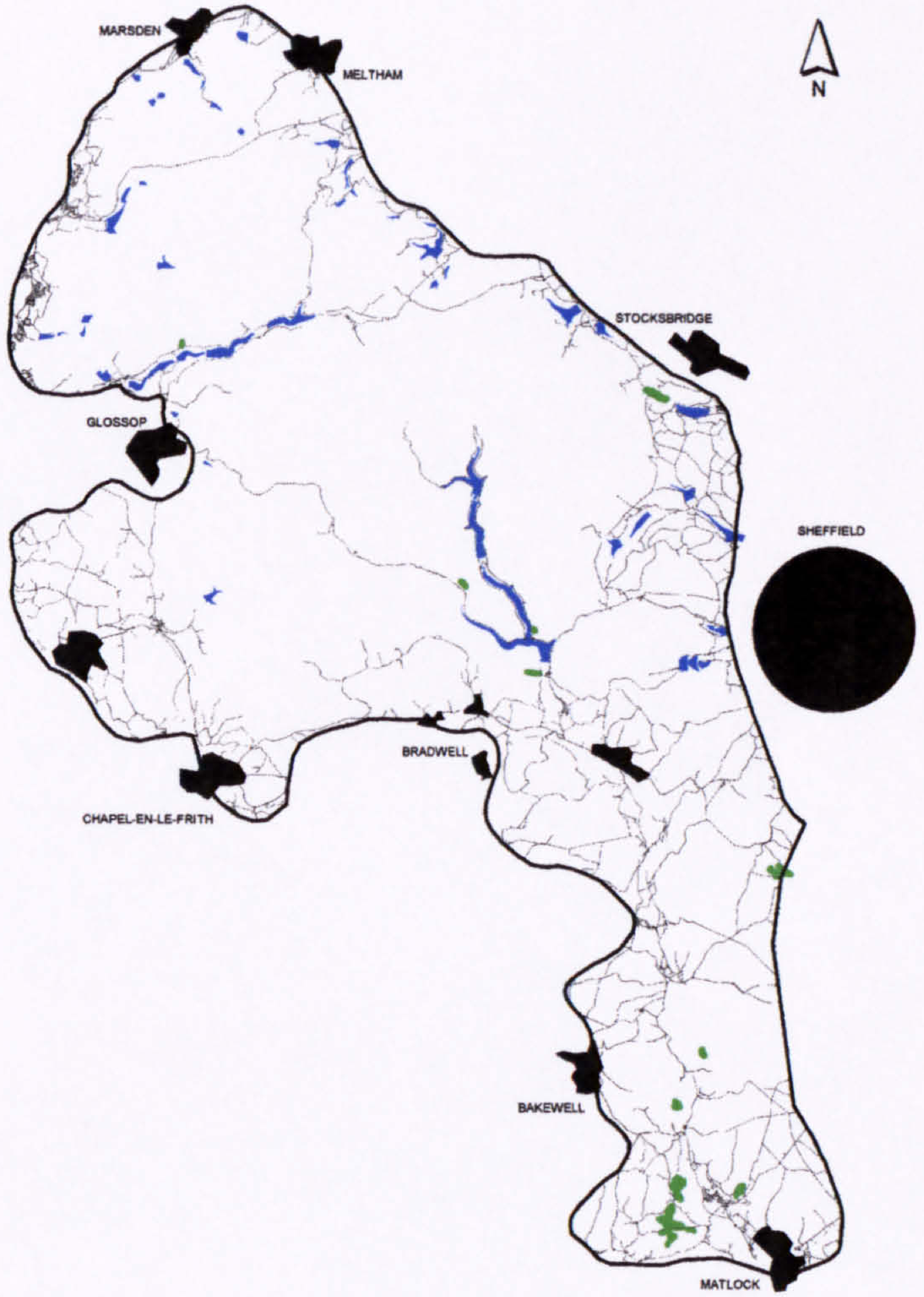


Figure 11.6
LBAP Objective 3: Convert PAWS back to native semi-natural woodland. Priority Dark Peak sites (100 ha at 18 sites), based upon combined biodiversity "site" and "landscape" scores. (See GIS CD for full scale GIS files and images).

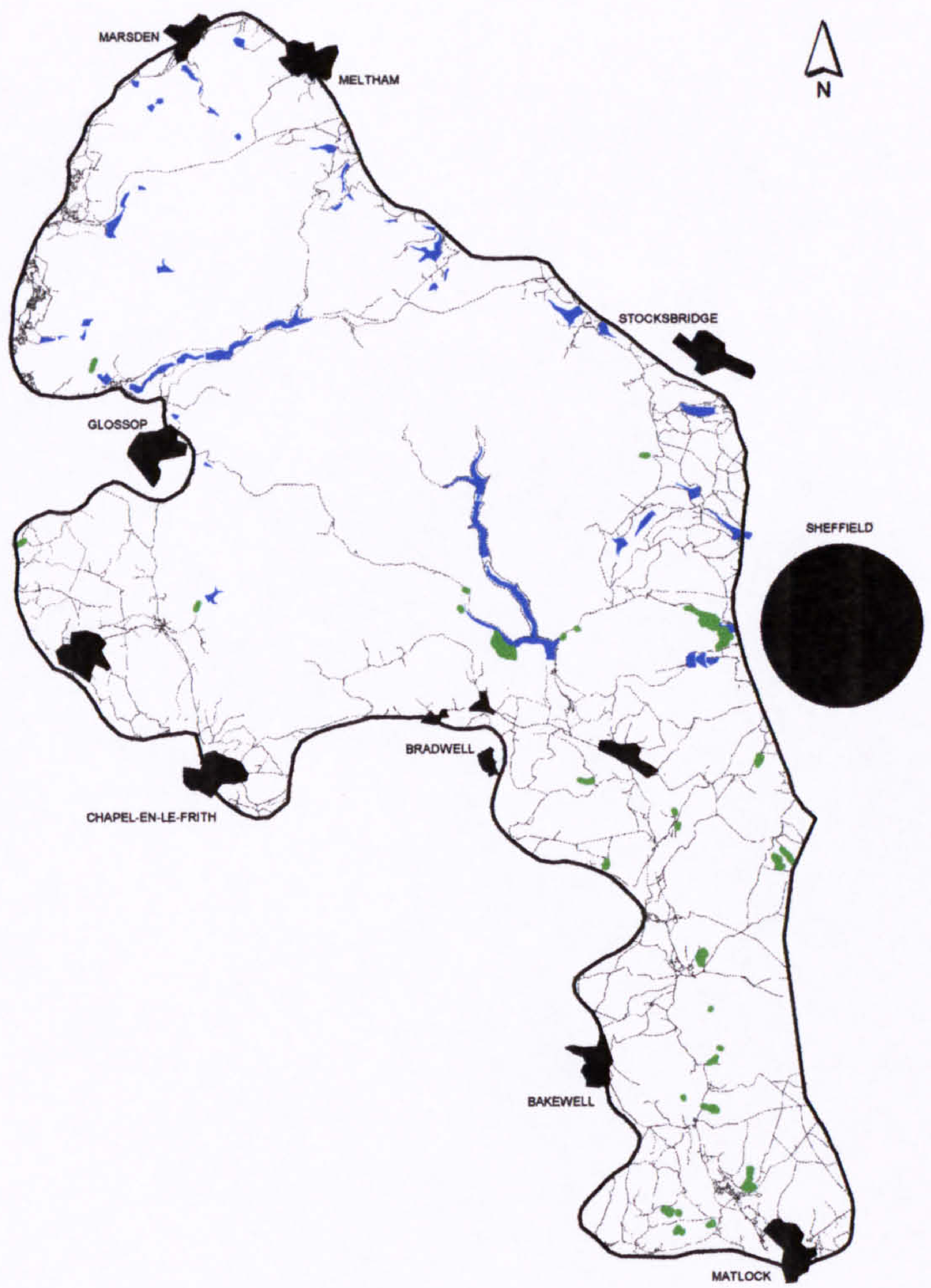


Figure 11.7
LBAP Objective 4: Creation of new native semi-natural woodland. Plantation sites. Priority Dark Peak sites (134 ha at 44 sites), based upon combined biodiversity "site" and "landscape" scores. (See GIS CD for full scale GIS files and images).

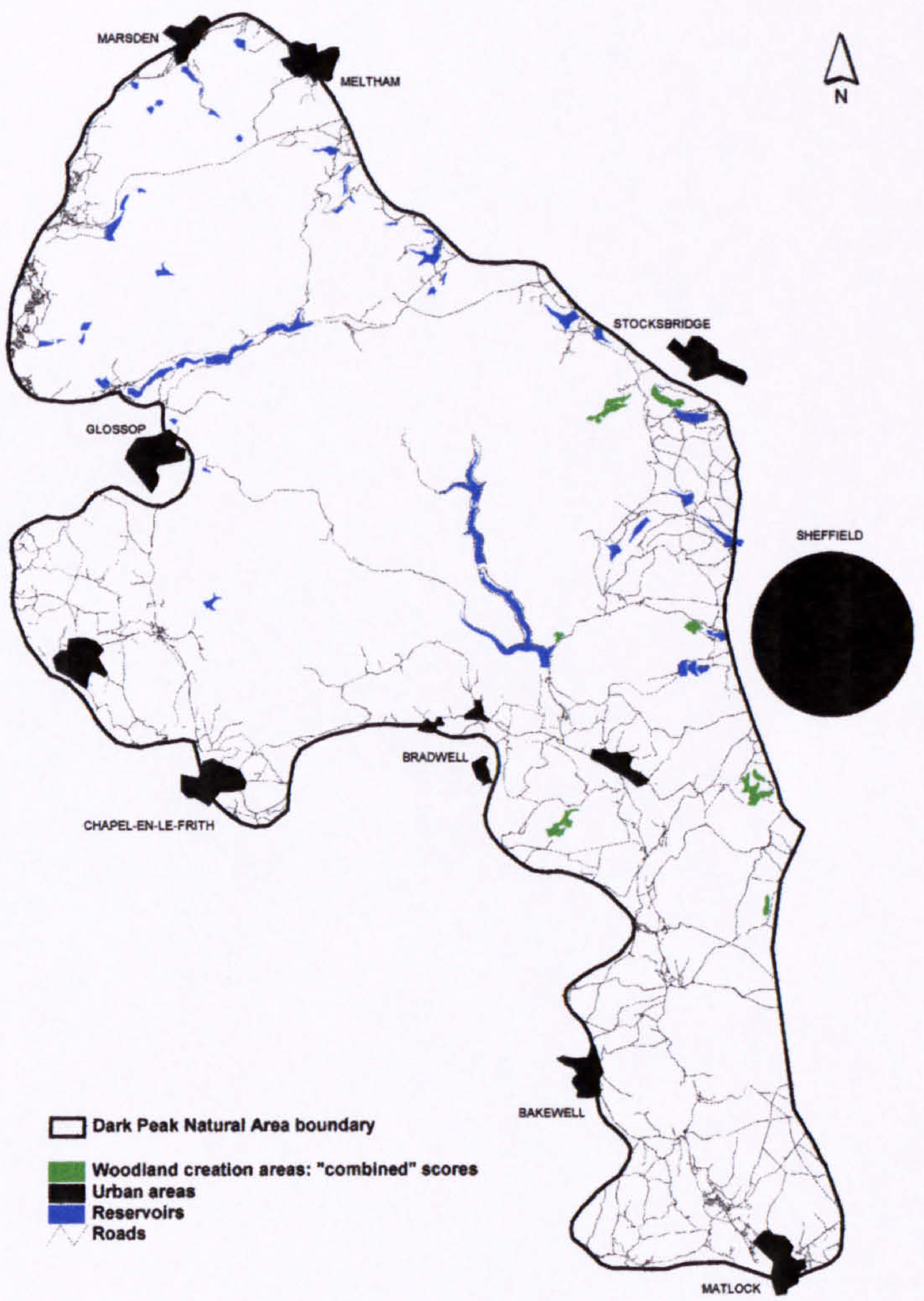


Figure 11.8
LBAP Objective 4: Creation of new native semi-natural woodland: open ground habitats. Priority Dark Peak sites (173 ha at 10 sites), based upon combined biodiversity "site" and "landscape" scores. Only sites > 4ha were scored. (See GIS CD for full scale GIS files and images).

11.5 Discussion

11.5.1 Woodland conservation strategies: consensus, limitations and research priorities

The UK Biodiversity Action Plan (BAP) process has led to the strategic consideration of woodland conservation at national and local scales, with targets set for woodland *conservation*, *restoration* and *creation* (Peak District National Park Authority, 2002, The UK Biodiversity Steering Group, 1995b). Increased awareness of the needs for both active restoration of habitats and addressing strategies at the landscape-scale, combined with policy drivers, have provided an arena for the use of landscape ecology driven landscape planning in BAP conservation (United Nations Secretariat of the Convention on Biological Diversity, 2001, Hawkins and Selman, 2002, Selman, 1996, Latham, 2003, Watts et al., 2005, Hamilton and Selman, 2005, Baskent and Keles, 2005, Ferris and Purdy, 2003). Several non-woodland studies in England have investigated the potential for spatial location targeting of uptake of agri-environment schemes to benefit conservation of habitats at the landscape-scale (Brown et al., 1998, Thompson et al., 1999c) and some have explicitly included BAP planning aims (Lee et al., 2001b, Bayliss et al., 2003). A range of woodland studies have also addressed woodland BAP aims (Gkaraveli et al., 2004, Griffiths et al., 2004b, Lee et al., 2002, Purdy and Ferris, 1999, Thompson et al., 2001b). BAP related GIS or landscape planning initiatives have been undertaken in England including research under the EU LifeScapes project, where English Nature undertook GIS mapping in conjunction with partners in the Suffolk heaths, Chilterns and Forest of Bowland. Several projects and conservation organisations have also undertaken "habitat opportunity mapping" for conservation at the landscape-scale, recently reviewed by RSPB (RSPB, 2004) and English Nature (Saunders and Parfitt, 2005). This range of initiatives have resulted in a number of Biodiversity planning maps e.g. (Lee et al., 2001a).

BAP related studies undertaken have utilised a range of methods (Chapter 6, Table 6.2), but a distinction exists between studies examining single habitat or woodland types and studies addressing multiple habitats. The level of detail examined tends to be less when multiple habitats are examined, but such studies do note that such an approach allows an examination of potential conflicts between priorities for key BAP habitats (Lee et al., 2001a). Recent work has shown that where spatial planning is incorporated within conservation action there are a number of benefits. Studies examining the effects of applying a strategic approach to new woodland creation have shown landscape planning can lead to wooded landscapes that are better connected than those that develop by random owner uptake of woodland creation schemes (Thompson et al., 1999b, Buckley and Fraser, 1998, Good et al., 1997). Additionally tests of forest reserve planning with and without spatial elements have shown the benefits of incorporating spatial planning (Siitonen et al., 2002). Reviews note that the use of spatial consideration in forestry and biodiversity planning is more important at regional scales, beyond that of stand level or individual ownership, promoting potential landowner co-operation

(Kurttila, 2001). However whilst multi-ownership planning may be of high benefit it may also be a constraint where potential planning projects are limited by land ownership boundaries (Naesset, 1997). Therefore even where such schemes are implemented they may be unable to take a true landscape approach unless adjacent landowners actively integrate their management plans as has only occurred in novel schemes such as the Alport Valley (Peak District) (Anon, 2002a). Alternatively, as with the spatial targeting of agri-environment schemes, some studies have noted the potential for landscape planning to actively target uptake of Woodland Grant Schemes (WGS) (Ray et al., 2004a, Ray et al., 2003b).

The range of studies already undertaken clearly show the potential for utilising landscape planning to aid woodland BAP delivery. Some consensus exists in key stages in suitable methodologies, such as utilising landscape ecology inspired values in attributing ecological value to woodland sites and landscapes (Hampson and Peterken, 1998, Smithers, 2000, Peterken, 2002b, Purdy and Ferris, 1999, Gkaraveli et al., 2004, Griffiths et al., 2004b), to incorporating assessment of existing woodland landscape and quality in determining relative conservation priorities (Gkaraveli et al., 2001, Good et al., 1997, Griffiths et al., 2004b, Latham, 2003, Peterken, 2002a). However the details of relative scoring between sites, the relative priority to identifying actual land parcels and ownership boundaries, or mapping broad areas, and the importance of small reserves or woodlands to conservation remain debated and have been variously applied (Purdy and Ferris, 1999, Latham, 2003, Gkaraveli et al., 2004, Lee et al., 2001b), often with a lack of scoring value justification (Purdy and Ferris, 1999, Latham, 2003). Problems therefore, are a lack of grounding or confidence that scoring justification relates to the study landscape in question, when they may derive from studies or theories proposed elsewhere. However consensus has also emerged within other areas. Several studies in particular have highlighted the potential of the riparian network for enhancing woodland connectivity through woodland conversion, restoration and creation, especially in the uplands (Cairngorms Partnership, 1999, Ray et al., 2003b, Hampson and Peterken, 1998, Good et al., 1997, Peterken, 1999, Peterken, 2002a, Peterken, 2002b), due to the inherent connectivity of riparian systems, the association of woodland with riparian areas, stream valleys and steep slopes and additional benefit such as aquatic transport of seeds and the regular use of riparian networks as movement corridors by mammal fauna both aiding likely seed dispersal and potential colonisation / enhancement of created / restored sites. Several studies have also now incorporated consideration of the landscape matrix, a key area requiring consideration, identified during the habitat fragmentation literature review (Chapter 4). The Woodland Trust used assessment of landscape matrix semi-natural areas to target woodland creation sites (The Woodland Trust, 2002), and several other studies have used information on the occurrence of matrix habitats around woodland sites to determine relative importance of expansion or colonisation (Gkaraveli et al., 2004, Latham et al., 2004, Lee et al., 2002). There has thus been a trend within studies, of a move away from pure assessment of structural connectivity, to such increasingly functional ecology based approaches (Lambeck, 1997, Ray et al., 2004b, Latham et al., 2004). However many studies incorporate various abiotic features as relating to habitat value and quality without clear evidence of their value, such as woodland size and isolation in assessing and designing landscapes (Thompson et al., 2001b, Lee et al., 2002, Griffiths et al., 2004b). Complications exist in such blanket use of abiotic values in that there is some suggestion that small woods may remain ecologically valuable, especially botanically and therefore also require conservation management and consideration within plans (Bennett et al., 2004, Dolman and Fuller, 2003, Lawesson et al., 1998, Gotmark and Thorell, 2003) (See Chapter 4). Additionally while much consensus exists on the importance of direct structural connectivity or very minimal functional isolation between woods for botanical colonisation and migration (Grashof-Bokdam and Geerstema, 1998, Peterken and Game, 1984, Mouflis and Buckley, 2004, Jacquemyn et al., 2003) rather less consensus exists for other species groups, such as the fauna.

These issues highlight the importance of clear clarification and justification of any scoring or prioritisation strategies in relation to species, species groups, life history strategies or focal species types. Alternatively other methods must be sought and justified, for example utilising key factors such as habitat quality, illustrated by the current study as linked to broad biodiversity relationships, or simplifying species-environment relationships by using life-history types of species guilds to target and prioritise based areas (Hansen and Urban, 1992).

More work also needs to be carried out on incorporating the different effects of habitat quality, which can arguably only be tackled with a detailed habitat-specific approach rather than considering multiple, or simple broad and undefined "woodland" habitats. Work therefore was required to more accurately link measures of habitat quality, habitat heterogeneity, woodland structure and local conservation value. Research questions arose that included: what is the relationship between the effects of management and of existing habitat quality versus spatial and fragmentation effects? Such aspects were also affected by consideration of the relative target species and habitats to which strategies were aimed, and whether particular species population structure, such as metapopulations were in existence and would affect the validity of particular methods. However the difficulty of accurately predicting the species population forms in a landscape is acknowledged and will almost always be beyond the scope of applied landscape-scale conservation projects, therefore a range of informed assumptions must be made. Some studies have included assessment considering species that are now extinct in a landscape, considering re-introduction values (Ratcliffe et al., 1998), and studies have considered the impact of woodland expansion on open ground species using generic focal species profiles (Ray et al., 2004b, Ray et al., 2004a).

A critical factor in the range of schemes currently implemented is study scale. Schemes have addressed scale variously by examining national or regional priorities and by utilising data with widely differing resolution. Where studies set minimum size and isolation limits they tie in any assessment of landscape structure to a limited set of species perception and landscape-scale interactions (Wiens, 1989, Wiens and Milne, 1989, With, 1994). It is often unclear, for example, if national studies utilising 10km grids to examine landscapes e.g. (Smithers, 2000) are appropriate for national planning of woodland species, when a range of other scales / data resolution have been addressed (See Chapter 4). Often study scale has simply been set by data availability or utilisation of existing study scales or mapping grids, and the effects of this must be considered in the interpretation of such studies. Few studies have examined the effect of study scale choice on practical conservation scheme application.

In contrast to strategic and theoretical planning frameworks some studies examining BAP and landscape-scale woodland conservation have examined woodland creation by simply focussing on intensive negotiations with landowners rather than broad ecology based planning initiatives in Dartmoor, NP, (Ince, 2001) and Shropshire (Thompson et al., 1999a). The focus in these studies allows equal or greater importance to be given to landowner awareness or interest in addition to ecological importance. In contrast the studies initially taking a more purely landscape ecology informed selection procedures and strategies once areas have been identified, classified and scored implementation of such schemes are strongly effected by biogeographic and socio-economic factors at the local scale (Hampson and Peterken, 1998). Additionally Hampson and Peterken (1998) noted their initial Forest Habitat Network planning was broad and acknowledged that important factors likely to influence the potential use of such forest habitat networks would apply at local scales, including woodland type, structure and edaphic and climatic factors. It therefore remains debatable and open to investigation as to the ways in which such socio-economic factors are consider within any BAP focussed conservation planning. e.g. whether such methods are incorporated a priori or are left for examination and addressing a posteriori, which may then require further funding and work to implement. It is clear that an element of flexibility, allowance or over-selection of target areas could be planned to incorporate effects of owner uptake, socio-economic, changing agri-environment schemes, and potential climate change impacts could usefully be planned within scoring and optimization or mapping strategies. Additionally the exact relationship between study scale and processes effecting local landscape composition and values must be considered and assessed in relation to the effects of data quality and resolution on project results. These are all areas that should be clearly noted and stated within BAP project methodologies.

Final points in the selection of appropriate strategy methods and implementation relate to proof of effectiveness, experimental rigour and monitoring. With conservation action and analysis occurring at the landscape-scale rigorous experimental testing of different conservation strategies is not possible, either ethically or financially. Therefore such studies must make use of a combination of evidence from existing detailed auto-ecological studies (Chapter 4) and informed choice though examination of the implications of landscape ecology modelling studies (Chapter 3). There may be trade-offs between the costs and benefits of detailed studies, such as exacting studies of species-habitat relationships, and the transferability of methods between different areas, or between different species or focal groups. High investment in knowledge on one group or area may ultimately be limiting to others. Methodologies chosen must therefore assess the reliability of earlier studies, in terms of study accuracy but also in terms of the applicability and transferability of information to the particular study landscape and scales in question. Much use is often made of various surrogate species and landscape ecology abiotic value based surrogate / indicator methods. Such methods may either be accepted as proven based upon the existing literature or elements of these assumptions may be tested within the study area to confirm and inform the evolving strategy methodology. Ultimately however it will be impossible to rigorously test all the assumptions of a landscape-based conservation strategy. Some authors have acknowledged that such methods and strategies may evolve and alter with time and have suggested that their success be tested by regular monitoring of communities and habitats once they have been applied (Lambeck, 1997). Other authors have noted that it may be beneficial to fully accept the potential limitations of unproven methods and therefore to apply mixed methodologies to a landscape as a form of "risk spreading" (Lindenmayer et al., 2002). Past FHN studies have made suggestions towards this approach by noting that while FHN approaches may be suitable at larger scales, that at more local scales, a more functional, landscape ecology approach, would be suitable (Cairngorms Partnership, 1999). A suitable approach could therefore potentially incorporate elements of landscape ecology informed planning, landscape assessment and hierarchical landscape classification combined with more detailed functional ecology assessment and potential surrogate species methods at finer scales. This is the scope of the study presented here. Key aspects include how additional clarity has been given to the target of conservation action, the particular local woodland types being conserved, and how focal species / surrogate species methods were enhanced to allow incorporation of habitat quality. Also it is rare for studies to actually examine in combination the different BAP strategies of conservation, restoration and creation and how such priorities interact. This potential for applying mixed methodologies and mixed scales has been noted by several studies.

11.5.2. Strategy development, implementation and comparison to previous studies

11.5.2.1 Methodology overview and application to LBAP aims

The current woodland conservation strategy was developed to map and prioritise areas for woodland conservation, restoration and creation, illustrating the implementation of a single

Habitat Action Plan for a Natural Area. The strategy follows from studies indicating that spatially targeted woodland conservation is beneficial and preferable to random uptake of action (Buckley and Fraser, 1998, Lee and Thompson, 2005). The most similar studies to the current research are perhaps: (Jerram, 1998, Good et al., 1997, Purdy and Ferris, 1999, Thompson et al., 2001b, Gkaraveli et al., 2004, Griffiths et al., 2004b, Nikolakaki, 2004). However no other studies have developed such a comprehensive strategy based upon habitat quality–biodiversity relationships extracted from woodland study at the Natural Area scale. The methodology incorporated mixed methodologies from several areas identified in the literature review (Chapter 6). Inspiration was taken from landscape ecology studies, but broad landscape ecology rules were not implemented without testing. The work followed earlier UK studies (Ratcliffe et al., 1998) that recognised that planning could be based on broad biodiversity surrogates combined to give an ecosystem approach where derived priority could apply to a wide variety of woodland species. The study was based upon measurement of a range of woodland biodiversity indicators suggested for potential use in Britain (Ferris and Humphrey, 1999).

The study used a combination of landscape assessment, habitat modelling (incorporating habitat quality effects) with isolation measures inspired by focal and generic focal species studies (Lambeck, 1997, Ray et al., 2004b, Latham et al., 2004). The literature review showed that habitat quality should be incorporated in planning (Buckley and Fraser, 1998) (p. 56), (Ray et al., 2004b) (p. 219) and a move was required away from the use of simple structural connectivity assessment at limited scales (Vos et al., 2001); therefore a functional connectivity approach was taken, implemented at multiple scales. The study implemented the conservation strategy using elements of woodland conservation zone mapping and site priority scoring (See Chapter 6). Vector polygons were used within a GIS system, prioritised by relative scoring to identify sites based entirely on mapped polygons unlike earlier studies where parts of the methodology used raster grid cell methods (Purdy and Ferris, 1999, Gkaraveli et al., 2004).

The study is unusual in addressing all principal BAP aims of conservation, restoration and creation. Only work on Upland Ashwoods on the Isle of Mull (Gray and Stone, 2003) and in the Cairngorms (Ratcliffe et al., 1998) have touched on implementation of all three aims, although with less specific prioritisation, and simpler methods. Several studies have examined both restoration and creation to varying degrees of detail: (Gkaraveli et al., 2004, Griffiths et al., 2004b, Peterken, 2000b, Ray et al., 2004b, Smithers, 2000, Peterken, 1999, Purdy and Ferris, 1999), or both conservation and restoration (Thompson et al., 2001b), or conservation and creation (van Rooij et al., 2004, Watson et al., 2001, Jerram, 1998, Peterken, 2002a), while the remaining studies have concentrated on woodland creation: (Lee et al., 2002, Nikolakaki, 2001, Nikolakaki, 2004, Buckley and Fraser, 1998, Cairngorms Partnership, 1999, Good et al., 1997, van Elegem et al., 2002) (See Table 6.2, Chapter 6). This emphasis on creation within the literature follows the frequent use of GIS in placement / selection studies where methods were easily transferable to landscape planning. Less work has been conducted on analysing woodland habitat or conservation quality of existing sites. The abundance of creation research reflects the methodological opportunities of examining habitat creation sites, even though much theory and research suggests the main conservation priority in most areas lies with conservation and enhancement of the existing research, followed by restoration with creation often coming last in priority terms (Humphrey, 2003, Pryor, 2003).

11.5.2.2 Site biodiversity prediction models and landscape ecology theory justification

The current research strategy aimed to identify sites with existing richness or potential at both the site and the landscape-scale in order to allow sites to be chosen that contribute to the wider woodland network and avoid prioritisation being given to sites that are only important in local terms. The premise of the strategy was that at a particular scale the woodland conservation value of a site was affected both by its current site status and the surrounding woodland network. By analysing the factors driving site biodiversity at the site scale, and investigating if deterministic features could be used to map biodiversity rather than factors such as area, then such biodiversity could be mapped across the woodland network, aiding conservation planning. This broad emphasis on consideration of values beyond the site scale has been shown by a number of recent studies (Thompson et al., 2001b, Lee et al., 2002) and is similar to the scoring method of the FC PAWS restoration guidance (Thompson et al., 2003), although that uses designations as indicators of quality. The current method predicted site biodiversity using abiotic indicators (principally habitat type and within-patch habitat quality), features which had been shown to be predictive of measured woodland biodiversity interest within the Natural Area (**Chapter 10**). Prediction within a GIS integrated multiple regression model in GIS (Jenness, 2006) allowed these biodiversity levels to be predicted and mapped across the Natural Area. The strategy was then applied to each of a set of woodland polygons in turn, according to the LBAP objective formulations.

Past studies involving similar prioritisation / mapping selection strategies have tended to base their analysis of woodland site value on either simple abiotic patch characteristics, e.g. area and isolation from other woods (Griffiths et al., 2004b, Nikolakaki, 2004, Gkaraveli et al., 2001) or on a combination of such abiotic values with scores based upon habitat type (e.g. broadleaved, vs. coniferous) and designations (e.g. SSSI, NR) (Purdy and Ferris, 1999, Gkaraveli et al., 2004). Such scoring systems tend to be based on broad landscape ecology rules combined with a range of studies indicating potential size thresholds, e.g. the studies by Peterken indicating how botanical diversity tends to increase with size at different step sizes (Peterken and Francis, 1999). However many studies do not justify their use of area and isolation thresholds (Purdy and Ferris, 1999, Griffiths et al., 2004b, Gkaraveli et al., 2004). This is acceptable for pilot studies investigating the potential of initial GIS strategies but becomes dangerous when applied conservation strategies are developed. The current study therefore aimed to ground such analysis in local woodland biodiversity–abiotic characteristic investigation, aiming to enhance the applicability and local focus of the study.

The current work followed earlier studies which showed it was possible to predict wood species richness from models based on environmental variables, for use in conservation strategy planning (Dumortier et al., 2002, Luoto et al., 2002). The study agreed with previous work which indicated that rather than numerous auto-ecological studies, that investigation of biodiversity and "well considered" independent variables can yield conservation principles (Honnay et al., 1999b). The present model, upon which the overall strategy development was based, was more effective than previous models using only GIS data to predict plant species richness in woods ($R^2 = 0.518$, $R^2 = 0.22$) (Dumortier et al., 2002, Thompson et al., 2001b). This work agrees with previous studies that have also found that patch area is unnecessary for biodiversity assessment / prediction and therefore emphasises that small but diverse woods can remain important for conservation planning e.g. (Honnay et al., 1999b).

The current study based assessment on links between a range of suggested British woodland biodiversity indicators from survey work and abiotic predictors of these, involving a theory-based test of common abiotic criteria, and whether area itself was a surrogate for internal patch deterministic factors. This evolved from early studies which showed how simple abiotic data types may be inadequate, and that the use of collated botanical species lists over long time periods, and from different sources, to represent biodiversity interest, was problematical e.g. (Lee et al., 2001b, Bayliss et al., 2003, Thompson et al., 2001b). The use of predicted biodiversity scores for individual woods, within the current work, allows relative values to be given not only to individual habitat types, but to individual polygons. The current strategy therefore uses a wider range of site values across the Natural Area, allowing both "site" scores and "landscape" scores to be of use for conservation planning. The study thus builds upon earlier studies that examined opportunities and constraints to woodland development and highlighted "priority" zones or areas where native woodland communities may occur due to environmental limits (Towers et al., 2001, Hester et al., 2003, Pyatt et al., 2001, Ray et al., 2003a). The present analysis builds upon such work by analysing the occurrence of factors that due to their potential deterministic / causal factors on biodiversity and woodland management intensity are linked to actual woodland biodiversity / quality value rather than just native woodland type occurrence. The strength of this methodology derives from its concentration on theory driven regression modelling, variable selection and testing, including comparative analysis of habitat quality–area variables rather than statistically driven model formulation (Tabachnick and Fidell, 2001), which is often seen in many studies. This allows more confidence in the model prediction compared to models built from statistical package selection which may result in random, statically efficient but biologically unrealistic factors being selected for prediction, even though the overall model prediction levels by such models may occasionally be higher (Luoto et al., 2002).

11.5.2.3 Strategy scales, landscape biodiversity scores calculation and functional connectivity

The method identified landscape scores from the occurrence and location of site biodiversity values using a landscape buffer system based upon collation of predicted values in nearby woods. The landscape score represents the sum quality of surrounding woodland biodiversity. The current study took inspiration and build upon the study by (Thompson et al., 2001b) which showed how the assumed patch area, shape and isolation links to woodland biodiversity were tested using botanical survey data. The current study differed however from (Thompson et al., 2001b) by using functional contrast within buffer zones around a site rather than shared perimeter values with land of different creation / conversion suitability and by modelling the biodiversity using habitat quality factors rather than area, shape and isolation. The study aimed to move beyond structural landscape assessment and planning research e.g. (Hampson and Peterken, 1998, Peterken et al., 1995) to include functional assessment from a semi-natural native woodland specialist species perspective (Wiens and Milne, 1989, With et al., 1997).

The current strategy methods use a sum system weighted by buffer landscape contrast to run a landscape biodiversity score to each wood polygon similar to a habitat quality version of the proximity score calculated by some such landscape metric programs such as Fragstats (McGarigal et al., 2002). This score reflect the amount and quality of woodland in the landscape surrounding a woodland site. Assuming movement ability within a particular buffer the calculation of this score is inspired by broad landscape ecology theory which recognises that landscape form, structure and permeability will affect species movement and presence (Farina, 1998, Forman and Gordon, 1986). The landscape score therefore reflects the availability of nearby woodland specialist "species pool", available for movement / colonisation, or which may use the current site as part of a wider habitat network. This broad indication of local habitat quality availability is the sole aim of such scoring and is not intended to explicitly state suitability for any particular species or group, although such use could be inferred by examination of the score at single buffer distance scales. This usage is similar therefore to the term "conservation potential" used to mean "those parts of the landscape which offer the greatest likelihood of being sources of species' populations" in (Thompson et al., 2001b).

The current buffer score system (Section 11.3.3), being based on individually predicted site scores, allows enhanced accuracy and less reliance on standard values for particular woodland biodiversity types. This is hoped to increase accuracy of the method, especially in the uplands where small but high biodiversity sites may be important.

The spatial scales and methods used in creating the landscape scores from the site scores were extracted from the literature as being applicable to woodland specialist species expected to occur within the Natural Area. The strategy scoring was applied such that analysis at the 4 scales of 20m, 100m, 500m and 1km assumed that, at each scale, movement could occur from the focal site to other woods within that distance. The total woodland biodiversity within each focal buffer distance was altered to give a functional connectivity perspective by reducing the biodiversity levels by the mean contrast value in the buffer. This was to ensure functional connectivity elements were incorporated, which are believed to be justifiable for the majority of woodland specialist species. Even wider ranging mobile bird species and bats which have been shown to follow woodland and semi-woodland features when moving between woods (Greenaway, 2004, Walsh and Harris, 1996, Forestry Commission, 2005, Hinsley et al., 1994) and thus will be affected y contrast levels in the buffer zone. A range of recent studies have incorporated functional connectivity measures with varying similarity to the current method of using landscape matrix contrast values to infer potential species movement: (Latham et al., 2004, Ray et al., 2004b, van Rooij et al., 2004, Nikolakaki, 2004). The functional method is preferable to using structural assessment / isolation measures for the majority of species for which planning is likely to occur. Early studies were to focussed on structural assessment of wood cover e.g. (Peterken, 1999).

The connectivity methods is justified by the fact that the study aims to reflect the likely species pool / woodland network value of sites at different scales by reflecting the level of woodland biodiversity quality likely to occur around a site at a particular scale and thus be available for colonisation / movement . The zones are generalised and represent ranges of species from dispersal limited to far dispersing species. The method is able to reflect whether a site for example has a high amount of woodland biodiversity value in close proximity (e.g. large extent of semi-natural broadleaved woodland within 20m) which is likely to indicate a high potential for movement of ground flora or invertebrates between sites – e.g. colonisation from the semi-natural source to a restored / converted/ creation receptor site.

The use of the landscape score created from 4 scales aims to enable sites to be prioritised that have high woodland value and connectivity at multiple scales compared to other woods of a particular type – or within a particular LBAP objective. Such a methodology does not focus on particular species groups therefore and different combinations of scales can cause high scores. This is thus a general approach where high landscape scores are aimed to reflect a high availability of features of high woodland biodiversity in the locality at a number of scales. Such factors are of use to broad conservation planning where suites of species typical of a woodland habitat such as Upland Oakwood's are the aim of the conservation planning. However such methods limit the use for exact species grouping, although the scores for each individual buffer zone – e.g. the 20m zone can be examined separately from the other zones, if for example only the value of woods for short dispersal distance (e.g. ancient woodland flora species) were of prime interest. The 4 scales methods – and it combinations believed to reflect a useful comprise allowing multiple scale value to be assessed and site to be selected that have high availability of woodland biodiversity in the vicinity / surrounding network.

The exact scales of use and application in such a study as this will always be open to some element of uncertainty. The scales were designed to reflect broad ranges of woodland specialist dispersal behaviour, and believed to give an accurate representation of this within the scope of such modelling. Several studies have examined particular species groups in detail. In an English study using species location records and ancient woodland landscape data amalgamated to the 10km grid scale models were able to accurately predict some woodland bird and mammal occurrence but failed to accurately reflect plant and invertebrate presence (Bailey et al., 2002). This suggests the much smaller scales used in the current study are likely to be more accurate for such species, but does also suggest that for woodland bird species re-analysis at larger scales to investigate network for more mobile species may be beneficial.

11.5.2.4 Strategy development summary

The strength of the project method is the prediction model development, implemented through landscape woodland analysis at several scales. The presented mapping scoring strategy is visually simple, easily repeatable and can be updated as sites change conservation status or value. The strategy shows that combining Phase 1 Habitat survey data with landscape classification can give useful GIS planning units for biodiversity application. The results provide site biodiversity values and allow quantification of local woodland landscape biodiversity value / network value / species pools. The study was based on an accurate assessment of local habitat cover, landscape character and opportunity and constraint mapping, as practised to different extents by previous studies (Jerram, 1998, Cairngorms Partnership, 1999, Griffiths et al., 2004b, Peterken, 2002a, Good et al., 1997). Due to this grounding in local habitat occurrence and landscape character assessment it is believed to be more useful than studies relying more purely on broad theory or thresholds taken from landscape ecology e.g. (Hampson and Peterken, 1998, Smithers, 2000, Peterken, 2000b, Peterken, 2002b)

The strategy provides the "site", "landscape" and "combined" scores for comparison and use in conservation planning. It is useful to be able to compare these scores. The emphasis of the strategy is that, at the scales studied, a wood with high combined "site" and "landscape" scores has both high predicted interest within the wood (or potential wood) and also has a high degree of woodland biodiversity in the surrounding landscape. The strategy proposes that such a wood therefore gains additional conservation importance beyond its inherent biodiversity value. The patch may act as a landscape link for mobile species or, if island biogeography models and metapopulation models apply, it may be important in allowing retention of mobile species in the landscape. Additionally such sites may simply contribute to a larger local multiple-patch of woods used as a single resource by wide ranging mobile woodland species. Therefore such woods with high "combined" scores are proposed as being high value. Additionally creation or restoration sites in such areas are expected to be able to develop high biodiversity interest, due to already occurring in close proximity to high biodiversity at one or more local scale, allowing more rapid colonisation or exchange of species than more distant woods. A wood restored in such areas would be re-colonised more quickly than distant sites, or may restore to a stage where its local woodland species are able to spread to nearby woods, compared to more isolated woods or woods occurring within low-quality woodland habitat.

The benefit of such scores can aid conservation by providing a standardised system which is not subjective and can therefore be used to compare to decisions made by conservation officers based on other sources and plans. Where conservation resources are required to be used to have maximum return or value then it is proposed that conservation of woods with combined high scores conserves both woods with high inherent value and high value to the broader woodland network, conserving connectivity and retaining the functional network system.

Ultimately the methodology relies on the assumption that the broad biodiversity summary value – abiotic conditions links found within the ancient woodland sites are applicable across the Natural Area to other woodland and semi-woodland habitats. This is considered reasonable. The extension then assumes that certain features will be linked to broad woodland biodiversity but within such values the exact occurrence of biodiversity features will differ. Relationships for example were found with stream occurrence and steep / variable topography and ground flora occurrence / survival and dead wood occurrence etc. These are transferable between sites such that where these features occur biodiversity levels will be higher than where they are absent, or less variable. However the exact mix of features may not always be present, some sites may have native tree cover and ground-flora but lack deadwood due to variability in past management practices. Therefore the scores and biodiversity assessments are believed to be transferable but in a generalised form, they cannot necessarily be extracted to exact species groups such as deadwood insects as this is too specific but the method remains useful due to the overall assessment of "native woodland biodiversity levels".

The strategy was implemented through zone mapping and scoring because this allows LBAP targets to be placed in context of importance, and can then be considered along with other aspects e.g. social or financial factors. This is considered preferable to the landscape design based studies e.g. (Peterken, 2002a, Smithers, 2000) where further work is required to determine the locations of proposed conservation actions, and leaving such outcomes generalised could lead to a lack of focus and ultimately inappropriate sites being considered for action than would have materialised through a more objective and comparative, prioritised approach. Additionally with the comparable elements of habitat quality / biodiversity the relative importance of sites can become clearer, more explicitly allowing trade-offs between potential conservation sites.

11.5.3 Utilising the strategy for LBAP planning

The project has mapped priority areas to meet the habitat area targets suggested by the LBAP, with slight modifications for Objective 4, woodland creation. Subject to the recommendations for further work made in Section 11.5 and the acknowledged limitation in Section 11.4.4 the project site, landscape, combined and effects scores hold much potential for use in conservation planning.

Examination of the separate site and landscape biodiversity scores allows sites with high current interest for either value to be identified and compared against current conservation agreements. Ranking sites by importance for one of these scores, within a particular LBAP objective would allow assessment within the GIS of what proportion of identified priority sites are currently conserved or in agreements. Updating of the GIS register would then allow conserved sites to be dropped from the list and the level of the LBAP target to be re-assessed. Additionally the ranking of sites could be used to organise field survey of potential priority sites or creation sites.

The principal current strategy using combined site and landscape scores tends to re-enforce the existing woodland system by selecting sites that are most likely to be colonised / share a species pool with nearby woodland areas. In contrast the strategy allows examination of effects scores – where the influence of the combined site and landscape prioritisation is shown on the relative site based importance. Sites with negative effects scores have relatively high site scores but low landscape scores and therefore do not appear as high priority sites when selections are made using the combined site and landscape scores. Such sites, within the current strategy are considered to hold high site based levels of interest but to be relatively functionally isolated compared to other similar woods of that value. Within the current methods therefore conservation at sites is proposed as being valuable to retain the site interest but it is proposed that such conservation will not contribute to Dark Peak woodland network conservation at larger scales due to such isolations. However such sites can be used to target action at broader scales if action were proposed to link or expand the woodland network to less connected sites.

Such sites would be key targets with which to link to the main network areas by creation of stepping stone woods – as previously proposed in several strategy / research areas (Buckley and Fraser, 1998, Kirby and Reid, 1997).

11.5.4 Strategy reliability and uncertainty

Any conservation strategy should be assessed for its reliability and the levels of inherent uncertainty, especially when based upon model predictions. The current strategy results show a range in likely accuracy and reliability levels. Examination of individual multiple regression models (Chapter 10) showed prediction was better between than within individual habitat types – such as ASNW only. Therefore site and landscape levels will tend to be most reliable when compared between different woodland types than within a single habitat type. The models within only ASNW for example showed lower predictions of scores. Therefore less reliance could be placed on ASNW site scores that were predicted or for predicted semi-natural broadleaved wood site scores in LBAP objective 2. However the majority of ASNW sites were directly surveyed and thus these results have high direct certainty. The majority of landscape scores however are calculated from the relative biodiversity levels of several woodland types surrounding a particular wood type. Due to the main accuracy of the prediction models in distinguishing values between habitats, and the fact that most landscape scores derive from an analysis of the mix of several types of woodland habitat around a woodland site, these scores have relatively high certainty. Indeed, even without considering the accuracy of the site biodiversity prediction scores, the landscape scores, due to their creation methods, hold value in the way they reflect the occurrence of woodland within the surrounding landscape. Therefore landscape scores are considered reliable.

In summary, considering the entire project methodology the surveyed ancient woodland sites, both PAWS and ASNW, hold scores that relate directly from actual survey work and can thus be used directly with certainty for relative conservation planning. The landscape scores reflect the occurrence and relative value of woodland around sites and although specific to the current individual project methodology are reliably indicative of local woodland context. The site biodiversity scores (for predicted sites), as derived values, are most resultant on the individual methods of the project and would be most open to alteration, resulting from future survey work or methodology alterations such as inclusion of additional predictive variables. However the site biodiversity assessment utilised causal and deterministic factors driving site biodiversity and indicative of the likelihood of site conversion / management intensity (slope steepness, stream presence, aspect variation etc). These are considered suitable factors to give an indication of site naturalness / conservation value to woodlands in the upland fringe, where planning is required in the absence of ground based survey information.

11.5.5 Relative importance of conservation, restoration and creation

Recent publications have indicated the relative priority that should be given to the alternative BAP aims of conservation, restoration and creation. Broadly authors suggest that the priorities should be active conservation / enhancement of key high interest woodland, followed by restoration of PAWS, conversion of plantation to native wood and finally creation of new woodland (Humphrey, 2003, Bailey and Pryor, 2004, Pryor, 2003, Wulf, 2003, Thomas et al., 1997).

11.5.6 Recommendations for future Dark Peak LBAP targets

The research found no shortage of opportunities for woodland restoration and conversion, or indeed for woodland creation, matching previous studies in the uplands (Good et al., 1997, Gkaraveli et al., 2004). Several studies have highlighted the importance of considering current landscape character during woodland conservation activities and planning (Good et al., 1997, Buckley and Fraser, 1998). In this respect, by considering the levels of activities would begin to alter Dark Peak character it is clear from examination of the figures that in terms of broad Upland Oakwoods and clough woodland, that opportunities exist for conversion of plantation that exceed many times current creation targets. If such native wood creation were combined with removal of plantations in inappropriate "non-woodland" zones for the landscape then such activities would allow a dramatic improvement in the "natural" character appearance of the area while actually incorporating significant native wood creation. In such zones this wood creation would not be apparent in visual terms where action incorporated a conversion stage as mixed open woodland prior to native woodland regeneration / creation. In areas to the north west of the Natural Area wood conversion opportunities are less apparent and woodland creation opportunities more extensive. In this area, due to landscape openness and form, and the already scattered occurrence of native woodland remnants, significant native woodland creation opportunities could be accommodated before the current landscape character was affected. Such sites tend to be visible from limited aspects and viewpoints such that it would take very high wood creation activity before the landscape appeared to be becoming more wooded. Perhaps the most apparent areas where creation would be valuable and would be visible would be in Longdendale, but in conjunction with current removal of plantation woods such increase would be unlikely to be detrimental to landscape character and would more likely re-enforce the natural elements of the landscape scene. In summary, it is recommend that:

- Woodland conservation targets be increased, based upon the current low occurrence of high quality habitat within the ancient Woodland sites overall
- Woodland restoration targets be increased, and as a minimum all PAWS be gradually converted to mixed woodland as an intermediate stage, involving "halo" thinning and removal of grazing as immediate steps

- A new woodland conversion target be introduced within the mapped "clough woodland" zone involving conversion of existing plantations to native cover. This option could be practised instead of woodland creation in the south east of the Natural Area where no new native woodland creation on open ground habitats should be allowed
- New native wood creation targets be increased, in line with the availability of physical opportunities and the clear biodiversity and landscape character improvement benefits. Such targets however should be analysed in relation to potential conversion targets and woodland "combined" and "effects" scores. The target should be applied so as only to relate to the centre and north west of the Natural Area, were existing woodland cover is lower.
- New targets could be developed to create new native woodland at high altitude. Such woods could act as experimental sites, to form buffers for climate change affects, to study changing woodland micro-climate conditions, and additionally to re-claim woodland within the zones in which it is currently extremely rare or absent. For example, given the areas of suitable habitat available, the potential contributions to bio-diversity and the minimal impact (in % cover terms) to open ground habitats, possible such targets could include the creation of at least 5 sites, of at least 5ha in each of the zones 450-500m and 500–550m.

11.6 Recommendations for further work

11.6.1 Alternative woodland score weighting and least-cost analysis

Significant opportunities exist in further research examining the relative effects that applying priority weighting to different woodland habitat, classification, designation or site and landscape scores have on ultimate woodland priority mapping. The current study gave additional but only moderate enhanced weighting to Ancient Woodland site biodiversity score. Examination of the relative values of ancient and non-ancient woods could allow more accurate weightings, while studies could investigate the effect of changes to such weightings on final mapped priority sites. Higher weighting to ancient sites would emphasise the ancient woodland clusters and distribution across the Natural Area rather than broader woodland biodiversity levels. Similarly it would be of interest to examine the effect of giving different weighting to the site and landscape scores when combined to give scores that are used in final woodland polygon prioritisation. The effect of giving additional weighting to sites with known designations or management agreements could also be investigated, as has been used in past grassland studies (Bayliss et al., 2003). This could potentially be investigated by using a system assessing the long term existence value of different woodland quality parcels / management units.

During the project methodology development computational limitations prevented utilisation of direct least-cost distance analysis methods to calculate the landscape score from the site biodiversity score and relative connectivity of each polygons within a buffer. As computer resources improve and GIS search algorithms develop it would be of interest to incorporate such direct methods of connectivity assessment into the methods e.g. (Ray, 2005).

An interesting extension to the strategy research would be further examination of how to ensure the landscape score, weighted by landscape contrast levels gives an accurate representation of the accessible / functionally connected woodland community in the surrounding area. Currently the method is affected by the amount of woodland of different quality levels occurring within the buffer zone, and the mean contrast level of land within the buffer. Problems exist because of the way this can average out the form of woodland cover in the buffer. Significant parts of the landscape in the buffer may show very high connectivity while other areas have high contrast and so reduce the overall score. This could be resolved using the direct method of least-cost distance analysis mentioned above. In contrast, methods could be taken to analyse woodland biodiversity values not in relation to the total area of land within the buffer zone, but only in relation to the area of clough or "woodland opportunity" landscape within the buffer. This would increase the ecological realism of the analysis allowing for example areas to be identified where woodland connectivity was already as high as practically possible within the buffer because all clough landscape zone in the buffer or "woodland opportunity" zone were already occupied by woodland.

11.6.2 Additional model verification and levels of survey intensity

The current strategy was based upon models derived from an examination of ancient woodland sites within the same Natural Area to which the strategy was applied. This was based upon knowledge that such sites have long-standing woodland cover with known management intervention and canopy cover. The models were extrapolated to similar woodland and semi-woodland habitats on non-ancient sites. Future work could usefully carry out fieldwork to examine the classification accuracy of these models within both non-ancient woodland and semi-woodland habitats such as scrub and scattered trees. It would also be interesting to repeat the study with such an additional range of fieldwork sites in another similar upland Natural Area such as the South West Peak to examine the extent to which woodland habitat quality – biodiversity relationship are similar and thus to examine how transferable the relationship may be to broader classification of woodland for conservation planning of uplands woodland in general.

An additional range of research could be an examination of the woodland biodiversity – habitat quality relationships that are able to be extracted from both ancient woodland and non-ancient woodland sites, resulting from differing levels of woodland fieldwork survey intensity. This would give insight into what levels of the resource area should be surveyed in order to produce useful predictive models for application in conservation planning. Within the current research significant time was involved in the surveying of ancient woodland sites, and recommendations of suitable survey level intensity would be useful for future studies. Such work could be conducted by re-analysis of the current range of survey data or could be conducted within a different Natural Area.

11.6.3 Additional study scales

The analysis scales for the current strategy were set in relation to typical woodland species movement distances and were felt to be suitable for a Natural Area scale project. Two areas of future research could examine relationships at additional scales. Future studies could include analysis at larger scales than the maximum 1km search scale used here. This would require examination of more than one Natural Area, as beyond 2km search distances significant areas of a Natural Area would be affected by edge-effects, where data was not collected from within the current Natural Area of study. Such studies could weight the value of woods in adjacent areas based on the perceived similarity of woods in each adjacent Natural Area to the focal study area. There is further potential to identify core forest areas, or major landscape links where the relative value of conservation activity could be further assessed at broad scales where linkage across the entire Natural Area or between core clusters of woods could be considered , e.g. as in previous studies (Hampson and Peterken, 1998, Kirby and Reid, 1997). Conversely an additional range of research could examine factors at a sub Natural Area scale, perhaps using catchments as study areas, within which habitat quality – biodiversity relationships were examined separately. If analysis were conducted at such scales a useful model may be the "ecological woodland units" in Wales (Latham, 2003). Recent analysis techniques could be used to fit a regression model to the environmental variables, this could include moving window regressions (MWR) (Lyod, 2007) where regression fitting could be applied at local scales within the Dark Peak to fit biodiversity to local conditions – or examination of Geographically weighted regression (GWR) (Lyod, 2007) to more fully explore the remnant geographic landscape trends in the data. These would require additional data collected at these local scales and larger datasets available for confirmatory studies.

11.6.4 Additional fieldwork, digital and remote sensed data

It would be interesting to repeat a range of the present research using additional, or higher quality GIS data. Such data could be included in direct site biodiversity evaluation, while more recent and accurate digital Phase 1 data would increase the reliability of the landscape contrast mapping and the assessment of potential woodland pre-cursor habitats. Analysis could investigate the use of a more extensive suite of topographic and soil hydrology variables such as hydrology index and planiform and profile curvature, as investigated in previous studies (Luoto et al., 2002). The potential benefits to assessment of woodland biodiversity levels using remote sensed data is recognised (Innes and Koch, 1998), however recent improvements in analysis has shown how it is increasingly possible to identify within-patch woodland structure features or even identify particular tree species canopies within woodland areas from remote sensed data (Foody et al., 2005, Brown et al., 2006, Thessler et al., 2005, Bradbury et al., 2005). Incorporation of such additional accuracy data would further minimise survey requirements within an analysis similar to the current study.

11.6.5 Standardising management units, and the use of reserve planning algorithms

While the project methodology applied biodiversity prediction to whole woodland polygons, it would be possible to divide such woods into smaller management units comparable to forestry compartments for planning purposes. The use of GIS grid cells has been investigated by some researchers (Purdy and Ferris, 1999) but has significant limitations. More potential may exist in using an overlay grid or hexagons to cut polygons into smaller mapped vector units. Within the study area many woods were relatively small, and as such could be expected to be managed as single units. Methods could hover be applied to divide larger woods, where for some of the largest conifer plantations it is likely to be unreasonable to treat whole woods as suitable planning units. Opportunity for further research exists, potentially using such standardised planning units, with current conservation biology planning methods, which are increasingly able to include information on spatial planning during the planning of a potential reserve system (Siitonen et al., 2003). The LBAP targets could be allocated using mathematical reserve planning algorithms incorporating various elements of extra consideration of spatial connectivity or boundary cost and reserve area relationships (Baskent and Keles, 2005, Kurttila, 2001, Siitonen, 2003).

11.6.6 Extension to additional LBAP groups

The current study was purposely limited to a single BAP habitat. It would be interesting to repeat the analysis examining wet woodland habitats in the Natural Area – to which different topographic factors would apply, and then run combined analysis of both habitats to identify diverse woodland complexes with several BAP habitat types. Conservation strategies applied to multiple BAP types would be likely to identify different priority areas, for e.g. woodland creation by selecting areas rich in multiple soil or topography / landscape types.

11.6.7 Landscape character driven site and landscape cover thresholds

One area of future research limited to analysis in relation to woodland creation opportunities would also involve analysis at additional scales. While the current methodology analyses priority creation areas in relation to site and landscape interest levels, further analysis could add an element, similar to the threshold cover suggestions of Peterken (Peterken, 2000b, Peterken, 1999) analysing conservation opportunities in relation to actual local current woodland cover and the areas of opportunity land available. Analysis could thus identify priority creation areas in local landscapes where the proportion of the clough landscape zone containing woodland cover is already high. In such areas although the current method may map potential high quality woodland creation sites based on site and landscape woodland biodiversity scores, examination of current and potential wood creation areas may determine the area already to have reached a suitable woodland cover density. In such areas conversion of existing wood to native woodland cover would be a much higher proportion than woodland creation. In contrast similar site and landscape score woodland creation sites in areas of the landscape where overall woodland cover was low compared tot eh area of clough landscape, then woodland creation importance would remain high.

An interesting area of further work was partly incorporated in the early pilot study by (Purdy and Ferris, 1999). The methods examining restored woods incorporated assessment of what the combined area of restored woods would be when merged with existing nearby woodland. This method would be interesting to integrate with the current study with a view to setting upper threshold, both of individual woodland size and of local woodland % cover at sub Natural Area scales in order to maintain landscape character. Addition of such scoring could for example sallow the relative targeting, within the current system of new native wood creation towards areas currently with lower woodland % cover, while conversion areas from plantation to native could effectively be targeted towards areas with relatively high overall woodland cover.

11.6.8 Additional landscape classifications

One focus of the current study was its application to the "clough woodland" landscape zone, which represented both the main areas of native woodland occurrence and areas with potential for woodland restoration / development. As part of the mapping of this zone separate core clough, additional slopes and adjacent bracken / low conservation interest zones were identified. While these separate zones were used to classify potential woodland creation and conversion habitats, only distance from core clough and the area of core cloughs within 1km radius were used directly in the analysis of the ancient woodland communities. A recent study examining the topographically similar ghyll woodlands in southern England (Burnside et al., 2006) used cluster analysis of site and vegetation data to analyse similar, albeit lowland, woodlands. There is potential to apply such analysis to the study sites in the Dark Peak aiming to separately analysis biodiversity – habitat quality relationships in different woodland site types, identified from the cluster analysis. Analysis for example of the dense, closed-canopy, narrow cloughs could reveal different trends to wider open or single sided wooded cloughs. This would be worthy of investigation. Such analysis would require additional survey sites but could potentially allow investigation of relationships in wet woodland sites and may allow current or areas with potential for development of humid W8 / W9 woodland to be identified from topography.

11.6.9 Modifying the application of the biodiversity targets

A final area of potential further work arises from the study by Purdy and Ferris (1999) where targets were devised assuming that only part of the identified woodland polygons would actually be conserved or converted due to other management, financial or recreation limitations. This could be applied to the current methods by assuming for example that only 70% of each identified site could be expected to be successfully managed as prioritised. Therefore increasing the regional area targets to account for this, and re-running the prioritisation process would select more sites overall, within which such smaller areas of work would be expected to occur. This would add an additional element of flexibility to the strategy process, whilst retaining the broader prioritisation of sites.

11.7 Chapter Summary

- Habitat type, and habitat quality were used as predictive variables to map woodland biodiversity across unsurveyed sites using associations from surveyed ancient woodland sites
- Predicted biodiversity levels were mapped using woodland within the identified clough landscape zone where sites are likely to have held woodland cover until recent decades, and where presence of remnant woodland species within wood including plantations is likely to be highest
- A strategy was developed using predictive biodiversity value at *site* and *landscape* scales
- Set focal scales were used to analyse predicted woodland site biodiversity values around woodland as a measure of the woodland biodiversity within dispersal distances / acting as potential colonist species pools for 4 focal woodland scales
- Analysis was used to examine high scoring sites for *site*, *landscape* and *combined* biodiversity levels
- The method represented a combination of ecological modelling, landscape assessment and GIS planning
- The strategy was used to produce an example set of priority woodland sites, using targets set by the Peak District LBAP for the Upland Oakwood habitat
- Priority sites were mapped using combined scores based on predicted *site* scores and *landscape* scores calculated accross all 4 focal scales
- Analysis can be recreated at individual focal scales where particular focal or guild groups are the concern of individual conservation action
- The strategy and the analysis upon which it was based could usefully be extended to consideration of further potential causal within-patch woodland conditions, such as additional hydrology and topography indexes
- Future analysis could also usefully extend the method to additional upland Natural Areas, such as the South West Peak, to test its relevance in a similar, but separate upland landscape

Appendices

This Appendix section includes additional information for relevant chapters. Each appendix is listed by reference to the Chapter to which it relates. Some chapters do not have an appendix and therefore numbers are not consecutive.

Appendix 1

Upland Oakwood NVC communities

- W4 *Betula pubescens–Molinia caerulea* woodland:

(a) *Dryopteris dilatata–Rubus fruticosus* sub-community , (b) *Juncus effusus* sub-community

Associated with peaty acidic soils, often along the drying edges of blanket bogs and characterised by the dominance of *Betula pubescens* over an often species-poor ground flora of *Molina caerulea.* In the two drier sub-communities listed here these species may be joined by an underscrub of *Rubus fruticosus, Lonicera periclymenum,* and *Dryopteris dilatata* (a). Alternatively in the *Juncus effusus* sub-community (b) a cover of frequent *Holcus mollis, Deschampsia caespitosa* and *Juncus effuses* are more typical, joined by an increased range of herbs including *Hydrocotyle vulgaris, Viola palustris* and *Lotus corniculatus.*

- W10e *Quercus robur–Pteridium aquilinum–Rubus fruticosus* woodland:

(e) *Acer pseudoplatanus–Oxalis acetosella* sub-community.

The W10e community is characteristic of base-poor brown soils in the upland margins and represents a transition to *Quercus petraea–Betula pubescens–Oxalis acetosella* (W11) woodland (Rodwell, 1991). This community is dominated by oak with varying covers of *Betula pendula* and species including *Acer pseudoplatanus, Fraxinus excelsior* and occasional *Ulmus glabra. Corylus avellana* may be frequent in the shrub layer with *Crataegus monogyna, Sambrucus nigra* and *Ilex aquifolium. Rhododendron* may be prominent in certain stands of this community. The ground flora typically holds a mix of *Pteridium aquilinum, Lonicera periclymenum, Rubus fruticosus* and scattered *Dryopteris dilitata* with lawns of *Holcus mollis* and areas of *Hyacinthoides non-scripta* all occurring over frequent *Oxalis acetosella.*

- W11 *Quercus petraea-Betula pubescens-Oxalis acetosella* woodland:

All sub-communities

This community type is typical of "moist but free-draining and quite base-poor soils" (Rodwell, 1991). The community is dominated by either *Quercus petraea* or *Betula pubescens* with only a scarce contribution from other tree species. Shrub species are also rather rare and scattered with *Sorbus aucuparia, Corylus avellana* and *Crataegus monogyna* occurring rarely in what is typically a very open woodland type. The ground flora is dominated by grasses with *Holcus mollis* the most prominent among *Anthoxanthum odoratum, Deschampsia flexuosa* and *Agrostis tenuis* with varying amounts of *Pteridium aquilinum.* Additional species may include low covers of *Blechnum spicant, Hyacinthoides non-scripta,* *Anemone nemorosa*, *Mercurialis perennis* and *Oxalis acetosella*. These species typically occur over a carpet of moss and the community is often heavily affected by grazing.

- W16b *Quercus–Betula–Deschampsia flexuosa* woodland:

  (b) *Vaccinium myrtiullus-Dryopteris dilatata* sub-community.

This woodland type is confined to very acid and oligotrophic soils and is typical of the upland fringes of the Pennines. These woods are typically dominated by *Quercus petraea* with *Betula* species and little contribution from other trees although *Castanea sativa*, *Populus tremula* and *Sorbus aria* can be rare. The ground flora of these woods are characterised by *Deschampsia flexuosa* and *Pteridium aquilinum* with scattered *Vaccinium myrtillus* and *Calluna vulgaris*.

- W17 *Quercus petraea–Betula pubescens-Dicranum majus* woodland:

  All sub-communities.

This community is typical of " very acid and often shallow and fragmentary soils in the colder and wetter north-west of Britain" (Rodwell, 1991). These woods are often dominated by *Quercus petraea* with various covers of *Betula*, often *Betula pubescens*. The ground flora is typically dominated by a mix of *Deschampsia flexuosa*, *Pteridium aquilinum* and *Vaccinium myrtillus* with a range of scattered herbs including *Galium saxatile*, *Potentilla erecta*, *Melampyrum pratense*, *Oxalis acetosella* and *Teucrium scorodonia*. The ground flora often occurs among a matt of moss species.

Appendix 2

No Appendix

Appendix 3

No Appendix

Appendix 4

No Appendix

Appendix 5

Appendix 5.1

The adverse effects of clear-felling. Reproduced from: (Pryor et al., 2002).

Full light conditions and disturbance, which may permit coarse vegetation to effectively oust shade-tolerant ancient woodland species

Damage from extraction machinery; including direct damage to ancient woodland components, ground disturbance and compaction

Smothering by deep brash (especially from mid-rotation premature felling)

Retained veteran trees may be exposed to windthrow or dieback

Organisms associated with veteran trees may suffer directly from the loss of habitat trees, and indirectly from desiccation when trees are retained but isolated. Some organisms, e.g. bats, may also be affected by disturbance and change to the environment surrounding old trees

Dead wood communities, fungi and soil invertebrates may be damaged by rapid changes in microclimate and by ground disturbance and compaction

Slender semi-natural trees, including stems from old coppice stools will be exposed to wind damage

Habitat provided by maturing plantation trees will be lost

Ride use, to move the large quantities of timber, can damage some of the most important refuges for ancient woodland flora

New roads or improvements to existing rides can have a disproportionately high impact in smaller ancient woodland sites

Successor stands will be even -aged, re-initiating the plantation cycle

Appendix 5.2

Partial restoration management options. Source: (Thompson et al., 2003)

Use appropriate silvicultural systems to maintain woodland conditions.

Retain veteran trees

Maintain an open canopy around native trees, particularly veterans, allowing light to filter through to lower branches and the bole of the tree to enhance populations of epiphytic lichens and ferns.

Thin to enhance nationally uncommon or locally rare species of native trees and shrubs.

Maintain habitats of priority species (e.g. maintain open space for known populations of Species Action Plan invertebrates such as heath fritillary or chequered skipper butterflies).

Safeguard existing areas of ground-flora and aim for their expansion by maintaining canopy gaps and protecting less robust vegetation on rides.

Maintain a proportion of non-native trees to biological maturity, to provide large diameter deadwood (useful for bryophytes and fungi).

Retain all standing and fallen deadwood.

Extend the rotation length of even-aged stands. Within productive conifer stands, structural diversity typically begins to develop around the normal economic age of clearfelling. Diversity greatly increases with very long rotations as the 'old growth' stage is reached.

Competitive processes between different tree species are complex. Intimate mixtures may require regular management to maintain a proportion of native trees and shrubs. Discreet groups of native and non-native trees are likely to require less frequent management (although early thinning would be beneficial to increase light levels. Additionally, consideration should be given to eventual extraction routes and vulnerability of adjoining habitats).

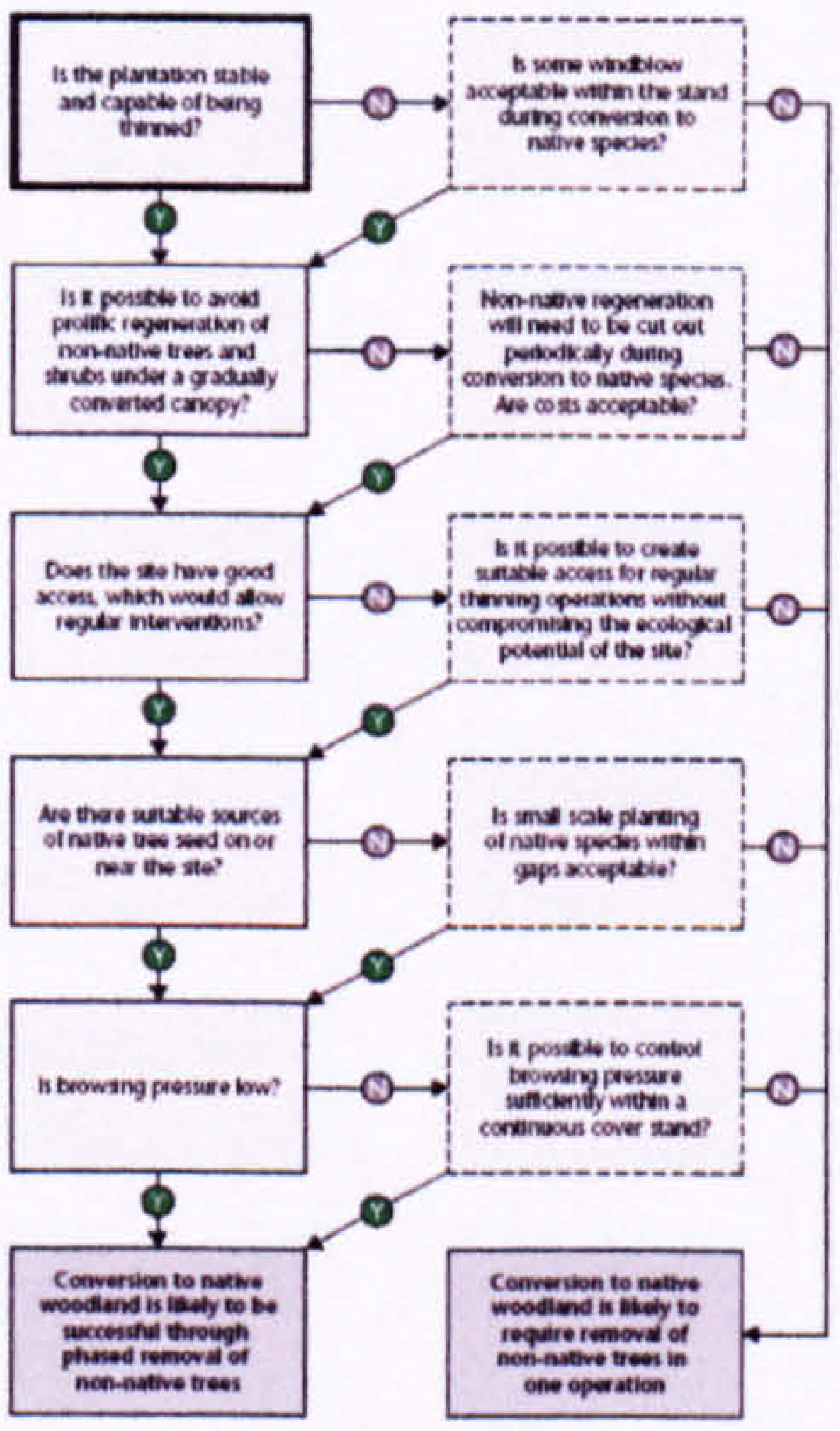
Replace densely shading non-native species with lighter canopied species or manage densely shading species as discreet groups.

Within a site, favour the restoration of microhabitats which are likely to support higher levels of biodiversity (e.g. wet flushes, rock outcrops, base-rich areas in otherwise acidic woodland).

Focus on the development of native trees with the potential to become veterans and standing deadwood in the longer term.

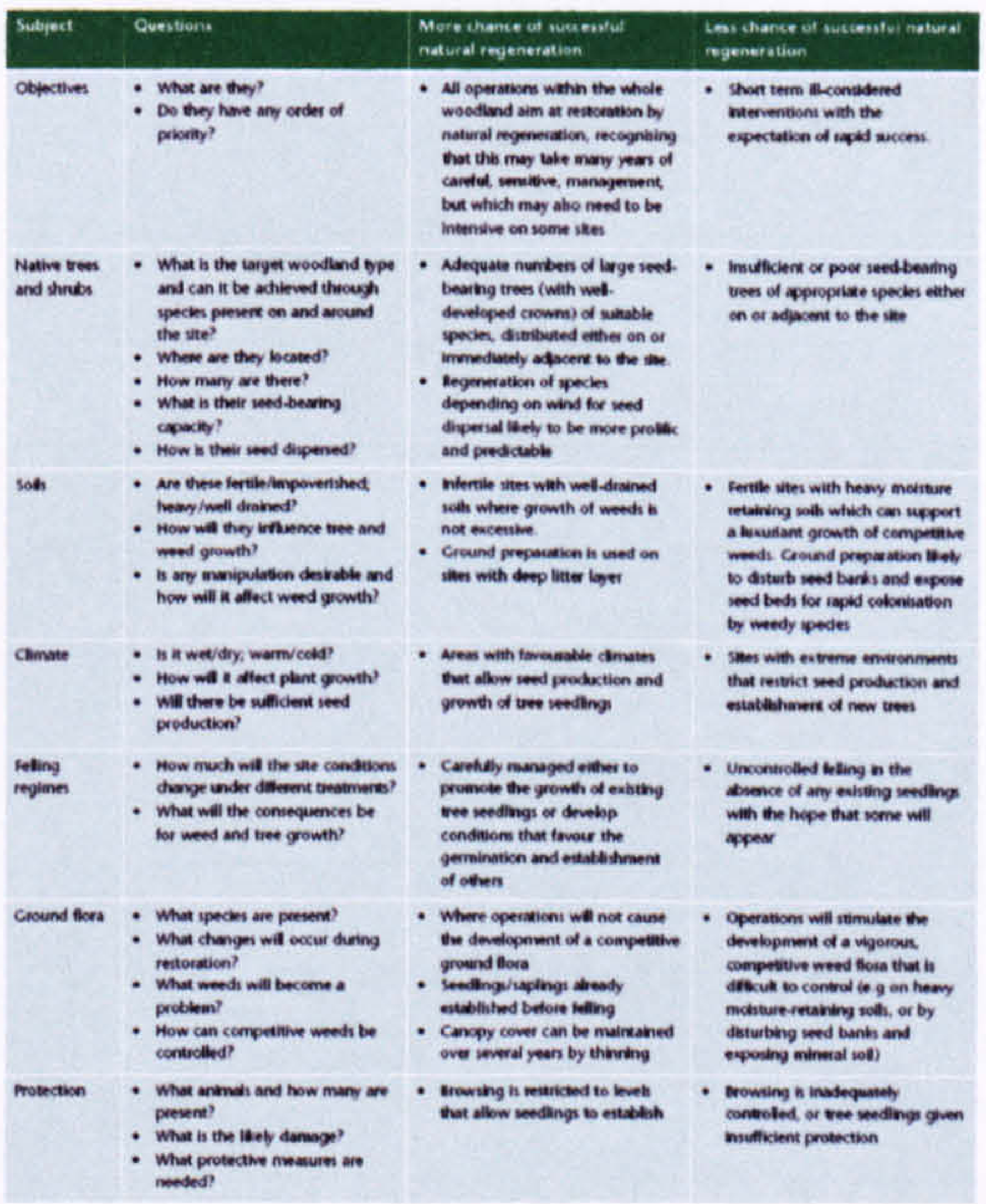
Appendix 5.3

Decision process to choose suitable PAWS restoration methods. Reproduced from (Thompson et al., 2003).



Appendix 5.4

Questions to consider where natural regeneration is likely to be successful. Reproduced from (Thompson et al., 2003) .



Subject	Questions	More chance of successful natural regeneration	Less chance of successful natural regeneration
Objectives	• What are they? • Do they have any order of priority?	• All operations within the whole woodland aim at restoration by natural regeneration, recognising that this may take many years of careful, sensitive, management, but which may also need to be intensive on some sites	• Short term ill-considered interventions with the expectation of rapid success.
Native trees and shrubs	• What is the target woodland type and can it be achieved through species present on and around the site? • Where are they located? • How many are there? • What is their seed-bearing capacity? • How is their seed dispersed?	• Adequate numbers of large seed-bearing trees (with well-developed crowns) of suitable species, distributed either on or immediately adjacent to the site. • Regeneration of species depending on wind for seed dispersal likely to be more prolific and predictable	• Insufficient or poor seed-bearing trees of appropriate species either on or adjacent to the site
Soils	• Are these fertile/impoverished; heavy/well drained? • How will they influence tree and weed growth? • Is any manipulation desirable and how will it affect weed growth?	• Infertile sites with well-drained soils where growth of weeds is not excessive. • Ground preparation is used on sites with deep litter layer	• Fertile sites with heavy moisture retaining soils which can support a luxuriant growth of competitive weeds. Ground preparation likely to disturb seed banks and expose seed beds for rapid colonisation by weedy species
Climate	• Is it wet/dry, warm/cold? • How will it affect plant growth? • Will there be sufficient seed production?	• Areas with favourable climates that allow seed production and growth of tree seedlings	• Sites with extreme environments that restrict seed production and establishment of new trees
Felling regimes	• How much will the site conditions change under different treatments? • What will the consequences be for weed and tree growth?	• Carefully managed either to promote the growth of existing tree seedlings or develop conditions that favour the germination and establishment of others	• Uncontrolled felling in the absence of any existing seedlings with the hope that some will appear
Ground flora	• What species are present? • What changes will occur during restoration? • What weeds will become a problem? • How can competitive weeds be controlled?	• Where operations will not cause the development of a competitive ground flora • Seedlings/saplings already established before felling • Canopy cover can be maintained over several years by thinning	• Operations will stimulate the development of a vigorous, competitive weed flora that is difficult to control (e.g on heavy moisture-retaining soils, or by disturbing seed banks and exposing mineral soil)
Protection	• What animals and how many are present? • What is the likely damage? • What protective measures are needed?	• Browsing is restricted to levels that allow seedlings to establish	• Browsing is inadequately controlled, or tree seedlings given insufficient protection

Appendix 6

Table A6.1
Strategy methods: Landscape Ecology based studies

Reference	Drivers / aims	Justification , theory and policy statements	Methods	Summary
(Bayliss et al., 2003)	Target land for conservation and expansion and link agri-environment schemes to BAP	Ratcliffe (1977) criteria e g. general landscape ecology benefits of high diversity, patch size, isolation, rarity. Examines "restoration potential", based on island biogeography theory	Used existing species diversity records and rarity values Calculated new values in GIS for storage and methods	Island biogeography driven study
(Buckley and Fraser, 1998)	Investigate options for woodland location creation, develop guidance for planning	Testing landscape ecology / island biogeography inspired de-fragmentation wood creation options.	Experimental analysis of alternative spatial options. Carrying out future land use changes and testing results on landscape metrics	Landscape ecology inspired testing of landscape scale woodland creation strategies
(Gkaraveli et al., 2004)	Driven by existing BAP and FC stated policy aims for conservation and restoration	Although not stated, based upon island biogeography re isolation and on acknowledging existing high interest and restoration potential of different categories of woodland	Used land cover maps, woodland designations e g. SSSI and ancient woodland status GIS used for data storage and manipulations	Biodiversity policy, Island biogeography, Designations as surrogates for site quality
(Griffiths et al., 2004b)	Targeting BAP allocation methods at two scales	Land parcel scoring only loosely justified by broad island biogeography / landscape ecology derived scoring	Each land parcel in GIS scored by values based on current habitat type, size and isolation from broadleaved woodland	Island biogeography inspired, GIS based
(Hampson and Peterken, 1998)	To reduce biodiversity decline, recent Forestry legislation and policy and FC broadleaves and Pinewoods initiatives	Mentions landscape ecology theory and hierarchy theory regards thresholds and woodland cover. Highlights structural connectivity	Theory based on importance of connectivity thresholds and landscape ecology. Suggest local studies need to be carried out to assess local woodland structure, and notes the need for a national vision of the network	Forest habitat network, landscape ecology and design guidance based
(Lee et al., 2001b)	Targeting habitat patches for conservation for BAP	Loosely justified but based on metapopulation biology, implied island biogeography and value of rarity and current species presence records	Used GIS to calculate 4 abiotic patch values for habitat patches polygons. Then compiled existing sp records across a very wide age range.	Metapopulation / island biogeography based study giving value to sp and physical features of patches
(Lee et al., 2002)	Targeting woodland creation in relation to ancient woodland location and BAP targets	Based upon landscape ecology and conservation research suggesting larger woods preferable and BAP policy statements.	Targets driven by ref to need to create woodland of size of total 100 ha	Landscape ecology driven study to map and prioritise wood creation sites
(Peterken, 2000b)	Landscape scale strategy to create forest habitat network, restoration and creation	Summarised applied ecology and landscape ecology studies of species movement and associations in wooded landscapes.	Examined minimum areas, thresholds, density, corridors. Focus on multi-species effects and on landscape structure, especially wood cover.	Landscape ecology driven strategy to develop guidance to create networks
(Peterken, 2002b)	To show that woodland conservation requires de-fragmentation and considering linkage and spatial character	Landscape ecology, FHN theory Highlights importance of patch area and isolation. Some species consideration.	Consideration of woodland history, current woodland management woodland species requirements and woodlands action planning	Landscape ecology driven framework and guidance
(Purdy and Ferris, 1999)	To examine integration of woodland data within GIS for woodland conservation planning	Report mainly focuses on GIS methodology and scoring / rationale for planning is only loosely justified through general landscape ecology rules and island biogeography consideration, minimising isolation and maximising area	Data integrated in GIS to classify ancient woodland by current canopy types. GIS used to undertake priority zone planning and mapping to identify key areas	Abiotic based assessment of conservation and creation potential based upon size and isolation
(Ratcliffe et al., 1998)	To establish a framework for forest expansion	Landscape ecology, expert knowledge	Assessed woodland network, considered key issues, examined a range of woodland "functional types" and species communities to devise wood conservation guidelines	Landscape ecology and island biogeography, mix of structural and functional connectivity methods
(Smithers, 2000)	Finding measures of woodland biodiversity to allow targeting of broad conservation action	Based upon consideration of island biogeography and landscape ecology and conservation literature. Identified key factors as ancient woodland, old growth, patch size, core area, edge, density and linkage of semi-natural open-ground habitats	Analysed current woodland cover and types against proposed methods and devised planning rules and features.	Abiotic and landscape based assessment measures
(The Woodland Trust, 2002)	Promotion of policy on landscape scale woodland conservation	Based upon consideration of island biogeography and landscape ecology and conservation literature. Identified key factors as ancient woodland, old growth, patch size, core area, edge, density and linkage of semi-natural open-ground habitats. Promoted landscape of high value will be 30% semi-natural woodland, 30% semi-natural habitats and 40% low intensity other land use	Analysed current woodland cover and types against proposed methods and devised planning rules and features.	Abiotic and landscape based assessment measures
(Thompson et al., 2001b)	Testing method for using abiotic patch characteristics to rank / prioritise areas of woodland conservation and restoration	Justification is that the abiotic patch characteristics chosen were known to be important to metapopulations.	Used GIS to calculate abiotic patch values, and to analyse patch species records form other sources.	Metapopulation theory, GIS based patch ranking

Table A6.2
Strategy methods: Landscape Assessment based studies

Reference	Drivers / aims	Justification, theory and policy statements	Methods	Summary
(Gkaraveli et al., 2001)	Testing proposed / potential conservation actions and examining current landscape woodland structure	General ecology / landscape ecology,	Used raster 40m landcover data, examined coniferous, broadleaved and scrub woods, Data analysed in GIS and fragstats	GIS simulation of conservation effects
(Good et al., 1997)	To utilise expert opinion and GIS to examine options for native wood creation in uplands	Expert based classification and use of expert knowledge	Use GIS and landcover data to analyse existing landscape, set opportunities and constraints. Landcover data and DTM. Existing wood was analysed to describe characteristic combinations of slope, aspect and altitude. Maps of similar combination were then produce to define potential suitable creation zones	GIS based expert rule devised woodland creation strategy mapping
(Griffiths et al., 2004b)	Allocation of BAP target actions at two scales	Landscape assessment, analysis of current woodland distribution and mapped landscape types	National targets analysed and distributed to landscape types based on analysis of potential for key habitats in each Landscape Type and by considering levels that would not disturb existing landscape character	Landscape assessment based targeting of BAP action
(Jerram, 1998)	Develop strategy for BAP, WGS and AONB management	Based on assessment of current / future ecology of the landscape	Classified landscape based on existing habitats, species records and topography Split to opportunities and constraints to identify suitable locations for woodland expansion	Map based classification following landscape assessment
(Latham, 2003)	Development of a management framework to prioritise woodland conservation planning	Recognises importance of existing woodland distribution and form and its relation to local landscape structure	Assessment of ecologically relevant landscape units based on assessment of woodland distribution and presence of woodland structural states	Landscape assessment classification to identify sub units for further analysis and prioritisation for conservation
(Peterken, 1999)	To produce a vision / FHN for regional woodland planning	Application of FHN concept, landscape ecology	Data collated on region, current woodland cover and history assessed.	FHN landscape assessment planning
(Peterken, 2002a)	To aid unified approach to native woodland restoration and expansion	Justified by reference to previous FHN literature, therefore by landscape ecology and island biogeography theory Largely structural	Identified relevant local spatial information, geology, soils, and reviewed current and historic woodland cover and typical land use types. Described conditions within the principal Landscape zones (e.g. LDU's). Area of current woods assessed and described in each zone. Specific recommendations given in each zone for FHN creation	Assessment of woodland cover and potential within different landscape zone to produce an overall FHN

Table A6.3
Strategy methods: Habitat / Environment modelling based studies

Reference	Drivers / aims	Justification , theory and policy statements	Methods	Summary
(Birnie et al., 2000)	To map the potential niche of bracken in GIS	Assumes that bracken habitat / niche relates to current environmental conditions	Collated range of environmental data in GIS then developed ecological rules to map where bracken occurs. Mapped the occurrence of bracken and tested it using existing data set to assess mapping accuracy	Showed was possible but with varying success in different areas against existing data
(Brown et al., 1998)	Enable focussing of agri-environment schemes	Study acknowledges the links at sites of conservation interest between multiple factors such as hydrology, vegetation cover and faunal records.	Method showed potential of combination of multiple datasets in GIS to allow investigation of habitat qualities, species associations and analysis against agri-environment schemes	Compilation of multiple data in GIS allowing investigation of habitat qualities and species occurrence records
(Cairngorms Partnership, 1999)	To map potential native woodland areas and types	Assume driving link between geology, topography and soil and woodland formation / occurrence	Examined areas of potential woodland cover against existing woodland areas and potential natural regeneration distances. Potential woodland maps seen as a template against which to examine woodland conservation action	Output showed where potential exists for linkage and woodland expansion in suitable areas to be achieved through natural regeneration
(Gray and Stone, 2003)	Case study of woodland planning for single BAP habitat	Relies on associations between landcover and geology in determining potential woodland distributions	Potential / predicted woodland distribution from existing landcover and geology / soils data. Existing woodland cover compared against predicted cover and creation and restoration zones identified	Mapping of single BAP habitat potential distribution and conservation, restoration and creation zones
(Palik et al., 2000)	Method for prioritising restoration areas based on landscape hierarchy analysis of current and past habitats	Theory is that hierarchical classification of landscapes can be used because ecosystem types are reliably identified from principal landscape factors including soils and geomorphology	Compiled data in GIS. Created hierarchical classification of ecosystem types across the area Analysed difference between past predicted extent of ecosystem types from landscape hierarchy to current habitat types from land use maps	Ultimately showed use of using past potential extents of vegetation types in GIS, showed strong impact of landform and soils and extent of different ecosystems
(Russell et al., 1997)	To develop a method to select areas for riparian restoration	Site selection rationale was that hydrology was determinant factor in location of riparian sites	Compiled existing habitats in GIS. Compiled DEM and hydrology data	Outcome was analysis of existing sites and habitat and of hydrological potential for habitat conservation and restoration
(Thompson et al., 1999c)	To re-design ESA tiers to reflect current areas and potential extent of chalk grassland	That potential for chalk grassland depends on geology, existing land use and the slope of land because low slopes have been converted to high value improved grassland	GIS used to collate land use, slopes data. Mapped existing resource, and mapped suitable geology, slopes and land use for conversion / restoration to chalk grassland. Used classification to analyse current and potential tiers.	Outcome was potential conservation zones
(Towers et al., 2001)	To predict potential woodland distribution from current environmental conditions	Links from expert knowledge between woodland distribution and bio-physical data for mapping	Simple overlay of soils and current land use data. GIS class combinations classified using expert knowledge into potential woodland categories using the NVC system	Mapped and classified potential woodland resource

Table A6.4
Strategy methods: Species based studies

Reference	Drivers / aims	Justification, theory, policy statements	Methods	Summary
(Brooker, 2002)	Testing practical conservation planning methods	Focal species / umbrella species methodology / rationale	Identified range of focal species and focal community. Selected species still present, to enhance sites for restoration 7 species identified	Focal community planning ecological neighbourhoods
(Coppolillo et al., 2004)	Developing refined focal species selection methods	Focal species	Methods for choosing a suite of focal species not just one. Scored focal species against criteria and used complimentarily to keep to a minimum needed	Focal species method, Landscape species approach
(Lambeck, 1997)	Developing conservation area selection methods	Based on umbrella species approach but extended to multi-species	Each species selected to represent a "threat" to a community or habitat and these used to design maximum acceptable threats to exist to support conservation	Focal species
(Latham et al., 2004)	BAP and national policy	Generic focal species approach	Utilised detailed land use map to classify landscape resistance values to different focal species and then map functionally connected networks to allow visually identification of core and priority areas for work	Generic focal species approach
(Nikolakaki, 2004)	Site selection for landscape planning at landscape scale	Umbrella theory, and importance of connectivity and patch size to metapopulations	Literature review of critical patch size and isolation levels Used GIS to analyse landscape where habitat creation and expansion will benefit umbrella and other species	Umbrella species. GIS mapping for habitat creation zones
(Ratcliffe et al., 1998)	To establish a framework for forest expansion	Landscape ecology and expert knowledge / literature of species requirement to consider network design	Examined species requirements in detail, then grouped into an ecosystem approach by examining broader requirements. Included some analysis of potential occurrence / suitability of landscape for key species by mapping minimum area requirements and isolation based on costs, including assessments of edge limits.	Essentially a surrogate species or focal species approach although not explicitly referenced.
(Ray et al., 2003b)	Method to identify areas for restoration and expansion of native woodland	Generic focal species approach to plan FHN. Based upon functional connectivity and landscape ecology, metapopulation theory	GIS analysis mapped potential woodland habitat, and analysed structure against 4 generic focal species profiles Examined ancient woodland distribution and woodland core areas. Modelled dispersal abilities distance affected by cost of habitats between	Generic focal species approach, includes analysis of open ground species
(Ray et al., 2004a)	To identify semi-natural woodland framework for development of a FHN	Generic focal species approach to plan FHN. Based upon functional connectivity and landscape ecology, metapopulation theory	GIS analysis mapped potential woodland habitat, and analysed structure against 4 generic focal species profiles. Examined ancient woodland distribution and woodland core areas. Modelled dispersal abilities distance affected by cost of habitats between	Generic focal species approach, includes analysis of open ground species
(Ray et al., 2004b)	Developing methods for BAP and WGS planning	Generic focal species approach to plan FHN Based upon functional connectivity and landscape ecology, metapopulation theory	GIS analysis analysed generic focal species profiles. Species modelled against minimum area required for viable population and from maximum recorded dispersal distances	Generic focal species approach, includes analysis of open ground species
(Sanderson et al., 2002)	Design for conservation planning over larger areas and several management units	Selection of landscape species. Justification is the umbrella/focal species approaches Species use large areas, multiple habitats. Hope to conserve ecosystem function and processes at large scales	Selected species chosen with which to plan conservation of landscapes, define the extent and grain of conservation area	Landscape species / focal / umbrella species planning across large, multi-habitat areas
(van Rooij et al., 2004)	Practical application of landscape design planning	Metapopulation theory and use of target eco-profiles as surrogate / focal species	Species chosen as target eco-profiles, then range of spatial option generated. Species characteristics mapped as dispersal distance, sensitivity to barriers, use of key areas and minimum area requirement sin the presence and absence of key area patches	Eco-profile surrogate / focal species based landscape planning
(Watson et al., 2001)	In conservation context assessment of the focal species approach	Justified by focal species methodology and assumptions	Landscape and fragments surveyed and analysed to find appropriate focal species for threats including patch size, habitat structural complexity, landscape connectivity	Focal species application

Table A6.5
Strategy implementation. Landscape design guidance

		Design guidance				
Reference	Location	Conservation	Restoration	Creation	Matrix	Sub-Landscape zones
(Hampson and Peterken, 1998)	Scotland	Retain existing woods Expand existing woods. Develop existing clusters of woods		Develop connections between existing linear clusters of woods		
(Peterken, 1999)	Scotland	Consolidate main river network. Link minor tributaries. Extend along river to headwaters. Increase covers within network areas to 30%+	Re-design plantation forests		Extend along riparian network, Extend locally onto the farmland plateau	Detailed advice tailored to individual landscape zones
(Peterken, 2000b)	England	Maintain / retain existing woodlands. Prioritise ancient woodland sites. Increase cover to threshold level 30%		Create core woodland areas (CFA's) Buffer / expand existing woods. Create woods adjacent to existing woods: set minimum isolation levels. Create large woods: set minimum patch sizes. Create a range of wood sizes	Link woodland areas. Use landscape features for links, especially riparian. Avoid net loss of natural habitats, Create on arable or leys near semi-natural habitats	
(Peterken, 2002b)	Britain	Retain existing woods. Increase woodland cover to 15% in UK Increase cover to 30% locally	Manage existing woods favourability for woodland species. Restore PAWS	Identify existing and potential core forest areas Ensure new woodland links to existing woodland	Design matrix habitats to have a close association with woodland	
(Peterken, 2002a)	England	Maintain open space in woods. Enhance age structure	Restore PAWS to native woods	Link new woods to improve connectivity	Restore riparian multi-habitat corridors in and between woods. Enhance semi-wood features and trees in pastures	Detailed advice given for separate landscape zones
(Ratcliffe et al., 1998)	England	Re-enforce native woodland networks. Minimise isolation of native woods		Create core forest areas. Create woodland to reduce isolation of outlying woods	Create landscape links. Retain and develop semi-woodland habitats in non-forest land	
(Ray et al., 2003b)	Scotland					Detailed advice given in separate landscape zones
(Ray et al., 2004a)	Scotland	Identified core areas for conservation		Expand core areas. Link woodlands. Reduce isolation	Minimum width of 150 for corridors / links	Detailed advice given in separate core areas
(van Rooij et al., 2004)	Cheshire	Not listed in study				
(Watson et al., 2001)	Australia	Conserve priority woods of above 100ha. Conserve diverse vegetation structure Conserve woods within 1 5km of five neighbouring patch		Create woods of at least 100ha. Create diverse vegetation structure. Create woods within 1 5km of five neighbouring patch		

Table A6.6
Strategy implementation: Habitat mapping based studies. AW = ancient woodland, AWS = ancient woodland sites

Reference	Methods	Summary
(Brooker, 2002)	5 raster grids analysed to assess suitability for wood expansion or enhancement. Rules = increase small patches, add habitat between existing patches, expand on correct soil types, only in ecological neighbourhoods, avoid existing patches. Areas were mapped by desirability but total area for work was not mapped, left for interpretation	Cells in GIS coded by desirability / habitat suitability Classified vegetation conservation desirability system
(Brown et al., 1998)	Multiple data on hydrology, vegetation and species faunal records compiled with data on agri-environment schemes. Mapping and analysis allowed fields with most suitable hydrology or with most frequent species records to be identified and mapped and these to be of use in comparing against existing or potential agri-environment schemes sites	GIS analysis GIS compilation of data source and mapping of high interest "hotspot" sites for comparison against conservation networks
(Cairngorms Partnership, 1999)	DTM, geology, soil and current land cover analysed in GIS. Potential native woodland extent and occurrence mapped from abiotic factors. Classified natural regeneration zones then applied to existing woodland cover. Where such zones occur within the potential native woodland distribution and where such areas promote linkage these are considered priority areas.	GIS raster analysis Mapped high priority natural regeneration zones to aid creation of regional FHN
(Gkaraveli et al., 2001)	Several conservation criteria run in a modelled or simulated landscape. Situations examined and mapped were conversion of coniferous to broadleaves, buffering and creation of woods between existing patches. The effects of habitat mapping / landscape simulation were analysed by undertaking Fragstats analysis to see changes in landscape metrics,	GIS raster analysis, landcover at 40m Landscape simulation of conservation works,
(Good et al., 1997)	Use GIS and landcover data to analyse existing landscape, set opportunities and constraints using Landcover data and DTM. Existing wood was analysed to describe characteristic combinations of slope, aspect and altitude. Maps of similar combination were then produce to define potential suitable creation zones	GIS raster analysis 50m resolution GIS based expert rule devised woodland creation strategy mapping
(Gray and Stone, 2003)	Native woodland model used to map potential distribution of a single BAP habitat – upland ashwoods. Predicted / potential habitat distribution was compared against existing woodland cover, AWS and against classified open ground habitat and woodland plantation sites. Potential conservation, restoration and creation zones identified by analysing areas of overlap between categories with high priority zones being identified where sites lay within 100m of existing AW / potential ashwood sites overlaps	GIS analysis comparing potential zones and existing cover. GIS predicted native woodland modelling and classification against existing habitat covers
(Jerram, 1998)	Landscape maps classified by wood creation potential. Areas classified by existing habitat, species records and proximity to existing semi-natural wood or AWS Areas with high potential for native woodland creation then mapped from the combination of these desirable features.	Map analysis of wood creation zones. Mapping of high priority native wood creation zones
(Latham et al., 2004)	Land use map classified by dispersal resistance / cost.	GIS analysis of cost / resistance surfaces. Generic focal species used to map core areas of functionally connected networks
(Lee et al., 2002)	Core areas mapped where functionally connected networks of different generic species occur Core areas highlighted as needing consideration for conservation works, as to quality and expansion.	GIS polygon mapping, based on buffering of woodland network and current land use. Landscape ecology based mapping of potential habitat creation areas to create new larger core areas of native woodland
(Nikolakaki, 2004)	Analysed buffers in relation to current land use and mapped priority areas where land was suitable for conversion – these were final mapped priority sites. Identified "zones" around AW clusters where planting could lead to create or larger core native woodland blocks. Identified areas where small patches could be expanded to meet min size, where such areas were within potential sustainable clusters of woods and where cost distance were low and would allow colonisation of such areas.	GIS raster mapping at 20m resolution and cost based buffering and analysis Opportunity mapping of zones that will enhance pop of an umbrella species due to patch size and connectivity and thus promote associated species
(Ray et al., 2003b)	Existing woodland buffered to define potential networks, mapped areas analysed to find potential linkage areas base don focal species. Existing zones mapped based on hypothetical dispersal and area requirements of focal species.	GIS polygon analysis. Generic focal species approach, mapping existing and potential networks and detailing potential expansion and linkage areas
(Ray et al., 2004a)	Existing woodland buffered to define potential networks, mapped areas analysed to find potential linkage areas based on focal species. Existing zones mapped based on hypothetical dispersal and area requirements of focal species.	GIS polygon analysis. Generic focal species approach, mapping existing and potential networks and detailing potential expansion and linkage areas
(Ray et al., 2004b)	Woodland buffered to define potential networks, mapped areas analysed to find linkage areas based on focal species. Existing zones mapped based on hypothetical dispersal and area requirements of focal species. Resulting maps and networks analysed to determine the predicted potential species and populations able to be supported. Gives insight into where work may be able to be planned.	GIS polygon analysis. Generic focal species approach, mapping existing and potential networks and detailing potential expansion and linkage areas
(Russell et al., 1997)	Created suitable hydrology zones using DEM analysis and hydrology flow / flow accumulation. Sites classed by suitability / priority by classifying wetness index by current classified habitats, some habitat prioritised fro existing value and conservation, some classed by restoration potential – ultimately GIS select sites within minimum distance to existing sites and of a minimum size	GIS raster analysis Site selection for restoration using GIS selection techniques and hydrology modelling
(Smithers, 2000)	Mapped areas of woodland and AWS and calculated core areas and local density based upon 10km grid squares. Creation prioritised where the % of AWS that is semi-natural is low and where the current cumulative core area of semi-natural habitat was low	GIS raster mapping and analysis. Surrogate planning to target woodland conservation and creation at national scale
(The Woodland Trust, 2002)	Mapped areas of woodland and AW types and calculated core areas and local density based upon 10km grid squares. Creation prioritised where the % of AW that is semi-natural is low and where the current cumulative core area of semi-natural habitat was low Included mapping and description of the identified priority creation zones	GIS raster mapping and analysis. Surrogate planning target woodland conservation and creation at national scale
(Thompson et al., 1999c)	GIS to collate land use and slopes data and map existing resource Suitable geology, slopes and land use identified for conversion / restoration. Used classification to analyse current and potential tiers.	GIS raster and polygon analysis Outcome mapped existing and potential conservation zones
(van Rooij et al., 2004)	Results of eco-profile species mapping used to map connectivity and to map options for landscape design and expansion. Zones mapped by connectivity / spatial cohesion, then areas mapped for each eco-profile identifying viable habitat networks Final results combined to map provisional ecological network across multiple ecosystems, each represented by results of one or more eco-profiles	GIS mapping of landscape design strategy. Eco-profile based conservation planning

Table A6.7
Strategy implementation. Scoring and optimisation based studies

Reference	Method	Scoring method	Study summary
(Bayliss et al., 2003)	Patches given 5 criteria based on biotic and abiotic values. Patches given scores, rank and combined rank based on equal weighting of all criteria	Simple selection algorithms select high rank site and land adjacent to high ranking sites using shared perimeter and patch class	Multi-criteria targeting of habitat conservation and expansion. Ranking of patch score
(Brooker, 2002)	5 raster grids analysed to assess suitability for wood expansion or enhancement. Rules: increase small patches, add habitat between existing patches, expand on correct soil types, only in ecological neighbourhoods, avoid existing patches	Score created by linear combination of grids with equal weighting	Cells in GIS coded by desirability / habitat suitability. Classified vegetation conservation desirability system
(Gkaraveli et al., 2004)	Cells given values based on designation and isolation distances, also PAWS polygons coded	GIS used to score with weighted linear combination. Weightings based on habitat type and isolation values	Cells and polygons in GIS coded by desirability / habitat suitability Multi-criteria evaluation, raster and polygon scoring in GIS
(Griffiths et al., 2004b)	Land parcels scored by existing habitat, size and isolation from broadleaved woodland	Desirability score for each land parcel weighted by scores for each Landscape Type to reflect a different scale of prioritisation. Scores priority areas by most appropriate landscape type in addition to analysing local neighbourhood around potential sites	Scoring of land parcels in GIS. Two scale scoring of woodland BAP action work
(Lee et al., 2001b)	Patches given 4 abiotic scores and scores based on species records. Two criteria, abiotic and biotic ranked separately to identify high ranking sites of core interest to conservation. Then correlation between two methods tested	Hotspots identified as highest potential / current conservation value and enhancement potential.	Ranking of polygon patch scores in GIS. Multi-criteria targeting of habitat conservation and expansion, hotpot analysis
(Palik et al., 2000)	Polygons / Patches analysed both against current land use and against their previous, predicted extent under a land use classification system. Scores based on calculating current area versus potential past area, and the degree of current dissimilarity between the two habitat / ecosystem types	High priority given to index where current area of habitat is low but in the past if was high, also high priority given to areas where there is only a small difference between current habitat type and past habitat type as ease of restoration will be higher	Scored polygons based on restoration potential index (RPI). RPI scoring based upon hierarchical analysis of landscape potential versus current landscape composition
(Purdy and Ferris, 1999)	Raster GIS used to assign values for woodland creation, but individual PAWS polygons classified by restoration potential Variations of strategies and different data resolution were examined within the test area	New wood creation based on raster grid "desirability" scoring, with moving window analysis. Scores based upon woodland size, type and relative isolation. Results per raster GIS cell	GIS raster and polygon based scoring within moving window analysis. GIS based raster grid cell and woodland polygon conservation and restoration scoring
(Russell et al., 1997)	Classified areas as low, med, high priority for preservation or restoration. Utilised size, isolation rules and hydrology modelling in addition to existing habitat cover maps	Simple classification rules applied in GIS, landcover classified by categorised hydrology index to derive high, med and low priority sites	Cells classified in raster GIS. Restoration and preservation zone modelling
(Thompson et al., 2001b)	Sites ranked by value based on abiotic patch criteria. Land use classified by conversion potential to woodland Ranks analysed in GIS and compared to existing species records. Correlation of ranking abiotic vs. biotic	Ranking of scores from different characteristics	Patches / polygons classified in GIS. GIS score ranking of current value and restoration potential

Appendix 7

Appendix 7.1

GIS source datasets

Ancient Woodland Sites Digital Inventory

The "Ancient Woodland Sites" data was downloaded from the English Nature website (http:www.English-nature.org.uk). Errors present within early source file from the website were corrected by comparison to other AWI data and subsequent editing. A single file was then created from the four source files by using the "Append" function of ESRI's MapMaker. The file then contained the range of information detailed below. The file visually displays both the areas of replanted and ancient semi-natural woodland.

Field name	Information
Aw_id_number	Unique identification number for each site
Aw_total_area	Total area in hectares of each site
Aw_semi_nat_area	The semi-natural area of a site in hectares
Aw_replanted_area	The replanted area of a site in hectares
Aw_grid_ref	6 figure grid reference of each site (the central point will always fall in the largest polygon)
P_wood_type	Whether that part of a woodland is semi-natural or replanted
P_semi_nat_area	The area of that sem-natural polygon in hectares
P_replanted_area	The area of that replanted polygon in hectares
P_easting	Where the polygon is on the eastings of the OS national grid
P_northings	Where the polygon is on the northing of the OS national grid
P_grid_ref	The six figure grid reference of that polygon
P_label	Text string attached to the polygon
quadrant	Area of the OS grid that the wood is found in eg SK
Ten_km_square	The 10 km square the wood is in eg SK12.

Dataset summary: Paper inventory produced during 1980's. Digital data produced 2000. Scale of data capture: 1:25,000. Originally based upon aerial photograph interpretation. Accuracy: includes all ancient woodland sites of 2ha and above that were present on the relevant 1920's base maps. Original data based upon County based Ancient woodland inventories, locally these comprised: Derbyshire, South Yorkshire, West Yorkshire and Greater Manchester.

Interpreted Forest Type / NIWT data

Acquired from Forest Research in ArcView shapefile format. The dataset includes all areas of woodland of more than 2ha classified by their structure (Wright, 1998). The following system is used:

IFT Classification	Notes
Coniferous	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 be present but greater than 80% of the area will consist of conifers
Broadleaved	The canopy of broadleaved woodland is generally more uneven than that of coniferous woodland made up of rounded crowns but with variation according to species, age and height, and season. Boundaries with adjacent 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
Mixed	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%
Shrub	This area is intended to include areas that may possibly be woodland, where 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%
Ground prepared for planting	Land in this category is areas recently converted from some other land use to woodland and will show plough furrows or mounding but the new planting (if present) cannot be discerned
Felled	Areas of woodland where the trees have been harvested or felled. Stumps of felled trees may be visible and there may be long heaps of felling debris ("windthrows"). The edges of the felled area will probably be sharply defined. Some standing trees within this limit may also be present but should be disregarded The areas concerned may also have been re-stocked but the new trees are not yet visible
Young trees	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 either on land new to woodland or where a felled crop has been replaced. Alternatively this category may represent areas of notified Woodland Grant Schemes. Polygons may represent the extent of approved/paid Grant Schemes and therefore do not necessarily indicate planted woodland throughout the whole polygon. Young trees should be present within the polygon

Dataset Summary: Aerial photography flown 1991-2000, includes data on Forestry Commission new planting and new woodland Grant Schemes to 31st March 2000. Scale of data capture; 1:25,000 Aerial photograph interpretation. Accuracy of dataset; Includes all wood over 2ha, woods identified as having tree cover with a crown density of, or likely to achieve 20% and a minimum width of 50m.

Natural Area boundary dataset

Downloaded from the English Nature website (http:www.english-nature.org.uk).

Ordnance Survey Land-line dataset

The land-line dataset comprises detailed mapping containing a wide range of recorded detail from field boundaries to indications of areas of sloping ground, cliff faces and streams. The data were downloaded as individual ".ntf" tiles in vector format geo-referenced to the national grid from the Digimap website (http.edinac.ac.uk/digimap). The data were converted to ArcView shapefiles using the "ntf converter" within ESRI's MapMaker programme. The many separate files were appended into 3 shapefiles using the "Append shapefile" function of MapMaker. These three files held information on, (1) water feature network, slopes and cliffs, (2) field boundaries and buildings (3) roads and other transport networks. *Dataset Summary:* Date of data capture; unknown, Scale of data capture; The tiles are mapped at variable scales depending on terrain and urbanisation. The majority of the area was mapped at 1:10,000 with rural areas at 1:5,000 and urban areas at 1:2,500.

North Peak Environmentally Sensitive Area (ESA) land-use dataset

This dataset was acquired from the Department for Environment Food and rural Affairs (DEFRA) in ESRI ArcView shapefile format. The dataset "North Peak Landcover Data" includes mapped polygons of land-use falling within the following categories within the North Peak ESA:

Landcover Habitat Class	Report Class	
Bare ground	*Bare ground*	All bare mineral soil (not peat) with less than 10% vegetation cover Minimum map unit of 30m x 30m.
Dry bog non-heather dominant	*Billberry/ Crowberry moorland*	All land with greater than 25% cover of dwarf shrubs other than heather (or > or = 13% if heather is also present within the 25%). Unimproved acid grassland species or cotton-grass make up remaining % cover. Minimum map unit of 30m x 30m.
Dry dwarf shrub heath, non-heather dominated		
Continuous bracken	*Bracken*	All land dominated by bracken, with greater than 75% canopy cover, that is with fronds of adjacent plants touching Minimum map unit of 30m x 30m.
Cotton-grass moorland	*Cotton-grass moorland*	All land dominated by cotton-grass (50% or more cover) and/or Sphagnum (excluding Acid flush) with less than 25% dwarf shrubs. Minimum map unit of 30m x 30m
Wet bog		
Short term ley grassland / arable	*Cultivated land*	All land in cultivation including arable and ley grassland that has been recognisably re-seeded and will normally be a monoculture Minimum mapping unit of 30m x 30m
Bare peat	*Eroding moorland*	All land with a dense network of exposed peat and eroding peat channels with 0-75% vegetation cover. Minimum maps unit of 30m x 30m
Eroding moorland		
Molinia dominated grassland	*Grass moor*	Unimproved extensive grazing dominated by acidic grassland species, either >25% purple moor grass or > or = 30% other unimproved acid grassland species Minimum mapping unit of 30m x 30m
Unimproved acid grassland		
Dry bog heather dominated	*Heather moor*	All land with greater than 25% heather cover (or >or= 13% heather if other dwarf shrubs are present within the 25%). Unimproved acid grassland species or cotton-grass make up the remaining % cover. Minimum map unit of 30m x 30m.
Dry dwarf shrub heath, heather dominated		
Wet heath / acid grass		
Improved grassland	*Permanent grassland*	All grassland showing signs of improvement, including meadows and pastures, does not include ley grassland. Minimum map unit of 30m x 30m.
Semi-improved acid grassland		
Semi-improved neutral grassland		
Acid flush	*Rough pasture*	All grassland, whether improved or unimproved, with more than 25% cover rushes, including acid flushes. Minimum map unit of 30m x 30m.
Juncus dominated marshy grass		
Semi-improved acid rough pasture		
Semi-improved neutral rough pasture		
Broad-leaved plantation	*Woodland and scrub*	All land with more than 30% cover of trees or native shrubs. Minimum mapping unit of 30m x 30m.
Broad-leaved semi-natural woodland		
Coniferous plantation		
Mixed plantation		
Mixed semi-natural woodland		
Recently felled coniferous plantation		
Scrub		
Cliff	*Rock exposure and waste*	All land with less than 10% vegetation cover and a high proportion of rock
Quarry		
Scree		
Open water	*Open water*	Lakes, reservoirs, ponds, pits, canals, and rivers where there are two lines defining the banks shown on the map Minimum map unit of 30x 30m
Amenity grassland	*Urban*	All built up land including dwelling, industrial and farm buildings and amenity grassland.
Urban		

Dataset Summary: Date of data capture; 1993 and 1999. Scale of data capture; 1:25,000 Aerial Photograph interpretation Accuracy of dataset; Minimum mapable area of approx 30m x 30m (0.01ha). Coverage; North Peak ESA area. Data mapping reference: ADAS (1997).

Land-form Profile Data – Digital Terrain Model (DTM)

This dataset was supplied by the ordnance survey as a DTM model in NTF format. The ESRI Map Manager programme was used to convert the NTF files to ASCII raster format. Using the "bulk import" script within Spatial Analyst in ArcView the bulk importation of the ASCII files was carried out, incorporating suitable legends and with conversion to Grid Format. Following this conversion the files were joined to create one DTM file using the mosaic / merge scripts supplied with the MapManager program to create one grid fields from the many separate source files.

Geology Dataset

A copy of the 1:50,000 digital geology map of the Dark Peak area was acquired from the British Geological Survey. This was in ESRI Shapefile format and incorporated directly into the GIS system. *Dataset Summary:* Date of data capture; Produced by digitising paper historical maps. Scale of data capture; Original maps based on 1:10,000 fieldwork but simplified to 1:50,000 scale. Digital maps created from the 1:50,000 paper sources.

Woodland Grant Scheme Data

A copy of the full WGS3 dataset was obtained from the Forestry Commission. The last update utilised within the project was dated March 2005. The data required much preparation to create a useable dataset due to the presence of many overlapping data polygons. Individual field values were extracted and placed in new themes for analysis.

Historical Maps

Historical mapping was used during analysis of the ancient woodland site boundaries. Site – www.old-maps.co.uk. Site launched in 2000 and holds free access to 1St Edition County Series maps at c. 1:10,000. Dates from mid 19th Century. Most of the project study area was covered by maps between 1850–1880's.

Ancient woodland Inventory – County Reports (paper report and mapping)

The various county AWI were produced in the late 1980's. The Project utilised the County Reports from Derbyshire, S. Yorkshire, West Yorkshire and Greater Manchester. These reports used a variety of sources to determine "ancient woodland sites". All woodlands above 2ha were recorded from early maps OS 1:25,000 First Series Maps (dates 1938 onwards). Woods were then checked against woods present on the First Edition OS map (Old Series). These maps were produced from 1808 to 1874 at a scale of 1" to 1 mile (1:63.360). In the Study Area these maps were produced from 1840 onwards. The reports note "it was always intended that the maps were "provisional" and included certain areas of unsure information so that if errors occurred then sites were positively included rather than risked being excluded....". The method used was:

1. First a list of sites was produced of all woods ABOVE 2ha on the OS First Series / 1: 25,000 maps (dates variously 1901 to 1939). So this identified currently present, large woods

2. The OS First Edition map (Old Series) – generally the 1" map (1:63.630) but occasionally in conjunction with the OS First Edition (County Series) 6" map (1:10,560) was then checked for presence of the woods (dates variously 1840–1855 for the 1" and 1854-85 for the 6")
3. Evidence on these woods from ground surveys or place name / archaeology research.

From these identified sites present in the mid 1800's a variety of sources and in some cases surveys were used to determine if these could be considered ancient woodland. Some were then removed from the list at this stage if information was available to show they were not ancient. In a minority of cases field place name and other information was used to add sites to the register where they were not present on earlier maps. This is particularly the case where "non-commercial" woods may not have appeared on early maps. Therefore a combination of maps and other evidence was used to draw up the list of sites. In the production of the AWI register this was followed up by the use of current aerial photo or ground survey / Phase 1 habitat information to label the woods as currently semi-natural or plantation. The following variations of ancient woodland stands were also classified as semi-natural for the purpose of the inventory, largely due to a lack of detailed site information or due to their location within an otherwise undisturbed ancient wood.

1. Birch woodland which occurs on disturbed ground inside ancient woods.
2. Small secondary, semi-natural stands within ancient sites that may have developed on former settlements, gravel pits etc.
3. Woods where semi-natural stands have been slightly modified by planting e.g. mixed woods containing a scattering of ornamental conifers or sweet chestnut (*Castanea sativa*) in mixed coppice.
4. Woods containing self-sown sycamore (*Acer pseudoplatanus*)

The inventory reports note that the identification of plantations of mature, native broadleaves was often difficult from aerial photographs. There are usually no obvious rows or other indications of planting. In some cases these may have been erroneously regarded as semi-natural.

Moss Vegetation Map: 1870's

Within the Peak District a historic vegetation map was produced by Moss in the 1870's. This was not concerned with directly assessing continuity of woodland sites does provide a map of important woodland areas, from which a certain amount of historical information can be derived. From the text of the accompanying report on the map it is evident that the area mapped by Moss as current oak wood or degenerating oak wood have held cover for some time and would be expected, especially in the case of degenerate oak wood to hold cover of old trees. These trees would be expected to be at least 100 - 150 yrs old if not much older. Therefore a conservative estimate would place these woods as being in existence since at least 1770 – 1720. It is of interest to note that the Moss map highlight these sites as "woodland", even though it may be classed as degenerate, but that the same sites may not be classed as woodland on OS maps or Estate maps in that some of the areas occur on riversides or open moorland slopes and would not have been considered to be commercial "woodland" types, therefore had less value and less need to be mapped. This comparison gives good insight into the different interpretation of map sources.

Phase 1 Equivalent Map Surveys

Paper habitat maps with the Phase 1 mapping system were examined. The maps were used to aid in the Aerial Photograph Interpretation work and in the creation of the datasets relating to the total woodland cover information discussed below. The quality of the data within these maps was variable, dated, and had limited coverage in certain areas. However this remains the most complete ground based dataset for several areas of the Dark Peak.

Data summary: Mapping was available from Derbyshire, South Yorkshire, Greater Manchester. Maps were produced during the mid to late 1980's. Scale of survey: Paper mapping at 1:10,000 scale.

Aerial Photograph Interpretation –ESA / National Park and MultiMap

Aerial photographs covering the North Peak ESA area were acquired from MAFF (now DEFRA). The photographs were utilised in conjunction with the Ancient Woodland dataset, Interpreted Forest Types, ESA landcover dataset and the various Phase 1 equivalent surveys of the National Park. The various datasets were compared visually within the GIS, any additional areas of scrub or woodland or scattered trees not present within the data were digitised. Where the aerial photos were available in GIS format the sites were digitised over the top of the aerial photos, where photographs were only available as stand alone images the coverage of the sites was estimated by eye and digitised into he GIS. The aim of the use of the aerial photographs was to identify areas of sparse scattered trees, as these were not recorded within other surveys. However small, sparse or open areas of scrub or woodland were also mapped where these did not also occur within other surveys. The methodology for the addition of data from the aerial photographs was as follows:

- Areas of woodland, scrub or scattered trees above (changed) 0.1ha (approx 30m x 30m size polygons) were digitised where they were absent from the IFT overlay.
- These were mapped where there was often a clear visual boundary and canopy density was in the range of 30-100%.
- Obviously linear areas of woodland, e.g. along roads where not digitised where they appeared to be less than 3 trees wide.
- Small areas of scattered trees or lines of riparian or field boundary trees were not digitised where these were present within enclosed field systems.
- Only "significant" sites were attempted to be identified and digitised, therefore not every field tree or copse could be added.
- Scattered trees were classified as:

Category	Dense	Open
Description	loose formations of trees or scrub, open to locally dense	very loosely scattered trees
Total cover within mapped area	10-30% locally	2-10% cover locally
Accuracy	Mapped separately where distance between pockets of scattered trees > typical inter tree distance within pockets	Sites only mapped with a minimum of 5 trees present. Sites with trees wider apart than 150m were not mapped
Boundaries	Boundaries difficult to map	Mapped boundaries are artificial and serve to encompass the collection of trees
Transitions	Where sites were split between those categories the dividing line was placed approximately along 50% of the line of gradation	

Appendix7.2

Assessing the accuracy of source digital datasets

The project included an assessment of the two main digital woodland habitat classification datasets available, the National Inventory of Woodland and Trees (NIWT) and the Environmentally Sensitive Area land use survey (ESA). An initial stage in the development of the GIS was also an assessment of the Ancient Woodland Inventory (AWI) data and identification of opportunities to increase its accuracy. The location and status of the AWI sites was of prime importance to the project, therefore significant time was spent investigating the accuracy and potential use of this dataset. Several data sources were available to the project that allowed an assessment of AWI accuracy:

- Digital English Nature (EN) Ancient Woodland Inventory (AWI) – constructed nationally from county-based inventory reports.
- AWI digitised locally by the Peak District National Park Authority (PDNPA) to site boundary level, without classification of replanted or semi-natural polygons (pdAWI).
- The English Nature county-based reports including paper maps of Ancient Woodland sites.
- Detailed information within case study areas including ecological and archaeological surveys and interpretation of locally available historical maps.
- Digital 1st Edition 6" scale (1:10,560) and 25" scale (1:2500) County Series OS maps dating from the mid 19th Century.
- National Inventory of Woodland and Trees (NIWT) data classifying all woodland over 2ha in size by canopy dominance type (Wright, 1998).
- Environmentally Sensitive Area (ESA) land use survey providing a full habitat classification of all habitats over 0.1ha.

Appendix 7.2.1

Comparing local and national AWI datasets

The national (AWI) and locally produced (pdAWI) inventories were compared. Each was examined by comparing coverage on the AWI and pdAWI against underlying Ordnance Survey (OS) map features (dry stone walls, rivers, streams, roads) and noting consistent differences. The following conclusions were drawn:

- In "enclosed" situations where field boundaries occurred the datasets were very similar.
- In unenclosed situations (cloughs, moorland fringe sites) significant differences in mapping accuracy were apparent.
- The pdAWI data was more accurate, for example regularly splitting sites to account for the presence of roads and other features.
- Certain sites showed very large discrepancies between the datasets.
- The most common difference was that EN AWI sites were larger and less accurately mapped in moorland fringe and clough situations.

The comparison of the data sources indicated that while the EN data had been digitised to account for the naturalness category of the woodland sites, accuracy was limited by its scale of digitisation. The availability of more accurate maps at the time of digitising led the PDNPA data to be more accurate. It was clear that potential existed to improve the accuracy and scale of resolution of the AWI dataset by utilising the original source EN paper maps while referencing underlying features visible on detailed OS GIS maps. All pdAWI sites were listed where there was some discrepancy with the underlying EN dataset. For these, the original county-based AWI report maps were examined. In cases where differences were due to apparent digitising errors the AWI dataset was updated to match boundary features on the OS Landline dataset. This enhancement was carried out between 1:2,500 and 1:5,000 scale. This process increased the accuracy of the EN data and the updated EN AWI dataset (upAWI) was used in all further analysis.

Appendix 7.2.2

Comparing the accuracy of AWI mapping

Two case studies were carried out to examine the quality of AWI data when further range of data sources were available. A range of archaeological and ecological information were available in the Upper Derwent Case Study Area. (Bevan, 1999; Winn, 2002). The purpose of the data comparison was:

- To examine the accuracy of plotting of EN AWI / upAWI sites
- To examine the accuracy of the EN AWI / upAWI site status classifications
- To examine the potential for the use of the 1st Edition OS 6" scale (1:10,560) and 25" scale (1:2,500) County Series maps in the identification and mapping of Ancient Woodland sites across the Dark Peak.

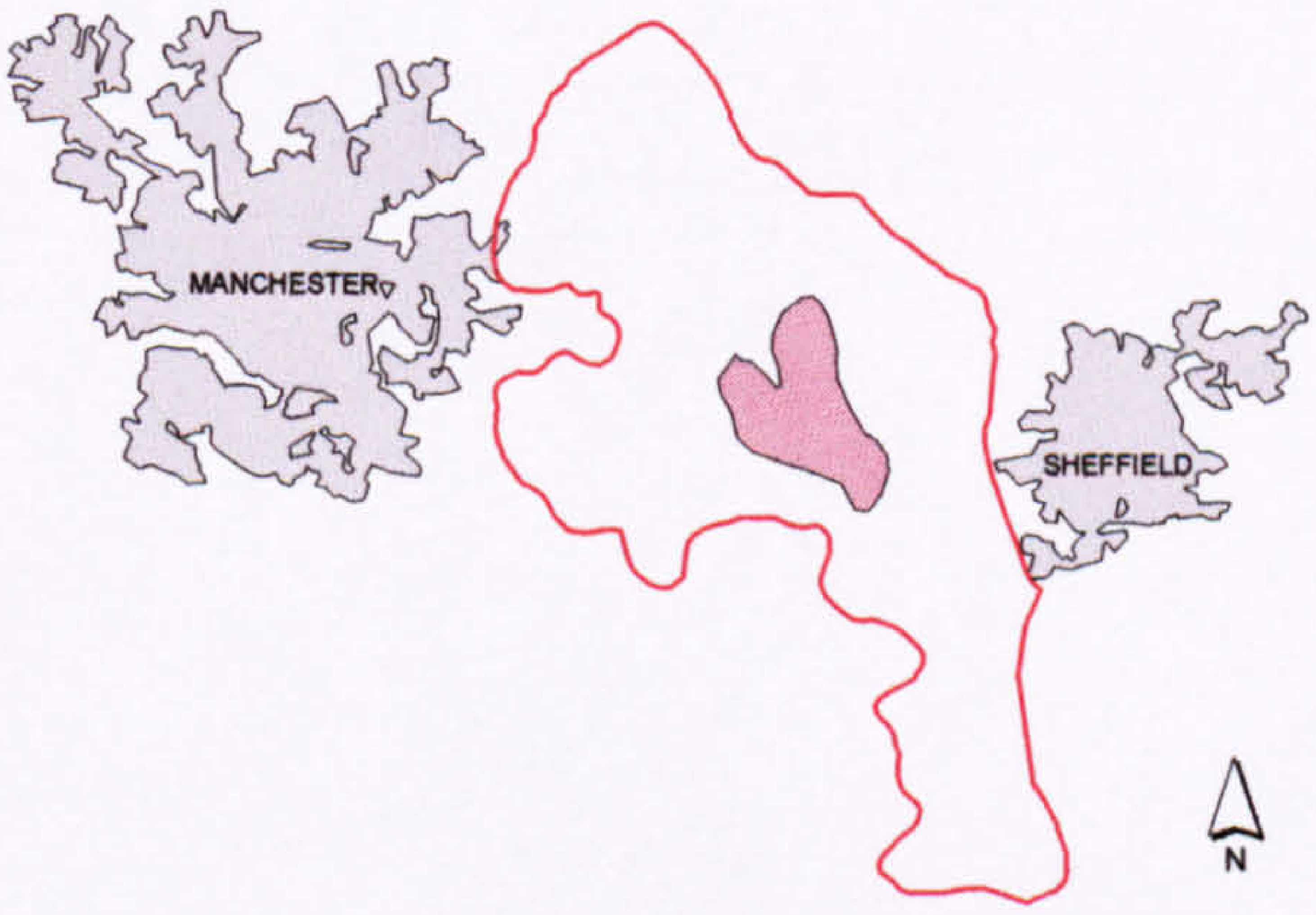


Figure A7.2.2.1
Location map of the Upper Derwent Case Study Area in relation to the Dark Peak Natural Area

Archaeological information was compiled by Bevan (1999) into "woodland change maps" detailing the changing status of woodland cover over time. This survey was more accurate than the evidence used to compile the original EN AWI. Ecological data resulted from recent site survey work (Winn, 2002). In addition to maps summarised within Bevan (1999), available historical mapping for the area included the OS 1st Edition 6" and 25" maps together with a copy of the Moss Vegetation map from the 1870's depicting major vegetation types across the Peak District. Maps were digitised and incorporated into the

GIS. Each site was examined and the full range of data sources viewed, allowing the presence or absence of woodland cover to be examined for time sequences through each of the data sources.

Table A7.2.2.1
The range of historic map based evidence available within the Upper Derwent Study Area. (B) = reported within Bevan, (1999), (L) = viewed within library, (D) = available as digital map source, (Fwk) = fieldwork survey maps, (W) = reported within Winn (2002).

17th C	18th C	19th C	20th C	21st C
1627 Senior (B)	1781 Elliot (B)	1808 Estate (B)	1920 OS 6" (D)	2002 (Fwk) (W)
		1810 Estate (B)	1925 OS 6" (D)	
		1840 OS 1" (L)	1955 OS (B)	
		1854 OS 6" (D)	1999 (Fwk) (B)	
		1858 OS 1" (B)		
		1870 c. 1" (L)		
		1878 OS 25" (D)		
		1880 OS 25" (D)		
		1880-81 OS 25" (D)		
		1882-83 OS 6" (D)		
		1898 OS 6" (D)		
		1898 OS 25" (D)		
		1899 OS 6" (D)		

Ecological Map Data Case Study EN AWI polygons were compared against ecological surveys for 8 Ancient Woodland sites in the Upper Derwent Valley. Each polygon was compared against the digitised Ecology survey and modified, where necessary, to reflect the information in the Ecology survey. The resultant polygons were compared to the original polygons and the differences recorded.

Table A7.2.2.2
Comparison of areas mapped by original EN AWI data and derived from fieldwork ecological surveys in the classification of Ancient Woodland habitats.

Class	Data Source	Polygons	Area (ha)
Semi-natural	EN AWI dataset	2	5.6
	Modified AWI	7	2.2
Replanted	EN AWI dataset	6	109
	Modified AWI	8	112.3
Total	EN AWI dataset	8	114 6
	Modified AWI	15	114 6

Results indicated the distinction within the EN AWI data between "semi-natural" and "replanted" was inaccurate for some sites. This was potentially caused by factors such as the dominant tree species or aspect and the degree of slope, all of which may affect the accuracy of classification from aerial photographs. In particular EN AWI mapping missed small areas of semi-natural habitat that could only be detected by ground survey and not from aerial photograph interpretation.

Historical Map Data Case study Bevan (1999) summarised archaeological information for the area, while additionally a variety of digital OS maps were available. Each AWI site was examined, the full range of data sources compared, and a table compiled listing the presence/absence and nature of depiction of woodland or tree cover at each site, for each of the main data sources. Site location was noted as enclosed or unenclosed, a classification that changed for some woods over different time periods. A positive record on a map source was given more weighting than a negative / absence record, with absence from a single map date not considered sufficient evidence for deletion of a site. Ultimately a decision for the location and boundary of the site was made from several sources and this was utilised to change the AWI data, for example where two or more map sources from two or more dates showed a consistent woodland boundary or presence. General notes were also taken on the relative accuracy of AWI cover in comparison to available datasets. Finally, summarised information from sources was used to modify the

EN AWI dataset to reflect the boundary of continuous woodland cover at each site. When all sites had been examined the modified dataset was compared to the original EN AWI data.

Table A7.2.2.3
Confirmed woodland age of Ancient Woodland sites within the case study area.

Confirmed age	Map date	No of sites	Site area (ha)	Total site area (%)
17th C	1627	15	107.84	40.9
18th C	1781	4	63.53	24 1
19th C	1808	4	26	9.9
19th C	1840-42	7	40 6	15 4
19th C	1870	3	25 7	9 7

Table A7.2.2.4
Estimated woodland age of Ancient Woodland sites within the study area. All sites mapped as "degenerate woodland" on Moss 1870's map have been assumed to be at least 150yrs old at the time of map production and are therefore estimated as being in existence since at least 1720.

Estimated age	Confirmed woodland age	No of sites	Site area (ha)	Total site area (%)
17th C	1627	15	107.84	40 9
18th C	1720	4	34 8	13.2
	1781	4	63.53	24.1
19th C	1808	4	26	9.9
	1840-42	6	31 5	11 9

Table A7.2.2.5
Comparison of published EN AWI dataset and Archaeological map

Ancient Woodland Inventory Data	Area (ha)
EN AWI data	249.5
AWI modified by Archaeological and historic map data	264

The original AWI was provisional and erred on the side of caution, sites were retained where there was uncertainty. This methodology was again followed. Given the wide range of data sources being compared, the original "purpose" for the depiction of map features varied. The Moss Map (1870's) was concerned with identifying broad vegetation types with emphasis perhaps highlighting sites Moss considered to be important examples of these habitats. The estate maps produced by Senior and Elliot and re-produced in part in Bevan (1999) were concerned with land falling within the Estate boundary and concentrated on detailing features of importance to the estate, financially or otherwise. The summary maps produced by Bevan (1999) are also in part an artefact of the purpose of his study, in examining the woodland history of the area from a predominantly management perspective. This was apparent in the areas mapped and considered woodland by Bevan in comparison to the original source OS maps. The current study has occasionally differed in the classification of woodland cover on sites compared to Bevan (1999). Differences were principally due to the degree of tree cover remaining during times of woodland "absence". Within the current study sites were considered continuously wooded where even shown as reduced to scattered tree cover for a short period of time when this occurred at sites within the unenclosed / moorland fringe zone. Additionally, although seen most consistently in comparing between OS maps, all maps used were limited by the scales at which they were produced. For any given scale there will be features that were too small to map. Large scale maps such as the 25" maps showed smaller woods than small scale maps such as the 1" maps. In addition to the effects of the omission of features and woods from some of the maps the nature in which woodlands were mapped and portrayed also differed with scale. Sites that may be shown as woodland on small scale maps may be able to be more accurately mapped as scattered trees or loose collections of trees on more detailed.

Table A7.2.2.6
Minimum map features recorded on the different OS scales

Map Source	Mapping limitations / notes
1" OS Map	"minor names of individual woods are shown only very selectively" (Crawley, 1975).
6" OS Map	Features smaller than 1ha are not normally shown. Various different categories of woodland, trees and brushwood are mapped.
25" OS Map	Research and include notes on notes on wood names / boundary types / woodland mapping / scattered tree mapping / furze / rough ground etc

When determining levels of accuracy by which sites were considered to be ancient, sites were labelled by the earliest map evidence establishing woodland presence. With the majority of maps the earliest recorded date can be interpreted as sole proof of the presence of the woodland since that date. It may be possible that woodland was only recently planted before the production of the map and therefore there can be no proof of the presence of the wood before that date. However for some information sources knowledge of the location of the site, or additional map information allowed an interpretation of the presence of woodland before the map production date. For example the presence of confirmed woodland on a map in a location where woodland is highly unlikely to have been planted strongly indicates the presence of natural woodland for some period of time before the map date. Similarly the Moss map indicates a category of woodland mapped as Degenerate oak / birch woodland. For these woodland sites to be considered degenerate in the 1870's indicates they have been present on that site prior to the production of the map, for a period of time long enough for trees to have matured and declined.

Using the map information available some sites have evidence of continuous cover from 1627 to the present day while others appear absent from the earliest estate map of 1627 but are shown on later maps. Other sites appeared on early maps but may be shown as absent from certain later maps. In some cases these periods of "absence" mapped by Bevan (1999) are shown on OS maps as periods of scattered tree cover. Such sites were retained on the upAWI where they were only absent from one data source over a limited period of time and due to the remaining evidence for these sites still suggesting a long period of woodland cover. Many of the sites within the case study, when examined purely from historical map sources could be more accurately termed "long established woodland" sites, rather than true ancient woodland sites. However noting the locations and terrain of many of these sites it would be highly unlikely that many did not retain some level of woodland cover even in periods of past forestry or grazing use. The majority of sites from the study were therefore retained as AW status sites except in cases where there was clear evidence of woodland removal and absence over a period of time. Areas of continuous woodland cover in these upland situations may in fact undergo fluctuations between wood pasture, scattered tree cover and more dense woodland conditions. Such fluctuations may cause woodland sites to expand and contract, perhaps driven by varying levels of grazing pressure and intensities of land use over time, but may retain some degree of ecological continuity of species. A more important change is the direct conversion of woodlands to agriculture by clearance followed by an intensive land use. The accurate interpretation of past woodland cover in these areas is problematic. Some areas not recorded in the detailed estate maps reviewed by Bevan (1999) for example at Castle wood (SK140910) and Alport wood (SK141897) may be relatively confidently considered long established / ancient due to their presence on older OS maps, the Moss map and location / topography. These areas were likely to have retained natural woodland cover for some time, but to have perhaps not been considered "woodland" by the estate maps as they were likely to have been relatively open pasture woodlands and consisted of "scrub" species without timber value such as Downy birch (*Betula pubescens*). In contrast areas at Banktop / Westend farms (SK151392 and SK 159933) contained areas of distinct "woodland" mapped by the estate maps. These areas were more likely to have been protected from grazing and produced higher quality timber crops and /or coppice. In summary the historic map data Case Study indicated:

- 41% of the area of Ancient Woodland Sites was confirmed as true Ancient Woodland in existence since the 17th Century while for 35% of the area of the sites the earliest available map based evidence was from the 19th Century and possible AW status has to be inferred from additional factors.
- When historic data was combined with ecological interpretation a high proportion of sites were considered likely to be true Ancient Woodland Sites (in existence since c.1600) but significant areas of these sites may more accurately be considered "long established woodland" in existence for at least c. 200 yrs, but may not be truly ancient.
- The exact location of EN AWI sites can be considered to be approximate, this is especially the case on open moorland / moorland fringe locations where map sources and dates may show different woodland boundaries. These may represent fluctuations in woodland cover or different accuracy in mapping.
- The mapped extent of sites may be generalised and represent an area of potential AW, within which several smaller, more numerous areas of AW may occur. This was principally due to the scale of mapping of the original sites, where small areas could not be accurately represented.
- The mapping of woodland on historic maps may be strongly linked to the perceived value or past management of woodland types. Woodland occurring within the "enclosed zone" was probably more likely to be managed, valuable, and to have been mapped than unmanaged woodland in the unenclosed zone.
- Knowledge of the ecological status of land surrounding Ancient Woodland sites can greatly enhance the interpretation of historical maps. Sites in the enclosed zone may occur adjacent to areas of pasture. In such areas woods are likely to be relatively intensively managed and enclosed from grazing. In unenclosed areas, where vegetation was unlikely to have been improved, woodland cover and decline may be due to broader landscape changes such as increased stocking levels and levels of timber use by local farmsteads. Remnant woodland sites occurring in unenclosed areas may therefore persist over long time periods at low densities and in some cases this may be a long-term cyclic phenomenon.
- The topography of woodland sites was an important consideration in the credibility of ancient woodland site status. Where sites occur on steep river ravines woodland products such as coppice and timber could have occasionally been harvested but woods were unlikely to have been grubbed out, and stock were unlikely to have been present in sufficient numbers, or to have had sufficient access to have grazed out such sites. Different stock types in different eras would have also had different mobility in such steep terrain areas; with for example cattle generally being less likely to graze very steep slopes than sheep.

In summary, the wide range of historic data enabled the accuracy of mapped EN AWI sites to be greatly increased, involving modification to boundaries, location and classification of many sites. The case study confirmed that available digital historic maps - County Series (OS 6") could be used to increase the accuracy of the AWI sites and boundaries. This was especially useful in confirming the detailed boundaries of sites when different dates of County Series maps were available to confirm the exact site boundaries over time. The case study also showed the variability of evidence used to class sites as ancient woodland and highlighted that many sites within the Dark Peak may best be termed "long established woodland".

Appendix 7.2.3

Assessing the accuracy of woodland habitat datasets

Following the methods outlined for AW sites, further data was required to classify the woodland habitats occurring within and around the AW resource in the general woodland network. Two sources of woodland habitat data were available, the National Inventory of Woodland and Trees (NIWT) and the Environmentally Sensitive Area (ESA) land-use datasets. Initial examinations compared their relative accuracy for two study areas; The Upper Derwent area, (a local concentration of AW sites, where recent survey results existed) and Longdendale area (where previous ecology surveys existed for AW sites).

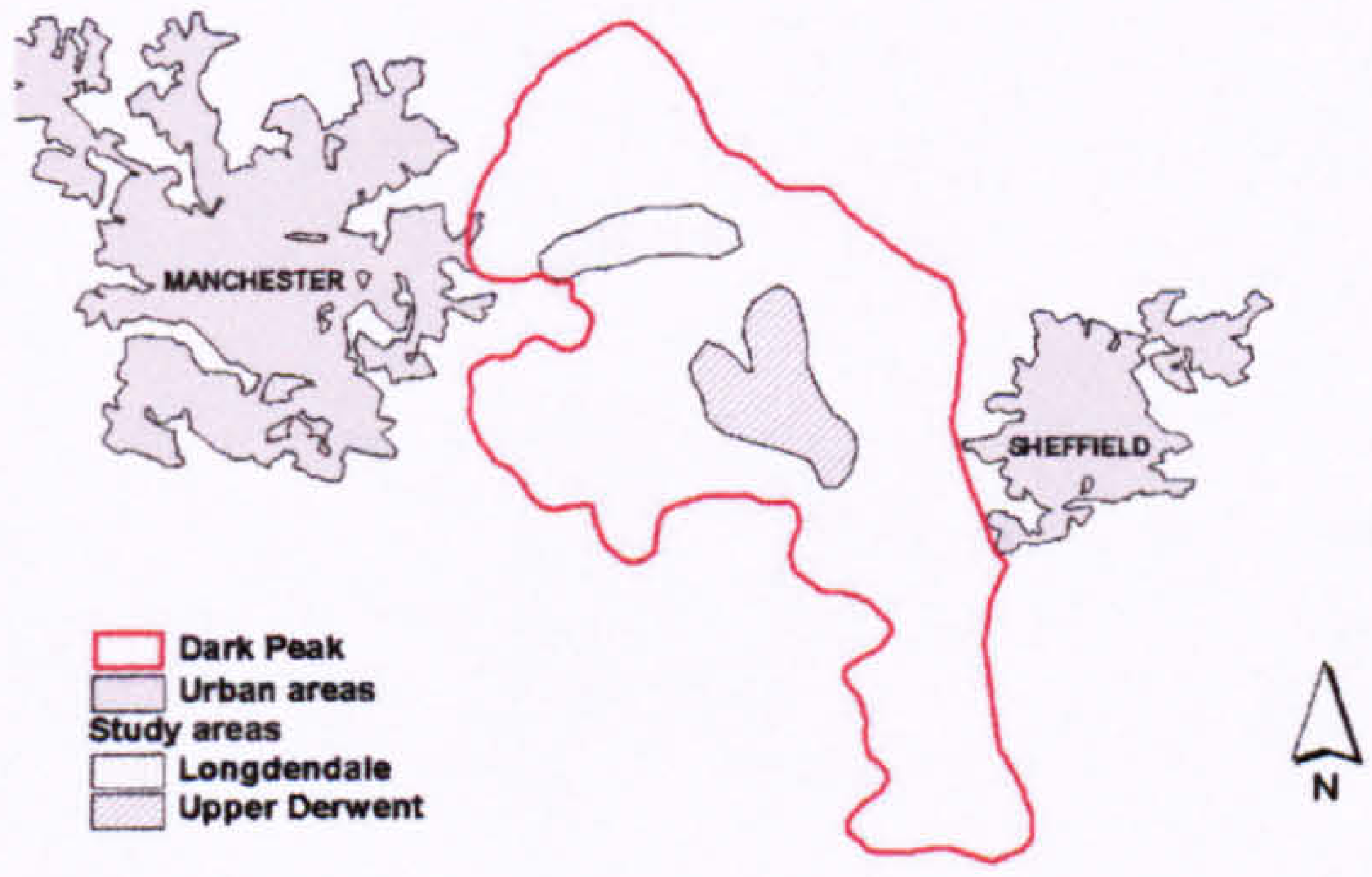


Figure A7.2.3.1
Location of the Upper Derwent and Longdendale Study Areas within the Dark Peak Natural Area

The AW sites in each study area were selected and the upAWI, NIWT and ESA data were compared in relation to the extent, classification and boundaries of each polygon. During this process the paper based AWI maps and ecological site survey reports from these sites were also examined. The results of this comparison are presented below.

Table A7.2.3.1
Differences in the accuracy of mapping of polygons features between the three digital datasets. (NIWT = National Inventory of Woodland and Trees, ESA = Environmentally Sensitive Area, upAWI = updated Ancient Woodland Inventory).

Data	Location issues	Mapping Accuracy	Classification accuracy
NIWT	NIWT data showed locations of recent management, young woodland, new planting and felling operations that did not occur within other datasets.	NIWT more readily mapped larger blocks of woodland as one polygon when sites were shown as separate polygons on the ESA data – indicating the ESA dataset was more accurate.	NIWT data showed locations where woods were classed as "young trees" or "shrub" and where other datasets also showed woodland. In these areas the NIWT data allows age / structure information to be transferred to the on the ESA data.
ESA	Generally there was a very high degree of overlap and agreement between the NIWT data and the ESA data in terms of extent and location.	ESA mapping was considered more accurate, mapping smaller, more numerous and separate polygons and less likely to create "cluster" polygons when sites actually comprised several separate woods compared to the NIWT data.	In several cases NIWT data differed on the classification of polygons compared to the ESA data even when boundaries were very similar. These polygons were typically mixed or coniferous woodland.
upAWI	Areas existed within the boundaries of AW Sites that were not mapped by either the ESA or NIWT data. Indicating that no woodland cover was present within areas of the AW sites.		Rarely for some of the smaller AW sites e.g. linear strips of broadleaved wood among larger coniferous woods, the ESA survey did not classify these areas separately from the surrounding woodland. Therefore in limited cases AW sites marked as semi-natural within the upAWI may be classified as plantation by the ESA data.

ESA data was more accurate than the NIWT data, within the ESA, while two categories of woodland, young woodland and new planting only occurred within the NIWT dataset. For additional woodland categories the NIWT data was considered more accurate than the ESA data. When compared to the woodland habitat datasets the upAWI dataset occasionally contained areas of land that were not classified as woodland by the ESA or NIWT. This indicated that pockets of AW site, although classified as Replanted or Semi-natural by the AWI may actually hold areas of open ground, non-woodland habitats.

Appendix 7.3

Increasing Ancient Woodland Site mapping accuracy

The results of the Case Studies indicated the need for a consistent accuracy assessment of all Ancient Woodland Sites. AW sites were updated by reference to the following data sources:

- Upper Derwent archaeological study
- Chatsworth Archaeology survey reports
- County Series maps (6" scale / 1:10,560) available digitally
- Current woodland cover as shown on the NIWT (FC data).
- EN Paper County based AWI reports
- 1:50,000 OS maps.

The County Series maps were the main resource used, being the only historic source available across the entire Natural Area. All sources were examined and used to further update the upAWI sites.

Upper Derwent Archaeological Study All the results of the Case Study comparisons in the Upper Derwent area were incorporated in the main upAWI file used within the GIS.

Chatsworth Estate Survey Reports The Chatsworth Estate report did not include detailed "woodland changes" maps, but included estate map reproductions. These were used together with the text of the report to clarify AWI status at several sites (Barnett and Bannister, 2002).

Digital County series (6") Historic Maps Each upAWI site boundary was examined and compared against the cover of woodland shown on available County Series, First Edition 6" (1:10,560) maps, accessible digitally for the entire Dark Peak (www.old-maps.co.uk). For problematical sites it was possible to purchase more accurate maps of a similar or slightly later date at a more accurate scale (25", 1:2,500 scale). These 25" maps were later available digitally within the Digimap service (www.digimap.co.uk). Sites were also compared against the current distribution of woodland cover as mapped within the NIWT dataset and current 1:50,000 OS maps. Sites were also compared against the original paper based County AWI reports in case digitisation errors had occurred in the digital dataset. For each site a range of data were recorded as to whether sites occurred in enclosed or unenclosed situations and the extent to which any boundary or extent changes could be mapped. The purpose of this exercise was to increase the accuracy of boundary mapping. A full chronological history of OS mapping at each site was not available at the time at which this stage of the project methodology was undertaken. Therefore cleared sites identified by the original AWI compilers were not examined in detail, the date of clearance not being obvious from early maps. Sites where there was no presence of woodland on early maps but marked as cleared were noted as possible errors. It was also noted that some cleared sites currently held woodland cover. At this stage the classification of these sites was not changed and they were not marked for survey. Following this updating process it was considered that changes made to the upAWI dataset led to an increase in mapping accuracy to approx 1: 10,000 scale across the Dark Peak. The updated upAWI was utilised in all subsequent analysis.

- Boundary accuracy improvements were possible where detail on County Series maps were used. This was especially useful where current AW sites occurred within expanses of other woodland types, where often these broader plantations had not been planted on the early historic maps.
- Where changes could not reliably be made by viewing County Series maps and it was possible other sources of information had been originally used to plot boundaries, these were not altered.
- Boundaries were altered, where possible, to reliable boundary features. However the upAWI boundaries were not amended to strictly match the area of woodland shown on the County Series 6" maps. The upAWI boundaries were not consistent with any one map source. Where small irregularities between the upAWI woodland boundary and boundaries shown on the County Series maps occurred these may show areas that were only recently felled, or coppiced on the 1800's 6" maps and may be present at other times and therefore not truly absent.
- In unenclosed sites the default for problematic sites was to retain the current upAWI site boundary and classification until survey. However in situations with sufficient information areas of semi-natural woodland and cleared areas were more accurately mapped. In such cases the boundaries of sites were matched to the extent of the woodland in the County Series maps, but only where the current distribution of woodland was the same as, or less than, the distribution present in County Series maps.
- Where significant changes were proposed, or significant discrepancies occurred between the upAWI and historic mapping, the site was noted and a list compiled for survey.

Ancient Woodland Site Locations Following comparison and mapping work the accuracy of the AWI dataset had been increased greatly. Several versions of the digitised AWI were then available to the project. These were the original EN AWI digital data (AWI), the AWI updated by comparisons to the PDNPA AWI (upAWI) and subsequent upAWI data amended following enhancements from the County Series maps (1800's) and associated historical and current woodland mapping. At this stage the updating of the AW boundaries was complete. With additional time the accuracy of the AWI boundaries could be increased further with the methods from the Case Study being applied to all the sites on the AWI and a full chronological map study being carried out for each site.

Appendix 7.4

Comparison of multiple historic map data for problematic Ancient Woodland boundary sites

Following the updating of the upAWI a list of potential problematic sites was created where only limited accuracy improvements were possible. Due to the availability of data and limited timescales further data was initially not acquired to consider these. However following site surveys a number of sites were considered to benefit from further accuracy improvements, by which time additional digital data had become available. For selected sites the full range of available map data were compared in sequence from the earliest available maps to current maps of woodland cover. For each site when sufficient comparisons were made any changes to the AW boundary that were required were noted and applied to the combined woodland dataset.

Appendix 7.5

Insights from woodland habitat surveys and habitat digitising

- There was some variability in the potential to distinguish scattered scrub (A22) from scattered trees (A32) during aerial photograph interpretation, in rare cases scrub (A2) recorded by aerial photograph survey were actually verified as Broadleaved, semi-natural woodland (A111) by ground survey
- When surveyed several sites that were originally classified by aerial photograph analysis as unclassified broadleaved woodland (A11) were actually coniferous plantation (A122) dominated by Larch. This conifer may appear broadleaved at certain times of the year when defoliated and errors may occur in the estimates of this type of woodland due to this. In rare cases during fieldwork sites noted as Broadleaved, semi-natural woodland (A111) by the ESA survey were also actually mixed plantation woodland (A132) with a high Larch species component
- Some woods encountered during fieldwork with abundant Rhododendron was coded as Broadleaved, semi-natural woodland (A111) instead of Mixed plantation (A132) or introduced shrub (J14)
- During surveys of semi-natural woodland identified by the PDNPA Section 3 areas map the polygons were often found to be broad zones that included smaller pockets of woodland or scattered tree cover rather than single woodland blocks. The PDNPA "S.3 other semi-natural woods" file however was a useful tool for checking areas of contradiction between Broadleaved, semi-natural woodland (A111) woods in the other digital data because it was more likely to have been based on survey data.

Appendix 7.6

Detailed buildings, transport network and urban theme creation methods

The OS Landline data was utilised, this has a high positional accuracy that ranges from 0.4m in urban areas to between 0.9 and 1.2m in rural areas up to 3.5m in mountainous upland areas (www.digimap.edina.ac.uk). This data was used to clarify where woodland had been digitised in error in urban areas, and to divide woodlands where they were crossed by roads or railways. The complex and lengthy methodology presented below was necessary due to the large number of features in the study area. The analysis was carried out separately for the area inside the DP and outside the DP and separately for the roads network and the buildings polygons before combining these in the final stages.

Creating the transport network All OS landline features relating to roads were selected within the GIS. Un-surfaced tracks were not included. The methodology created a roads polygon network buffered by 3m. This distance accommodated the pavement and accompanying grass verge. However it was not possible to directly buffer each line due to the large number of features present within the project GIS, meaning the computational limits of analysis within ArcView were reached. To increase the speed of analysis and overcome processing limitations each file was first dissolved into a single feature and then generalized to a positional accuracy of 0.5m in order to reduce the number of vertices. This was a suitable level within which the loss of accuracy was minimal. The buffering analysis was then carried out in separate stages with the Dark Peak divided into NE, SE, NW, SW sections. Files were subsequently combined using the ArcView merge command. A detrimental feature of the creation of the roads network by creating buffers was the creation of many small sliver polygons that occurred within or between the areas of buffered roads. These slivers represented areas of non data between the roads. To allow these slivers to be included in the analysis a background mask of the project area (DP and 10km +) was added to the roads network in each of the areas to create a single file representing the roads network and project area background mask. All polygons were then labelled by area and all small polygons less than 0.1 ha were dissolved into the roads network using the dissolve adjacent polygons extension (Jenness, 2005). These were generally holes within the roads network, i.e. areas of "background mask" data that represent small holes within the roads network. This analysis was carried out gradually due to the number of polygons present. Analysis was carried out in batches of 700-800 polygon dissolves in each analysis, the size of the minimum polygon to be dissolved being increased each time. In contrast to the area within the DP a continuous roads network was not required for the area outside the Dark Peak. Therefore for this analysis only the areas of roads features within 10m of woodland polygons were selected for the creation of the roads network. The roads file was then generalised to 0.5m to reduce the number of vertices and the whole file was then buffered by 3m. The resultant buffered transport network was dissolved using the Patch Analyst function (Rempel and Carr, 2003) and an area field calculated for each polygon. The file was then unioned to a background non Dark Peak landscape file and all polygons less than 0.1 ha were dissolved using the dissolve adjacent polygons extension (Jenness, 2005).

Creating the buildings network All OS landline features representing buildings inside the Dark Peak were selected. Limitations of computing ability due to the number of features present in the GIS meant buffering of the shapefile was not possible. The selection was therefore converted to a grid theme file with a cell size of 5m. The choice of cell size was a compromise between accuracy of representation by the raster data and speed of subsequent analysis. A distance theme grid was created from the 5m urban grid and a new grid theme created representing all land within 15m of the classified urban grid. This grid theme was converted to a vector shapefile which effectively represented all areas of buildings buffered by 15m with a background mask for all non urban habitats. Where houses occurred close together the buffer area had resulted in an amalgamation into large polygons. Therefore some large polygons represented towns and villages, while isolated farms or houses were presented by a single polygon with a 15m buffer. However within these amalgamated urban zones many small holes between the urban areas occurred where the buffers had not fully overlapped. To remove these holes within the urban areas all adjacent polygons less than 0.1 ha were dissolved (Jenness, 2005). This was the size below which the polygon was definitely less than one standard building in size. This removed small holes but also eliminated a very small number of buildings (4 -5). In order to accurately represent the urban areas, and to eliminate the excessive 15m buffer a 15m buffer was created on the inside of the polygon and the overlapping area removed leaving the actual urban areas without a buffer, but including amalgamated areas where they had formed due to the original buffer. However it was not possible again to directly buffer the file due to processing limitations. Therefore, the file was generalised to 3m (an acceptable compromise between resolution and processing ability). In contrast to the area within the Dark Peak a continuous urban network was not required for the area outside the Dark Peak. Therefore only the OS landline features relating to buildings within 10m of woodland polygons were selected for the creation of the urban network. The selection was then converted to a grid theme with a cell size of 5m. The same methodology as within the Dark Peak was then followed.

Creating the final combined Urban network Four files had been created, representing the buildings network and transport network separately for the areas within and outside the Dark Peak. Within the Dark Peak the buildings and transport data were combined using union and classified as urban land-use. Outside the Dark Peak the building file and transport file was also combined. Both the buildings and transport polygons were classified as urban land-use. All background mask polygons less than 0.1ha were then selected dissolved into adjacent urban areas based on the longest common border between polygons (Jenness, 2005a) thus eliminating many small gaps in the urban network. The two newly created urban network files for the Dark Peak and the surrounding buffer area were then combined following generalization to 1m accuracy. All small polygons (<0.1ha) in the background mask file, which represented gaps in the urban areas network, were then dissolved into the urban areas file using the dissolve adjacent polygons extension (Jenness, 2005a). Finally small urban areas polygons <0.1ha were removed from the urban file, to match the level of accuracy found in the main GIS data set.

Appendix 7.7

Sliver removal and GIS accuracy assessments

The final combined woodland GIS had a minimum polygon size of 0.1ha. This was chosen in order to compromise between accuracy and the occurrence of error sliver polygons. The minimum size of polygons digitised within the ESA land-use survey was stated as 30x30m, 0.09ha. In practice polygons within the ESA existed well below this size with small areas of bracken on the moorland being mapped at 0.004ha. The minimum polygon size digitised within the project was 35x35m (approx 0.1ha) although in practice smaller polygons were digitised. Editing of small polygons was used to remove all error and sliver polygons. It was accepted that this led to a slight reduction in accuracy of the GIS with the loss of polygons representing accurate data.

Table A7.7.1
Polygon sliver editing. (AW = ancient woodland, D11 = Dry dwarf shrub heath, A111 = Broadleaved, semi-natural woodland).

Data Source	Habitat class	Smallest polygon (ha)
ESA habitat survey	All habitats	0.0025
	Bracken (C11)	0.0040
	Smallest woodland (whole, non-error polygon)	0.0146
NIWT	Young trees polygons	0.0070
	Mixed woodland	0.0160
NIWT - non DP	Young trees	0.0070
	Mixed woodland	0.0020
EN AWI	Semi-natural (S)	0.2600
	Replanted (R)	0.6200
Dark Peak GIS	Scattered trees (digitised)	0.0410
	AW Young planted woodland	0.0150
	Non-woodland on AW site (AW D11)	0.0200
	AW woodland polygon (S A111)	0.3280

Sliver editing involved examining the minimum size of polygons created at each stage of analysis. Assessments were continuously made as to the source of possible slivers and whether they represented real data or errors. Typically woodland slivers were dissolved into adjacent polygons based on the longest common border between polygons (Jenness, 2005a). The accuracy of this process was maintained by first selecting only certain habitat types, with which to apply this sliver editing process, e.g. only woodland polygons. Where slivers were known to be errors they were either dissolved into adjacent landscape matrix polygons or were deleted.

Appendix 8

Appendix 8.1

Comparing NVC Upland Oakwoods communities and soils and geology occurrence

Table A8.1.1
Soils, drift and solid geology associations of the principal NVC Upland Oakwood communities (Rodwell, 1991).

Feature	W4	W10	W11	W16	W17
	a and b sub-communities	**e sub-community**	**All sub-communities**	**b sub community**	**All sub-communities**
Soils	Moist, moderately acid, but not necessarily oligotrophic peaty soils. Margins of blanket bogs or topogenous deposits that are elevated above surface water. Also on *flushed peaty* gleys.	*Base poor brown soils, "brown earths"*. Soils between rendzinas and brown calcareous earths and brown podzolic soils / true podzols. May have slight podsolization. When waterlogged are then stagnogleyic brown earths or true stagnogleys (some clay-rich profiles would now be classed as pelosols). pH 4 - 5.5	Moist, free-draining , quite base-poor soils. No more than incipient podsolisation. Brown earth or brown podzolic soil. pH 3.5 - 5 W11a: approaching a mull brown earth. W11b: siliceous boulders with thin and fragmentary rankers	Very acid and oligotrophic soils. Free-draining. Brown podzolic type. Humo-ferric podzols, humic rankers and stagno-podzols pH <4	Very acid shallow, fragmentary soils. Humic rankers, brown pozols, Podzols (w. humus and iron pans)
Geology	Often on junctions of sandstones and shales or drift covers.	Agrillaceous rocks and superficials. Carboniferous culm and Coal Measure shales. Glacial drift or head. Occasionally found on the drier alluvium	Argillaceous rocks Upper Carboniferous shales. Interbeded or intruded rocks of less extreme character among masses of predominantly acidic deposits, Colluvium, head, till and fluvioglacial deposits	Tops, freely weathering faces and colluvial slopes. Carboniferous *sandstones* and *grits*	Arenaceous bedrock. Carboniferous sandstones. Also intrusive igneous rocks, lavas, quartzites, and gneisses
Topography		W10e occupies weathered dips of cuestas and lower slopes of valley sides. Picks out areas of better surface drainage, often on ground with only very gentle slope		W16 woodland clothing the resistant grit scarps of cuestas	Does not occur where flushed with base-rich water. Strongly associated with rugged topography produced by weathering of harder rocks. Can be particularly common over boulders or steep precipitous edges due to inaccessibility for grazing.
Zonations / transitions		Transitions to W16 when podsolized soils			Where *glacial* drift *head occurs transitions* to W11 occur, Where coarse grained arenaceous sedimentaries or igneous to fine grained sedimentaries geology occurs, transitions to W11

Appendix 8.2

Full description of landscape zones

Altitude zones	Slopes zone	Streams zone	Landscape zone Description
Very High upland (<550m)			Moorland plateau
High upland (>400 < 550)	Very steep (25+)	Streamside (0-50m)	High Upland clough
		Quite near streams (50-150m)	High upland ridge/face
		Far from streams (150-300)	High upland ridge/face
		Ridges/peaks/plateaus/floodplains (300m+)	High upland ridge/face
	Steep (15 – 25)	Streamside (0-50m)	High Upland clough
		Quite near streams (50-150m)	High upland ridge/face
		Far from streams (150-300)	High upland ridge/face
		Ridges/peaks/plateaus/floodplains (300m+)	High upland ridge/face
	Moderate (10 – 15)	Streamside (0-50m)	High Upland clough
		Quite near streams (50-150m)	High upland slopes
		Far from streams (150-300)	High upland slopes
		Ridges/peaks/plateaus/floodplains (300m+)	High upland slopes
	Gentle (5 – 10)	Streamside (0-50m)	High upland streamside
		Quite near streams (50-150m)	High upland slopes
		Far from streams (150-300)	High upland slopes
		Ridges/peaks/plateaus/floodplains (300m+)	High upland slopes
	Flat (0 – 5)	Streamside (0-50m)	High upland plateau streamside
		Quite near streams (50-150m)	High upland plateau
		Far from streams (150-300)	High upland plateau
		Ridges/peaks/plateaus/floodplains (300m+)	High upland plateau
Upland (300 – 400m)	Very steep (25+)	Streamside (0-50m)	Upland clough
		Quite near streams (50-150m)	Upland clough slopes
		Far from streams (150-300)	Upland ridge / peak / valley
		Ridges/peaks/plateaus/floodplains (300m+)	Upland ridge / peak / valley
	Steep (15 – 25)	Streamside (0-50m)	Upland clough
		Quite near streams (50-150m)	Upland clough slopes
		Far from streams (150-300)	Upland ridge / peak / valley
		Ridges/peaks/plateaus/floodplains (300m+)	Upland ridge / peak / valley
	Moderate (10 – 15)	Streamside (0-50m)	Upland clough
		Quite near streams (50-150m)	Upland slopes
		Far from streams (150-300)	Upland slopes
		Ridges/peaks/plateaus/floodplains (300m+)	Upland slopes
	Gentle (5 – 10)	Streamside (0-50m)	Upland streamside
		Quite near streams (50-150m)	Upland slopes
		Far from streams (150-300)	Upland slopes
		Ridges/peaks/plateaus/floodplains (300m+)	Upland plateau
	Flat (0 – 5)	Streamside (0-50m)	Upland plateau streamside
		Quite near streams (50-150m)	Upland plateau
		Far from streams (150-300)	Upland plateau
		Ridges/peaks/plateaus/floodplains (300m+)	Upland plateau
Upland fringe (200-300m)	Very steep (25+)	Streamside (0-50m)	Upland fringe clough
		Quite near streams (50-150m)	Upland fringe slopes
		Far from streams (150-300)	Upland fringe ridge / peak / valley
		Ridges, peaks, plateaus or floodplains (300m+)	Upland fringe ridge / peak / valley
	Steep (15 – 25)	Streamside (0-50m)	Upland fringe clough
		Quite near streams (50-150m)	Upland fringe clough slopes
		Far from streams (150-300)	Upland fringe ridge / peak / valley
		Ridges, peaks, plateaus or floodplains (300m+)	Upland fringe ridge / peak / valley
	Moderate (10 – 15)	Streamside (0-50m)	Upland fringe clough
		Quite near streams (50-150m)	Upland fringe slopes
		Far from streams (150-300)	Upland fringe slopes
		Ridges, peaks, plateaus or floodplains (300m+)	Upland fringe slopes
		Ridges, peaks, plateaus or floodplains (400m+)	Upland fringe slopes
	Gentle (5 – 10)	Streamside (0-50m)	Upland fringe streamside
		Quite near streams (50-150m)	Upland fringe slopes
		Far from streams (150-300)	Upland fringe slopes
		Ridges, peaks, plateaus or floodplains (300m+)	Upland fringe plateau
		Ridges, peaks, plateaus or floodplains (400m+)	Upland fringe plateau
	Flat (0 – 5)	Streamside (0-50m)	Upland fringe plateau / floodplain
		Quite near streams (50-150m)	Upland fringe plateau / floodplain
		Far from streams (150-300)	Upland fringe plateau
		Ridges, peaks, plateaus or floodplains (300m+)	Upland fringe plateau
lowland (<200m)	Very steep (25+)	Streamside (0-50m)	Lowland clough
		Quite near streams (50-150m)	Lowland clough slopes
		Far from streams (150-300)	Lowland ridge / peak / valley
		Ridges, peaks, plateaus or floodplains (300m+)	Lowland ridge / peak / valley
	Steep (15 – 25)	Streamside (0-50m)	Lowland clough
		Quite near streams (50-150m)	Lowland clough slopes
		Far from streams (150-300)	Lowland ridge / peak / valley
		Ridges, peaks, plateaus or floodplains (300m+)	Lowland ridge / peak / valley
		Ridges, peaks, plateaus or floodplains (400m+)	Lowland ridge / peak / valley
		Streamside (0-50m)	Lowland clough
	Moderate (10 – 15)	Quite near streams (50-150m)	Lowland slopes
		Far from streams (150-300)	Lowland slopes
		Ridges, peaks, plateaus or floodplains (300m+)	Lowland slopes
		Streamside (0-50m)	Lowland streamside / floodplain
	Gentle (5 – 10)	Quite near streams (50-150m)	Lowland streamside / floodplain
		Far from streams (150-300)	Lowland floodplain
		Ridges, peaks, plateaus or floodplains (300m+)	Lowland floodplain
	Flat (0 – 5)	Streamside (0-50m)	Lowland floodplain
		Quite near streams (50-150m)	Lowland floodplain
		Far from streams (150-300)	Lowland floodplain
		Ridges, peaks, plateaus or floodplains (300m+)	Lowland floodplain

Appendix 8.3

Detailed editing of clough zone boundaries

Initially the detailed clough landform analysis had resulted in three raster results files. Each of these contained small areas that were isolated from the main blocks of identified clough zones. Analysis created broad zones by creating buffered boundaries from these files. The core cloughs and additional slopes sites were initially combined into a single grid and converted to a shapefile where sites less than 0.2 ha were deleted. The file was then buffered externally 25m and then by 25m internally such that the original extent of the zone was regained, but with a smoothed boundary, many small gaps had been filled. Similar processing was undertaken for the bracken only slopes. The subsequent grid was converted to a shapefile. Due to the frequent occurrence of small fragmented areas, only larger sites were considered to hold high potential. Sites less than 1ha were deleted. The zone was buffered by 30m and then internally by 40m resulting in a smoothed zone that had been reduced in size by 10m. Subsequently the shapefiles were converted to grids and combined. Bracken areas within cloughs were reclassified as cloughs. The resulting file was converted to a shapefile and all polygons less than 0.2 ha deleted. This process resulted in a smoothed and edited combined cloughs/adjacent slopes zone and bracken only slopes. Following buffering, analysis was undertaken to re-map the original 3 classes of core cloughs, additional slopes and bracken areas. This was achieved by creating a new core cloughs zone combining the cloughs grid from the TPI landform analysis (canyons, deeply incised streams,) with the core cloughs data from the detailed clough landscape analysis, and using a buffered and smoothed copy of this to re-code the combined smoothed cloughs / slope file. The core clough zone was analysed to create a buffered zone without holes and isolated patches. This was achieved by taking the original core cloughs file and then adding the landform opportunity file from the TPI analysis. A distance grid from this new combined core landform/clough file was created and a query run to select areas within 32m of the core cloughs. Then a grid was created of the areas that did not hold core cloughs areas and a distance grid was created from this file. All cells were selected that were equal to or less than 28m. This resulted in a new combined core landform/cloughs file, cleaned and buffered by 4m. This smoothed and buffered file was combined with the original two category clough file (core cloughs/adjacent slopes combined and bracken only). This produced a new 3 category cloughs file with core cloughs, adjacent slopes and bracken only areas, with all categories having been edited and smoothed, and buffered to create simplified landscape zones.

Appendix 8.4

Areas of habitat with conservation potential for native wood cover, classified by clough zone type

Habitats representing opportunities for woodland conservation, restoration or creation occurring within the clough landscape zones

Habitat	Zones	Area (ha)
Young woods	Core Clough	95.1
	Adjacent Slopes	33.8
	Bracken / low interest	33.9
Broadleaved woodland	Core Clough	4.1
	Adjacent Slopes	1.1
	Bracken / low interest	1.4
Broadleaved, plantation	Core Clough	364.8
	Adjacent Slopes	145.1
	Bracken / low interest	74.9
Coniferous plantation	Core Clough	872.7
	Adjacent Slopes	360.0
	Bracken / low interest	291.1
Mixed plantation	Core Clough	425.7
	Adjacent Slopes	134.6
	Bracken / low interest	100
Scrub	Core Clough	18.3
	Adjacent Slopes	3.7
	Bracken / low interest	3.1
Scrub, dense	Core Clough	38.0
	Adjacent Slopes	17.7
	Bracken / low interest	8.5
Scrub, scattered	Core Clough	62.9
	Adjacent Slopes	35.8
	Bracken / low interest	22.8
Scattered trees, close	Core Clough	141.2
	Adjacent Slopes	44.2
	Bracken / low interest	32.5
Scattered trees, open	Core Clough	169.3
	Adjacent Slopes	88.2
	Bracken / low interest	79.8
Felled	Core Clough	26
	Adjacent Slopes	8.2
	Bracken / low interest	12.5
Acid grassland, unimproved	Core Clough	1133.2
	Adjacent Slopes	609.2
Acid grassland, semi-improved	Core Clough	205.7
	Adjacent Slopes	116.6
Acid grassland, semi-improved (Rough)	Core Clough	59.2
	Adjacent Slopes	27.1
Neutral grassland, semi-improved	Core Clough	347.1
	Adjacent Slopes	209.6
Neutral grassland, semi-improved (Rough)	Core Clough	23.2
	Adjacent Slopes	8.3
Improved grassland	Core Clough	56.3
	Adjacent Slopes	44.5
Improved or Semi-improved grassland (enclosed grass)	Core Clough	1352.7
	Adjacent Slopes	965.7
Marshy grassland (Soft rush dominated)	Core Clough	15.2
Marshy grassland (Purple moor grass dominated)	Core Clough	1.2
	Adjacent Slopes	1.0
Marshy grassland / Wet bog (Purple moor grass dominated)	Core Clough	385.6
	Adjacent Slopes	220.9
Bracken	Core Clough	540.2
	Adjacent Slopes	210.7
	Bracken / low interest	214.4
Heathland / unenclosed	Core Clough	217.3
	Adjacent Slopes	174.1
Dry dwarf shrub heath	Core Clough	1806.4
	Adjacent Slopes	846.1
Wet heath / acid grassland mosaic	Core Clough	30.7
	Adjacent Slopes	17.2
Acid flush	Clough	69.2
Bare peat	Core Clough	3.1
	Adjacent Slopes	3.4
Eroding moorland	Core Clough	6.7
	Adjacent Slopes	7.6
Cliff	Core Clough	3.9
	Adjacent Slopes	1.2
	Bracken / low interest	0.3
Scree	Core Clough	31.0
	Adjacent Slopes	19.0
	Bracken / low interest	17.5
Quarry	Core Clough	3.2
	Adjacent Slopes	2.6
	Bracken / low interest	1.1
Arable / short term ley grassland	Core Clough	11.0
	Adjacent Slopes	9.6
Amenity grassland	Core Clough	4.6
	Adjacent Slopes	0.8
Bare ground	Core Clough	0.5
	Adjacent Slopes	2.2
	Bracken / low interest	1.0
Bare ground	Core Clough	26.2
	Adjacent Slopes	10.8

Habitats representing opportunities for woodland conservation classed by occurrence in landscape zone, with % cover of the total resource of each habitat shown

	Zone	Area (ha)	% of total habitat
Young woods	Core cloughs	95	30
	Adjacent slopes	34	11
	Bracken / low conservation interest	34	11
	Total	163	51
Broadleaved, semi-natural	Core cloughs	889	48
	Adjacent slopes	195	11
	Bracken / low conservation interest	110	6
	Total	1194	65
Broadleaved, plantation	Core cloughs	365	32
	Adjacent slopes	145	13
	Bracken / low conservation interest	75	7
	Total	585	52
Coniferous, plantation	Core cloughs	873	27
	Adjacent slopes	360	11
	Bracken / low conservation interest	291	9
	Total	1524	47
Mixed, plantation	Core cloughs	426	38
	Adjacent slopes	135	12
	Bracken / low conservation interest	100	9
	Total	660	59
Scrub	Core cloughs	18	54
	Adjacent slopes	4	11
	Bracken / low conservation interest	3	9
	Total	25	74
Scrub, dense	Core cloughs	38	35
	Adjacent slopes	18	16
	Bracken / low conservation interest	9	8
	Total	64	59
Scrub, scattered	Core cloughs	63	37
	Adjacent slopes	36	21
	Bracken / low conservation interest	23	13
	Total	121	72
Scattered trees, close	Core cloughs	141	33
	Adjacent slopes	44	10
	Bracken / low conservation interest	33	8
	Total	218	51
Scattered trees, open	Core cloughs	169	23
	Adjacent slopes	88	12
	Bracken / low conservation interest	80	11
	Total	337	46
Bracken	Core cloughs	540	36
	Adjacent slopes	211	14
	Bracken / low conservation interest	214	14
	Total	965	64

Appendix 9

Appendix 9.1

Edge depth distances used within the Fragstats core area analysis. Semi-woodland = dense scrub, scattered scrub and close scattered trees

	Edge depth distance to:							
Focal habitat	Broadleaved, semi-natural	Broadleaved, plantation	Conifer, plantation	Mixed, semi-natural	Mixed, plantation	Semi-woodland	Unimproved open	Improved open
Broadleaved, semi-natural	0	0	8m	0	0	4m	12m	12m
Broadleaved, plantation	0	0	8m	0	0	4m	12m	12m
Conifer, plantation	0	0	8m	0	0	4m	12m	12m
Mixed, semi-natural	0	0	8m	0	0	4m	12m	12m
Mixed, plantation	0	0	8m	0	0	4m	12m	12m

Appendix 9.2

The original patch variables prior to data reduction

Habitat class	Phase 1 habitat survey code
Area	Area (ha)
Patch topology	Perimeter Gyrate index Para ratio Shape index Fractal index Circle index
Connectivity	Contig index 1^{st} NN distance 2^{nd} NN distance
Elevation	Elevation min, max, range, mean, std, med, range / ha
Slope	Slope min, max, range, mean, std, med, range / ha Slope class variability, Slope class / ha
Aspect	Aspect variability Asp variability / ha

Appendix 10

Appendix 10.1
Abiotic variables: calculation methods

	Data variable	Calculation method
Area	Area (m^2)	GIS polygon area calculation
Shape	Shape index, Fractal dimension, Circle index, Para, Perimeter	Fragstats
Topography	Elevation : minimum, maximum, mean, range, range / ha	Patch polygon summarise from DTM
	Slope : minimum, maximum, mean, range, range / ha	Patch polygon summarise from DTM
	Aspect variability, variability / ha	Patch polygon summarise from DTM
Landscape (structural)	Distance to stream (m), and distance to clough (m)	Patch polygon summarise from calculated distance grids
	Area of clough in 1km, and urban area in 1km	Patch polygon summarise from calculated area grids
	Area of contiguous ancient woodland site	Spatial join based on theme representing contiguous sites
	Number of ancient woodland sites *	Summary count of patches within the buffer zone
	Total area of ancient woodland *	Summary area addition of patches within the buffer zone
	Proximity score of ancient woodland *	Total area of ancient woodland in buffer / (mean distance to ancient woodland^2)
	Area weighted isolation score of ancient woodland *	(Σ individual patch area x distance) / total area within focal zone
	Mean patch isolation of ancient woodland *	(Σ distance to each ancient woodland) / number of ancient woods
	Mean patch area of ancient woodland *	(Σ area of each ancient woodland) / number of ancient woods
	Number of semi-natural woodland sites *	Summary count of patches within the buffer zone
	Total area of semi-natural woodland *	Summary area addition of patches within the buffer zone
	Proximity score of semi-natural woodland*	Total area of semi-natural woods in buffer / (mean distance to semi-natural woods^2)
	Area weighted isolation score of semi-natural woodland *	(Σ individual patch area x distance) / total area within focal zone
	Mean patch isolation of semi-natural woodland *	(Σ distance to each semi-natural woodland) / number of semi-natural woods
	Mean patch area of semi-natural woodland *	(Σ area of each semi-natural woodland) / number of semi-natural woods
Landscape (functional)	Compartment core area and core area index	Fragstats
	Contrast value (patch)	Fragstats
	Mean contrast value of landscape *	Buffer polygon summarise from calculated "landscape contrast" grid
	Mean cost value of landscape *	Buffer polygon summarise from calculated "landscape contrast" grid
	Area weighted "least cost" isolation· ancient woodland *	Mean least-cost distance to ancient woodland / total area of ancient woodland
	Area weighted "least cost" isolation· semi-natural woodland *	Mean least-cost distance to semi-natural woods / total area of semi-natural woods
	"Least cost" proximity of ancient woodland *	Total area of ancient woodland in buffer / (mean least-cost distance^2)
	"Least cost" proximity of semi-natural woodland *	Total area of semi-natural woods in buffer / (mean least-cost distance^2)

* Features were collated by creating buffer polygons around woodland sites at 20m,100m,500m and 1km. Buffers polygons were created to retain the polygon id of their central focal patch, allowing query results within the buffer to be returned to the central woodland patch for analysis. Analysis of the focal buffer zones utilised the "Identify features within distance" GIS script (Jenness, 2003) to link search results within each buffer polygon to the focal woodland patch.

This analysis was conducted in order to collate both structural and functional data variables for woodland sites. The size of the study area, large number of woodland sites and data resolution required limited the methods able to be applied. Form the potential habitat for which landscape data could be collected combined ancient woodland sites (irrespective of habitat type) and combined semi-natural woodland sites were considered to represent both the known areas of historic woodland and known recent semi-natural woodland habitats respectively, and to act as indicators of past and current sources of woodland species. The current computer processing power versus data resolution limited some analysis methods where forms of least cost analysis were adapted to allow for the large study areas being examined (Appendix 10.4). Within several of the landscape variable analysis the project analysis of landscape character / topography was used to add detail to the functional metric analysis (Appendix 10.3, 10.4).

Appendix 10.2
Contrast and edge distance used within patch Fragstats analysis

Focal habitat	Edge depth distance to: Brd semi-nat	Brd, plantn	Con plantn	Mix, sem-nat	Mix plantn	Semi-wood	Unimpd open	Improved Open	Anc Brd, Semi-nat	Anc Mix Plantn	Anc Brd, plantn	Anc Con plantn	Anc Mix plantn
Ancient broadleaved, semi-natural	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Ancient broadleaved, plantation	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Ancient conifer, plantation	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Ancient mixed, sem-natural	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Ancient mixed, plantation	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Broadleaved, semi-natural	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Broadleaved, plantation	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Conifer, plantation	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Mixed, sem-natural	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0
Mixed, plantation	0	0	8m	0	0	4m	12m	12m	0	0	0	8m	0

Note: Semi-woodland = dense scrub, scattered scrub and close scattered trees, Anc = ancient, brd = broadleaved, plantn = plantation, Con = coniferous

Habitat contrast levels	Component habitats	Contrast
Broadleaved, semi-natural		0
Broadleaved, plantation		0 1
Mixed, semi-natural		0 2
Mixed, plantation		0.2
Conifer, plantation		0.3
Ancient broadleaved, semi-natural		0
Ancient broadleaved, plantation		0.1
Ancient conifer, plantation		0.3
Ancient mixed, semi-natural		0.2
Ancient mixed, plantation		0 2
Semi-woodland habitats – dense	Dense scrub, scattered scrub, dense scattered trees	0 2
Semi-woodland habitats – open	Open scattered trees	0.3
Bracken, continuous		0.2
Young planted woodland		0.3
Open 0.4	Acid flush, felled woodland	0 4
Open 0 6	Unimproved and semi-improved acid grassland, marshy grassland, quarry, scree, rock, dry dwarf shrub heath, heath variations and mosaics	0 6
Open 0.8	Unimproved and semi-improved neutral grassland	0 8
Open 1	Improved grassland, amenity grasslands, urban habitats, reservoirs, and moorland habitats	1

Note: Level to which patches contrast from native semi-natural woodland. Ranging from 0 (very similar, no contrast) to 1 (very different, highly contrasting habitats)

Appendix 10.3
Landscape contrast grid calculation

For the landscape variable analysis a grids was created to indicated contrast levels within the landscape matrix. The grid was based upon the contrast value assigned to different habitat polygons within the vector data (**Appendix 10.2**), converted into grid format and altered by relation of habitat occurrence to landscape character and topography.

Habitat contrast levels	Component habitats	Contrast	Within clough zone
Broadleaved, semi-natural		0	
Broadleaved, plantation		0.1	
Mixed, semi-natural, Mixed, plantation		0.2	
Conifer, plantation		0.3	
Ancient broadleaved, semi-natural		0	
Ancient broadleaved, plantation		0.1	
Ancient conifer, plantation		0.3	
Ancient mixed, semi-natural, Ancient mixed, plantation		0.2	
Semi-woodland habitats – dense	Dense scrub, scattered scrub, dense scattered trees	0.2	
Semi-woodland habitats – open	Open scattered trees	0.3	
Bracken, continuous		0.2	
Young planted woodland		0.3	
Open 0 4	Acid flush, felled woodland	0.4	0.3
Open 0 6	Unimproved and semi-improved acid grassland, marshy grassland, quarry, scree, rock, dry dwarf shrub heath, heath variations and mosaics	0.6	0.5
Open 0 8	Unimproved and semi-improved neutral grassland	0.8	0.6
Open 1	Improved grassland, amenity grasslands, urban habitats, reservoirs, and moorland habitats	1	

Appendix 10.4
Landscape cost, and least-cost grid calculation

Habitat groups	Component habitats	Cost	In core clough
Semi-natural woods	Broadleaved semi-natural woodland, mixed semi-natural woodland, ancient broadleaved semi-natural woodland, ancient mixed semi-natural woodland,	1	
Plantations	Broadleaved plantation, ancient broadleaved plantation, mixed plantation, ancient mixed plantation	1	
Dense semi-woodland	Dense scrub, young woodland	1.5	
Conifer plantations	Coniferous plantations, conifer plantation on ancient woodland site	1.5	
Open semi-wood	Scattered scrub, close scattered trees, introduced shrub	1.5	
Water	Stream , river	2	
	pond	10	
Structure rich open habitats	Open scattered trees, bracken, rock, scree, cliffs	2	
Unimproved and slight structure	Dry dwarf shrub heath, marshy grassland, marshy grassland / Molina dominated degraded bog habitats, grass-heath mosaics, blanket bog and moorland habitats, acid flush, Eroding moorland, felled woodland	5	2
Open habitats - unimproved	Unimproved acid grassland, quarry habitats,	5	2
Open habitats – semi-improved	Semi-improved acid grassland, rough semi-improved grassland, semi-improved neutral grassland,	5	2
Water	Reservoirs	20	
Open artificial habitats	Unclassified semi-improved / unimproved grassland	5	2
	Bare ground, Improved grassland, Cultivated / arable, Amenity / improved grass	5	
	Roads / urban	10	

A grid detailing the cost value of each 5m cell was created using values from the table above. Habitats were given relative dispersal / movement cost values to represent a broad spread of woodland species by giving habitats structurally and compositionally similar to semi-natural woodland low cost values and high cost values to artificial habitat or habitats with low structural diversity which may be avoided by woodland species, or would be unlikely to contain any existing woodland species interest. Many animals species will more favourably move through semi-woodland or structurally diverse habitats in comparison to open habitats and in addition to producing direct faunal dispersal these species may act as disperses of flora, e.g. birds, deer, badgers etc. This methods of basing values on "resemblance to the optimal habitat" has been used in past studies (Knappen et al., 1992). Due to the more favourable conditions existing within the clough landscape zone (sheltered conditions, high humidity, less exposure), the cloughs were hypothesised to act as likely dispersal corridors and therefore habitats were given lower cost values where the patches occurred within the core clough landscape zone. These values allow functional variables to be derived, in addition to the structural metrics.

The grid, detailing the cost values for cells was then analysed to create least-cost distance grids for ancient woodland and semi-natural woodland habitats. However prior to this analysis the grid was altered by running a 3x3 rectangle mean pass over the grid, returning an altered 5m cell grid. Although the grid was a high resolution version of the underlying vector polygon data potential exists in such cost surfaces for "cracks" to occur in high cost areas such as roads and linear habitats. These cracks – where gird corner edges meet, cause problems for least cost analysis algorithms (Rothley, 2005, Theobald, 2005) and running a mean filter over the grid is an effective method of dealing with such potential data problems.

Following this pre-analysis least-cost distance grids were created separately for ancient woodland, and semi-natural woodland habitats, detailing the least-cost values from each cell to the nearest woodland of that habitat type, accounting for travel costs within the landscape matrix.

Appendix 10.5
Species records within surveyed ancient woodland compartments

NBAP		LBAP		Notable	
Latin name	English name	Latin name	English name	Latin name	English name
Hyacinthoides non-scripta	*Blubel*	*Gymnocarpium dryopteris*	Oak fern	*Acer campestre*	Field maple (AWIS)
Formica lugubris	*Wood-antl*	*Leucobryum glaucum*	White hair moss	*Carex paniculata*	Greater tussock sedge
		Tilia cordata	Small leaved lime (AWIS)	*Epipcatis helleborine*	Broad leaved helleborine
		Melampryum pratense	Common cow wheat (AWIS)	*Equisetum telmatia*	Great horsetail (AWIS)
				Dryopteris carthusiana	Narrow buckler fern (AWIS)
				Prunus padus	Bird cherry (AWIS)
				Populus tremula	Aspen (AWIS)
				Viola palustris	Marsh violet (AWIS)
				Luzula sylvatica	Greater wood-rush (AWIS)
				Viburnum opulus	Guilder rose (AWIS)

Ancient Woodland indicator species (AWIS) species recorded during site surveys

Latin	English name	Latin	English Name
Acer campestre	Field maple	**Luzula sylvatica**	Greater woodrush
Allium ursinum	Wild garlic	*Lysimachia nemorum*	Yellow pimpernel
Anemone nemorosa	Wood anemone	*Malus sylvestris*	Crab apple
Brachypodium sylvaticum	False wood brome	*Melampyrum pratense*	Common cow-wheat
Bromus ramosus	Hairy brome	*Melica uniflora*	Wood melick
Carex laevigata	Smooth sedge	*Mercurial perennis*	Dog's mercury
Carex remota	Remote sedge	*Millium effusum*	Wood millet
Carex sylvatica	Wood sedge	*Oreopteris limbosperma*	Lemon scented fern
Chrysosplenium oppositifolium	Opposite leaved golden saxifrage	*Oxalis acetosella*	Wood sorrel
Conopodium majus	Pignut	*Populus tremula*	Aspen
Corydalis claviculata	Climbing corydalis	*Potential sterilis*	Barren strawberry
Dropteris affinis	Scally male fern	*Primula vulgaris*	Primrose
Dryopteris carthusiana	Narrow buckler fern	*Prunus avium*	Wild cherry
Epipacatis helleborine	Broadleaved helleborine	*Prunus padus*	Birch cherry
Equisetum sylvaticum	Wood horsetail	*Rosa arvensis*	Field rose
Equisetum telmateia	Great horsetail	*Sanicula europaeus*	Sanicle
Galeobdolon luteoalbum	Yellow archangel	*Solidago virgaurea*	Goldenrod
Galium odoratum	Woodruff	*Stellaria holostea*	Greater stitchwort
Geum rivale	Water avens	*Taxus baccata*	Yew
Hyacinthoides non-scripta	Bluebell	*Tilis cordata*	Small leaved lime
Hyperi pulchrum	Slender St., john's wort	*Ulmus glabra*	Wych elm
Ilex aqiufolium	Holly	*Veronica montana*	Wood speedwell
Lathyrus montana	Bitter vetch	*Vibumun opulus*	Guelder rose
Lonicera periclyemum	Honeysuckle	*Vicia sepium*	Bush vetch
Luxula pilolsa	Hairy woodrush	*Viola palustris*	Marsh violet

Appendix 10.6
Biodiversity indicators: correlations between the indicators

Table A10.6.1

Spearman's rho correlations of compartment structure indicators. Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

		NVC	Native tree and shrub sp	NVC / ha	Trees Shrubs / ha	Native tree % cover
Oak % cover	*Brd, ASNW*			-.20*	-.26**	.45**
	Brd, PAWS	.33**	.44***	.33**		.41**
	Cons, PAWS		**.62*****			.42**
	Mix, PAWS					
NVC	*Brd, ASNW*		.53***	.20*		
	Brd, PAWS		.53***	**.92*****		.33**
	Cons, PAWS			**.99*****		
	Mix, PAWS		.38**	**.84*****		.26*
Native trees and shrub species	*Brd, ASNW*					
	Brd, PAWS			.41**	.28*	.45***
	Cons, PAWS				.33*	.55***
	Mix, PAWS					
NVC communities / ha	*Brd, ASNW*				**.86*****	
	Brd, PAWS					.30*
	Cons, PAWS					
	Mix, PAWS				.29*	.30*
Tree + shrub sp / ha	*Brd, ASNW*					
	Brd, PAWS					
	Cons, PAWS					.50***
	Mix, PAWS					

* Correlation is significant at the 0.05 level (2-tailed)., ** at the 0.01 level (2-tailed)., *** at the 0.01 level (2-tailed)

Table A10.6.2

Spearman's rho correlations of compartment composition and conservation interest / richness. Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

		AWIS	BAP, LBAP, notable	BAP, LBAP, Notable / ha	AWI / ha
Oak % cover	*Brd, ASNW*				
	Brd, PAWS	.30*			
	Cons, PAWS	.31*			
	Mix, PAWS				-.24*
NVC	*Brd, ASNW*	.32***	.26**		
	Brd, PAWS	.43**	.31*		
	Cons, PAWS				
	Mix, PAWS	.38**	.29*		
Native trees and shrub species	*Brd, ASNW*	.73***	.52***	.22*	.30**
	Brd, PAWS	.80***	.64***		
	Cons, PAWS	.66***	.43**		
	Mix, PAWS	.80***	.56***		
NVC ha	*Brd, ASNW*			.43***	.63***
	Brd, PAWS	.27*			
	Cons, PAWS				
	Mix, PAWS				
tree_and shrub sp / ha	*Brd, ASNW*			.57***	.82***
	Brd, PAWS			.66***	.81***
	Cons, PAWS				.34**
	Mix, PAWS			.30*	.80***

**** Correlation is significant at the .0001 level (2-tailed). *** Correlation is significant at the .001 level (2-tailed).
** Correlation is significant at the .01 level (2-tailed). * Correlation is significant at the .05 level (2-tailed).

Table A10.6.3

Spearman's rho correlations of compartment structure indicators. Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

		Native shrub % cover	Total canopy % cover	Canopy layers	Veterans	Canopy age	Ground flora % cover	Ground flora potn % cover	Deadwood
Native tree % cover	*Brd, ASNW*		.78***	-.21*	-.24**		.29**	-.37***	
	Brd, PAWS	.35**		.51***	.43***				.49***
	Cons, PAWS	.50***							
	Mix, PAWS	.28*			.31*				.25*
Native shrubv % co	*Brd, ASNW*			.39***					
	Brd, PAWS			.71***					.27*
	Cons, PAWS			.32*					
	Mix, PAWS			.43***					
Total canopy % cov	*Brd, ASNW*			-.32**	-.27**			-.31**	
	Brd, PAWS					-.30*		-.28*	
	Cons, PAWS			-.32*				-.54***	
	Mix, PAWS								
canopy_struct	*Brd, ASNW*				.34***	.26**	.24*		.30**
	Brd, PAWS				.34**				.33*
	Cons, PAWS							.35**	
	Mix, PAWS					.34**	.30*		.24*
Veterans	*Brd, ASNW*					.23*			.43***
	Brd, PAWS					.52***			.64***
	Cons, PAWS								
	Mix, PAWS					.48***			.25*
canopy_age	*Brd, ASNW*						.35***	-.32**	
	Brd, PAWS							.25*	.32*
	Cons, PAWS								
	Mix, PAWS								.31*
Ground flora actual cover	*Brd, ASNW*							-.86***	.22*
	Brd, PAWS							-.39**	
	Cons, PAWS								.30*
	Mix, PAWS							-.60***	

* Correlation is significant at the 0.05 level (2-tailed)., ** at the 0.01 level (2-tailed)., *** at the 0.01 level (2-tailed)

Table A10.6.4
Spearman's rho correlations of compartment structure and composition. Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

		Oak % cover	NVC	Tree + shrub sp	NVC / ha	Trees + shrub / ha
Native tree % cover class	*Brd, ASNW*	.45***				
	Brd, PAWS	.41**	.33**	.45***	29*	
	Cons, PAWS	.42**		.55***		.50***
	Mix, PAWS		23*		30*	
Native shrub % cover class	*Brd, ASNW*	- 26*	24*	.44***		
	Brd, PAWS	27*	.44**	.60***	.46***	.27*
	Cons, PAWS	.34**		.49***		.33*
	Mix, PAWS		26*	39**		
Total canopy % cover class	*Brd, ASNW*	.35***	21*	26**		
	Brd, PAWS	-.39**				
	Cons, PAWS	-.35**		-.31*		
	Mix, PAWS					
canopy_ structure	*Brd, ASNW*	- 21*	26**	22*		
	Brd, PAWS	.27*	.33**	.52***	.31*	
	Cons, PAWS			.31*		
	Mix, PAWS				29*	24*
veterans_	*Brd, ASNW*					
	Brd, PAWS	26*		.32*		
	Cons, PAWS	.37**				
	Mix, PAWS					
canopy_age_	*Brd, ASNW*	.30**				
	Brd, PAWS					
	Cons, PAWS					
	Mix, PAWS					
Ground flora actual % cover	*Brd, ASNW*	24*	.34***	25**		
	Brd, PAWS		.70***		.69***	
	Cons, PAWS		.36**	.32*	.36**	
	Mix, PAWS		.49***		.50***	
Ground flora potn % cover	*Brd, ASNW*	- 25**	- 29**	- 23*		
	Brd, PAWS					
	Cons, PAWS					
	Mix, PAWS		-.37**		- 37**	
deadwood	*Brd, ASNW*					
	Brd, PAWS	.33**	.35**	.53***		
	Cons, PAWS			.32*		
	Mix, PAWS	25*	24*		26*	

Table A10.6.5
Spearman's rho correlations of compartment structure and conservation interest / richness. Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

	habitat	AWI species / patch	BAP +LBAP + notable	BAP + LBAP + notable / ha	AWIS / ha
Native tree % cover	*Brd, ASNW*				
	Brd, PAWS	.35**			
	Cons, PAWS				
	Mix, PAWS				
Native shrub % cover	*Brd, ASNW*	.41***	26**	21*	21*
	Brd, PAWS	.48***	.41**		
	Cons, PAWS	29*			
	Mix, PAWS	.36**			
Total canopy % cover	*Brd, ASNW*	26**	20*		
	Brd, PAWS				
	Cons, PAWS	-.41**	-.47***	-.39**	
	Mix, PAWS	.34**	.30*		
canopy_struct_log10_1	*Brd, ASNW*				
	Brd, PAWS	.47***			
	Cons, PAWS				
	Mix, PAWS				
veterans_log10_1	*Brd, ASNW*				
	Brd, PAWS				
	Cons, PAWS				
	Mix, PAWS				
canopy_age__log10_1	*Brd, ASNW*			19*	
	Brd, PAWS			- 25*	
	Cons, PAWS				
	Mix, PAWS				
Ground flora actual %	*Brd, ASNW*	.35***	28**		
	Brd, PAWS				
	Cons, PAWS	.40**	29*		
	Mix, PAWS				
Ground flora potn % cover	*Brd, ASNW*	-.33***	- 26**		
	Brd, PAWS				
	Cons, PAWS	.33*	.41**	.37**	
	Mix, PAWS				
deadwood__log10_1	*Brd, ASNW*				
	Brd, PAWS	.49***			
	Cons, PAWS	.34**			
	Mix, PAWS				

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Appendix 10.7
Biodiversity indicators: group differences and pair-wise comparison

Table A10.7.1
Uni-variate post hoc pair-wise comparison tests and approximate rank order of results for variables where group tests have shown significant differences between habitats. Tests used differ depending on the distribution of indicator data. Anv, LSD = Anova with post-hoc LSD. KW,MW = Kruskal Wallis with post hoc Mann-Whitney, Chisq = Chi-square test and visual assessment of post hoc differences. N = ASNW:114, Brd PAWS: 61, Con PAWS: 57, Mix PAWS: 66.

Variable type		Rank range	Test	ASNW	Brd, PAWS	Mix, PAWS	Cons, PAWS
Conservation interest	AWI species (AWIS)	High – low	Anv, Lsd	1	1	1	2
	AWIS / ha	High – low	KW,MW	1	1	1	1
	Notable+BAP/ha	High – low	KW,MW	1	1	1	1
Composition	Oak % cover	High – low	KW,MW	1	2	2	3
	Birch % cover	High - low	KW,MW	1	3	2	3
	NVC communities	High – low	KW,MW	1	2	2	3
	Native trees and shrub richness	High – low	Anv, Lsd	1	2	2	3
	NVC communities / ha	High – low	KW,MW	1	2	2	3
	Native trees + shrub richness / ha	High – low	Anv, Lsd	1	1,2	1,2	2
Structure	Native tree cover (%)	High – low	KW,MW	1	3	4	2
	Native shrub cover (%)	High – low	KW,MW	1	2	2	3
	Total canopy cover (%)	High – low	Anv, Lsd	2	1	1	1
	Canopy structure layers	Complex-simple	KW,MW	1	2	2	3
	Veteran tree presence score	Present - absent	Chi sq	1	2	3	4
	Canopy age score	Old – young	Chi sq	1	2	3	4
	Ground flora cover (%)	High – low	KW,MW	1	2	2	3
	Potn ground flora cover (%)	High – low	Anv, Lsd	2	1	1	1
	Deadwood presence score	Abundant-absent	Chi sq	1	3	2	4

Appendix 10.8
Ancient woodland abiotic characteristics

Ancient woodland compartments ranged from 0.12 to 33 ha, although the majority of compartments were small, between 1 and 7 ha in size. There was no significant difference between habitats (Fig A10.3.2).

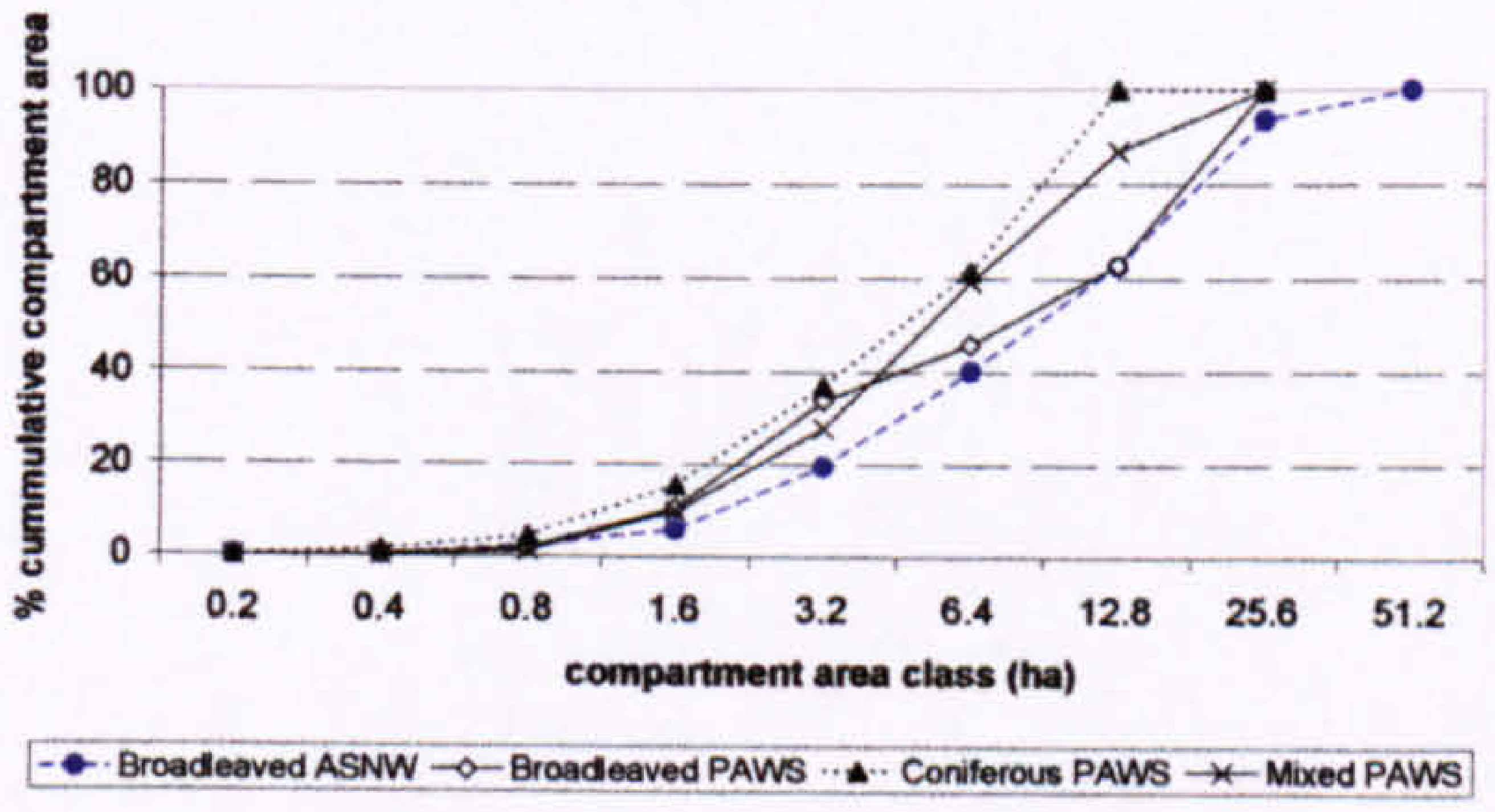
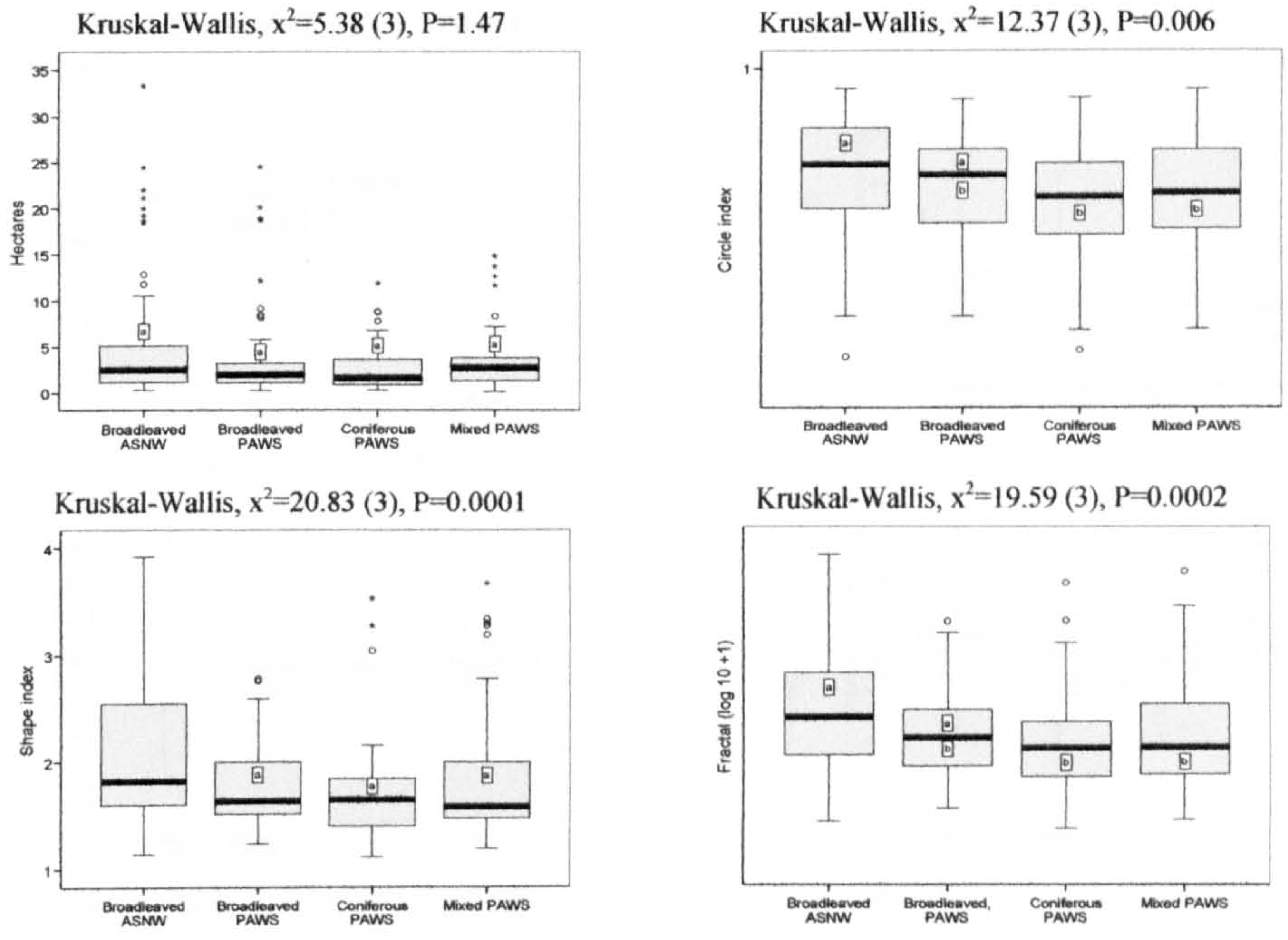


Figure A10.8.1
This chart shows the contribution of compartments classified into 9 area classes to the total area of each main habitat type. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site. N = ASNW:114, Brd PAWS: 61, Con PAWS: 57, Mix PAWS: 66.

Shape index and fractal index represent complexity, more complex compartments returning higher values, while circle index identified a trend from compact to elongated shapes (Fig A10.32). Broadleaved ASNW compartments had a significantly higher shape index than the other habitats while fractal and circle index showed similar values between ASNW and broadleaved PAWS, although higher than mixed and coniferous PAWS.



Kruskal-Wallis, x^2=5.38 (3), P=1.47

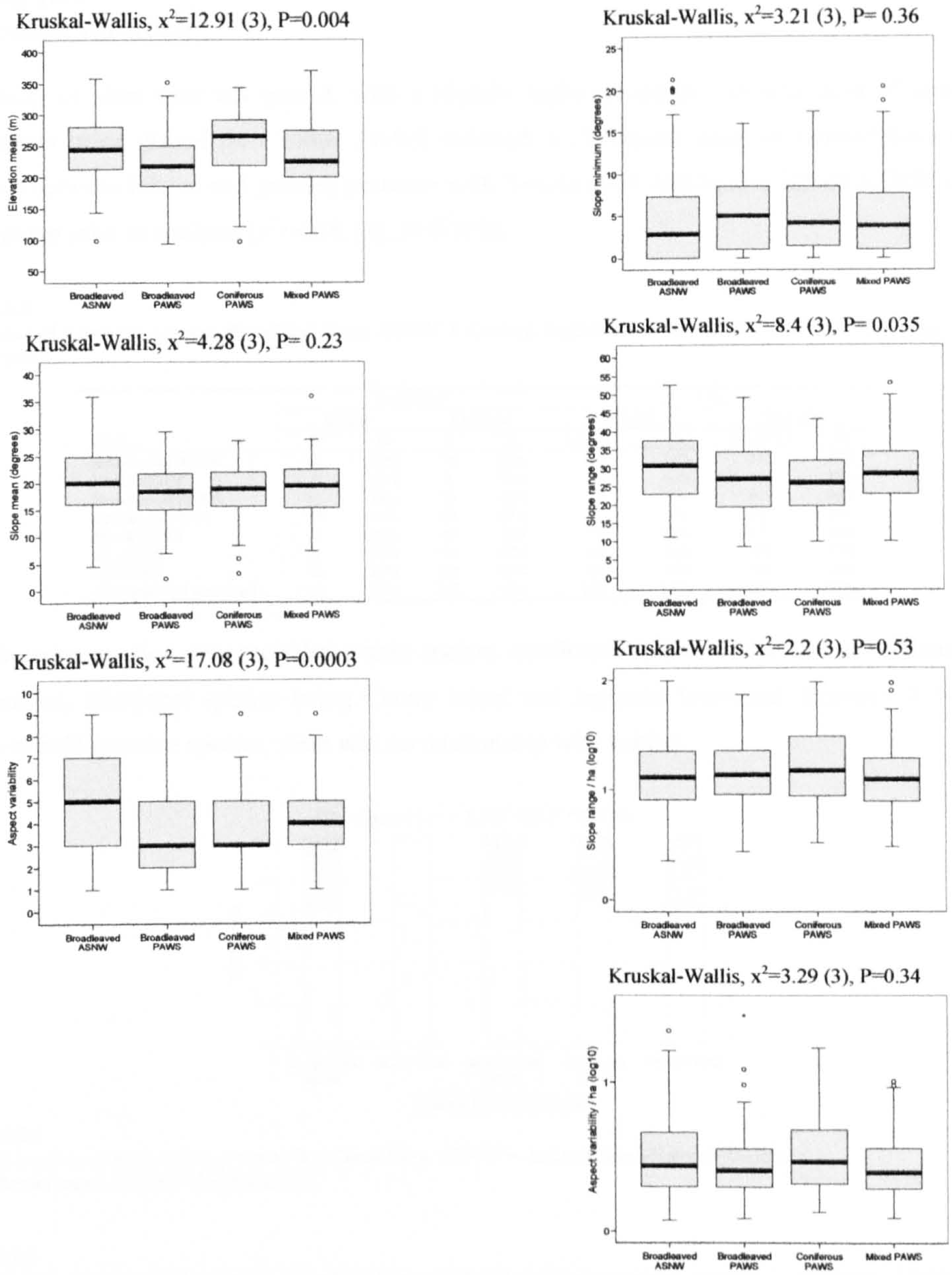
Kruskal-Wallis, x^2=12.37 (3), P=0.006

Kruskal-Wallis, x^2=20.83 (3), P=0.0001

Kruskal-Wallis, x^2=19.59 (3), P=0.0002

Figure A10.8.2
Boxplot of patch area (ha), shape and circle index and fractal dimension of the main four woodland habitats. The plot details the median value as a thick bar and interquartile range of values as the box. Points indicate extreme values. Habitats with the same letter do not differ significantly following post hoc Mann-Whitney tests with Bonferroni correction to retain a familywise error rate of 0.05. N = ASNW:114, Brd PAWS: 61, Con PAWS: 57, Mix PAWS: 66.

Compartments were recorded between 92m-405m, with elevation range from 3m-184m. Slopes ranged from 0-54 degrees. Topography indicators were analysed to test the null hypothesis of no association between abiotic conditions and habitat type, and that Broadleaved ASNW occurred on more variable and extreme terrain than PAWS compartments. There was no significant difference between the habitats in slope mean, slope minimum, slope range / ha, or aspect range / ha. However significant differences were found within the elevation mean, aspect variability and slope range. Slope range values are highest in the broadleaved ASNW compartments, being significantly higher than conifer PAWS. Slope range was not significantly different between the PAWS. Aspect variability showed a trend with Broadleaved ASNW having higher levels than both Broadleaved and Coniferous PAWS, but not from Mixed PAWS. Taken together these differences suggest that generally Broadleaved ASNW compartment have the most extreme or variable topography of the different habitats, while Coniferous PAWS and to some extent Broadleaved PAWS tend to occur in less topographically variable situations. Mixed PAWS sites were seen to occur with some similarities to Broadleaved ASNW for some of the variables.


Kruskal-Wallis, x^2=12.91 (3), P=0.004

Kruskal-Wallis, x^2=3.21 (3), P= 0.36

Kruskal-Wallis, x^2=4.28 (3), P= 0.23

Kruskal-Wallis, x^2=8.4 (3), P= 0.035

Kruskal-Wallis, x^2=17.08 (3), P=0.0003

Kruskal-Wallis, x^2=2.2 (3), P=0.53

Kruskal-Wallis, x^2=3.29 (3), P=0.34

Figure A10.8.3

Boxplot of patch topography. The plot details the median value as a thick bar and interquartile range of values as the box. Extreme values are indicated by points. Habitats with the same letter do not differ significantly following post hoc Mann-Whitney tests with Bonferroni correction to retain a familywise error rate of 0.05. N = ASNW:114, Brd PAWS: 61, Con PAWS: 57, Mix PAWS: 66.

Table A10.8.1

Compartment topography indicator records. Values with the same letter in their superscripts do not differ significantly from one another according to pair-wise tests with a Bonferroni correction test with a .05 limit on familywise error rate.

		Elevation mean (m)		Aspect variability		Slope range (deg)	
Habitat	N	Mean	Median	Mean	Median	Mean	Median
Broadleaved ASNW	114	242.05	244^{AB}	4.96	5.00^{A}	30.32	30.85^{A}
Broadleaved PAWS	61	219.89	217^{C}	3.85	3^{BC}	27.17	27.14^{AB}
Coniferous PAWS	57	250.46	265^{AD}	3.70	3^{BD}	25.95	26.06^{B}
Mixed PAWS	66	235.36	224.5^{BCD}	4.09	4.00^{ACD}	28.60	28.54^{AB}

Table A10.8.2

Compartment topography indicator records. Figures were rounded to 2 decimal places. These variables were not found to show significant differences between habitats. ASNW = Ancient semi-natural woodland, PAWS = Plantation on Ancient woodland site.

		Slope range/ha		Aspect variability/ha		Slope min (deg)		Slope mean (deg)	
Habitat	N	Mean	Median	Mean	Median	Mean	St.Dev	Mean	St.Dev
Broadleaved ASNW	114	18.78	11.98	2.82	1.81	4.97	2.86	19.84	20.01
Broadleaved PAWS	61	16.86	12.67	2.52	1.57	5.30	5.05	18.17	18.42
Coniferous PAWS	57	21.92	13.86	3.11	1.98	5.44	4.17	18.34	18.87
Mixed PAWS	66	16.28	11.35	2.24	1.49	5.38	3.84	19.01	19.37

Appendix 10.9
Management variables

The majority of sites were not grazed, with a slightly higher proportion of total area of semi-natural compartments being grazed than within PAWS although a Chi-square analysis showed there to be no association between habitat and grazing presence with Broadleaved ASNW and Mixed ASNW collapsed into one group prior to analysis (x^2=4.58, (3), *P*=0.205).

Table A10.9.1
Grazing status of surveyed Ancient Woodland Sites. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

	Frequency				Area			
	Grazed		Enclosed		Grazed		Enclosed	
Habitat	N	%	N	%	Area (ha)	%	Area (ha)	%
Broadleaved ASNW	36	31%	78	69%	122	24%	386	76%
Mixed ASNW	2	50%	2	50%	2	66%	1	33%
Broadleaved PAWS	11	18%	50	82%	17	8%	205	92%
Coniferous PAWS	18	31%	39	69%	25	17%	123	83%
Mixed PAWS	17	26%	49	74%	39	18%	177	82%
All ASNW	38	32%	80	68%	124	24%	387	76%
All PAWS	46	25%	138	75%	81	14%	505	86%
All established woodland	84	28%	218	72%	205	18%	893	82%

Several invasive species were recorded within ancient woodland compartments. The most abundant was Rhododendron, additional species being Cherry laurel and Japanese knotweed. Between 15%-23% of habitat area held invasive species, there was no relationship with habitat.

Chi-square (x^2 = 2.321 (3) *P* =0.508).

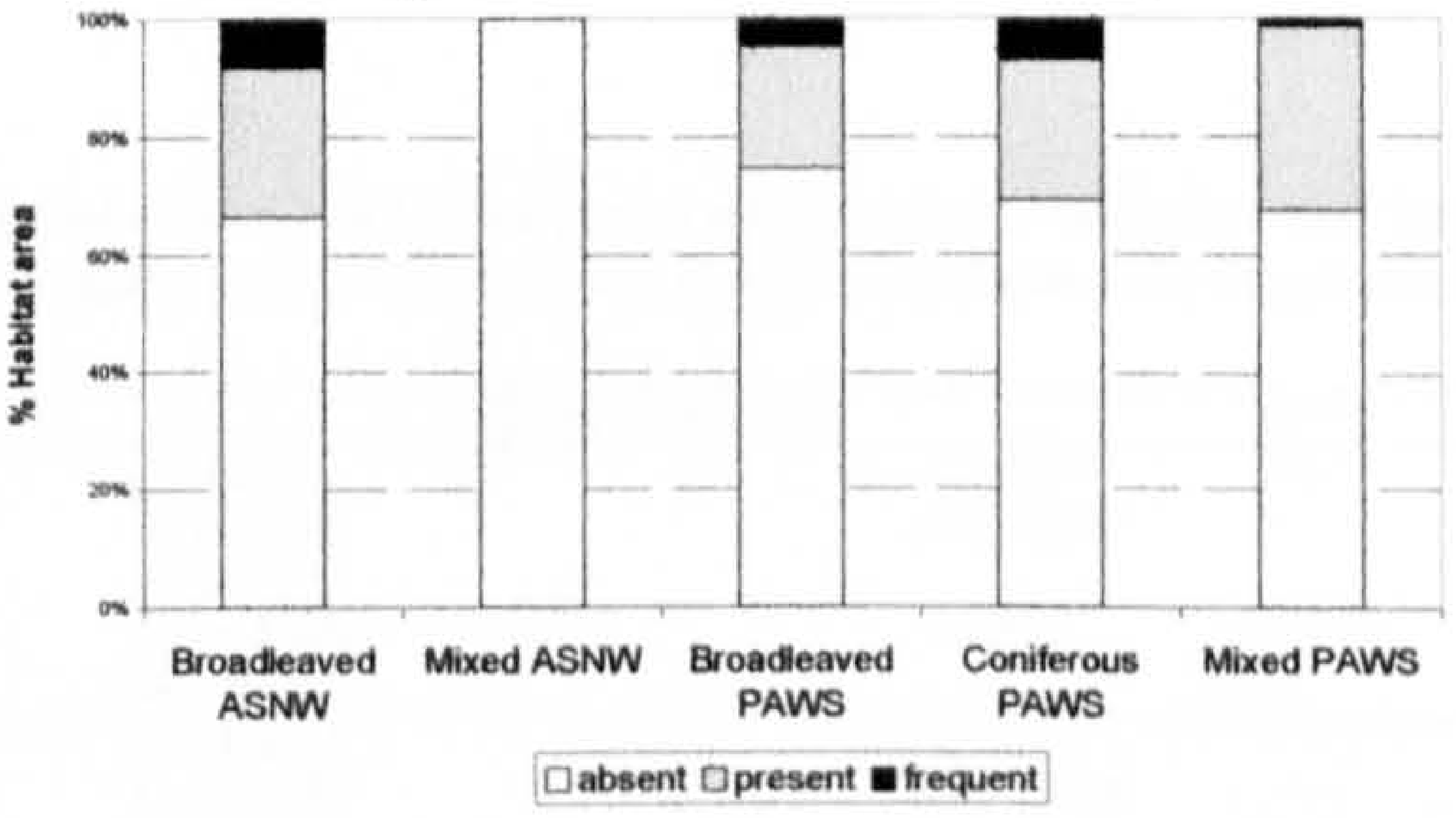


Figure A10.9.1
Presence of invasive species within Ancient Woodland Sites. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

Table A10.9.2
Invasive species presence within Ancient Woodland Sites - Combined invasive species presence / abundance. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site.

			Habitat area (%)			Habitat area (ha)		
Habitat	N	Area (ha)	absent	present	frequent	absent	present	frequent
Broadleaved ASNW	114	508.61	66.6	25.2	8.2	338.64	128.41	41.56
Mixed ASNW	4	3.57	100.0	0.0	0.0	3.57	0	0
Broadleaved PAWS	61	222.27	74.7	20.8	4.5	165.94	46.24	10.09
Coniferous PAWS	57	148.17	69.2	23.9	6.8	102.58	35.47	10.12
Mixed PAWS	66	215.87	67.5	31.2	1.2	145.81	67.37	2.69
ASNW	118	512.18	66.8	25.1	8.1	342.21	128.41	41.56
PAWS	139	586.31	70.7	25.4	3.9	414.33	149.08	22.9
All established woods	257	1098.49	68.9	25.3	5.9	756.54	277.49	64.46

Table A10.9.3
Rhododendron species presence / abundance within Ancient Woodland Sites. ASNW = Ancient Semi-Natural Woodland, PAWS = Plantation on Ancient Woodland Site

			Habitat area (%)			Habitat area (ha)		
Habitat	N	Area (ha)	absent	present	frequent	absent	present	frequent
Broadleaved ASNW	114	508.61	68.9	22.9	8.12	350.44	116.61	41.56
Mixed ASNW	4	3.57	100	0	0	3.57	0	0
Broadleaved PAWS	61	222.28	80.1	15.3	4.5	178.1	34.12	10.09
Coniferous PAWS	57	148.17	69.2	23.9	6.8	102.6	35.47	10.12
Mixed PAWS	66	215.87	70.6	28.1	1.2	152.43	60.75	2.69
ASNW	118	512.18	69.1	22.8	8.1	354.01	116.61	41.56
PAWS	139	586.32	73.9	22.2	3.9	433.08	130.34	22.9
All established woods	257	1098.5	71.6	22.5	5.9	787.09	246.95	64.46

Appendix 10.10

Correlations between abiotic variables and biodiversity scores

Table A10.10.1
Spearman's rho correlations of biodiversity and habitat quality variables. Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

		Biodiversity score		NMS1	NMS2	NMS3
Topographic diversity	*All data*	.380***	*All data*		.331***	.277***
	Brd, ASNW	.374***	*Brd, ASNW*	-.418***	-.278**	-.118
	Brd, PAWS	.496***				
	Cons, PAWS		*PAWS*		.292***	.254**
	Mix, PAWS	.404**				
Elevation mean, Slope mean	*All data*		*All data*			
	Brd, ASNW		*Brd, ASNW*			
	Brd, PAWS	-.360**				
	Cons, PAWS		*PAWS*		-.242**	
	Mix, PAWS					
Stream distance	*All data*	-.374***	*All data*	-.210***	-.129*	-.340***
	Brd, ASNW	-.273**	*Brd, ASNW*	.331***		
	Brd, PAWS	-.549***				
	Cons, PAWS		*PAWS*	.239**	-.305***	
	Mix, PAWS	-.261*				
Clough distance	*All data*		*All data*		-.118*	
	Brd, ASNW		*Brd, ASNW*			
	Brd, PAWS					
	Cons, PAWS		*PAWS*			-.211**
	Mix, PAWS					
Area	*All data*	.321***	*All data*	-.315***	.415***	
	Brd, ASNW	.366***	*Brd, ASNW*	-.509***	**-.706*** **	
	Brd, PAWS	.416**				
	Cons, PAWS	.517***	*PAWS*	.389***	.256***	.217**
	Mix, PAWS	.315**				
Shape	*All data*	.294***	*All data*		.154**	.275***
	Brd, ASNW	.214*	*Brd, ASNW*			-.223*
	Brd, PAWS	.277*				
	Cons, PAWS		*PAWS*		.220**	
	Mix, PAWS					

Table A10.10.2
Spearman's rho correlations of biodiversity scores and functional and structural isolation and landscape measures
Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

		Biodiversity score		NMS1	NMS2	NMS3
Core area index	*All data*		*All data*	-.225***	.171**	
	Brd, ASNW		*Brd, ASNW*	-.203*	-.270**	
	Brd, PAWS					
	Cons, PAWS	.419**	*PAWS*	.309***		.156*
	Mix, PAWS					
Contiguous ancient, woodland site area	*All data*		*All data*	-.191**	.207***	
	Brd, ASNW		*Brd, ASNW*	-.223*	-.309**	
	Brd, PAWS					
	Cons, PAWS		*PAWS*	.250**		.172*
	Mix, PAWS					
Functional isolation SF1	*All data*	-.157**	*All data*			-.242***
	Brd, ASNW		*Brd, ASNW*		-.277**	
	Brd, PAWS					
	Cons, PAWS		*PAWS*	.178*	-.177*	
	Mix, PAWS					
Functional isolation SF2	*All data*	**.668*** **	*All data*	.154**	.490***	**.646*** **
	Brd, ASNW	.286**	*Brd, ASNW*	-.337***	-.474***	
	Brd, PAWS					
	Cons, PAWS		*PAWS*		.322***	
	Mix, PAWS					
Functional isolation SF3	*All data*		*All data*	.135*		
	Brd, ASNW		*Brd, ASNW*			-.319**
	Brd, PAWS					
	Cons, PAWS		*PAWS*	-.160*		
	Mix, PAWS					
Area of ancient woodland in 20m	*All data*	-.138*	*All data*	-.206***		-.138*
	Brd, ASNW		*Brd, ASNW*			.209*
	Brd, PAWS					
	Cons, PAWS		*PAWS*	.196**		
	Mix, PAWS					
Area of ancient woodland in 500m	*All data*		*All data*			
	Brd, ASNW		*Brd, ASNW*			
	Brd, PAWS					
	Cons, PAWS		*PAWS*	.211**		
	Mix, PAWS					
Area of semi-natural Secondary woodland in 20m	*All data*	.291***	*All data*		.269***	.259***
	Brd, ASNW		*Brd, ASNW*		-.249**	
	Brd, PAWS					
	Cons, PAWS		*PAWS*		.145*	
	Mix, PAWS					
Area of semi-natural Secondary woodland in 500m	*All data*	.239***	*All data*		.227***	.183**
	Brd, ASNW	.195*	*Brd, ASNW*		-.200*	-.212*
	Brd, PAWS					
	Cons, PAWS		*PAWS*			
	Mix, PAWS					

Table A10.10.3
Spearman's rho correlations of biodiversity score with structural isolation variables
Very large correlations are indicated in bold (0.6+), less than moderate correlation are in greyscale (<0.3).

		Biodiversity score		NMS1	NMS2	NMS3
Area of ancient woodland In 1km	*All data*		*All data*			-.140*
	Brd, ASNW		*Brd, ASNW*			
	Brd, PAWS					
	Cons, PAWS		*PAWS*			
	Mix, PAWS					
Area of semi-natural, secondary woodland in 1km	*All data*		*All data*			-.137*
	Brd, ASNW		*Brd, ASNW*			-.191*
	Brd, PAWS					
	Cons, PAWS		*PAWS*			
	Mix, PAWS					
Number of ancient woodland In 1km	*All data*	.277***	*All data*		-.179**	-.305***
	Brd, ASNW		*Brd, ASNW*			
	Brd, PAWS					
	Cons, PAWS		*PAWS*		-.253**	
	Mix, PAWS					
Number of semi-natural, secondary woodland in 1km	*All data*	.237***	*All data*	.173**	.177**	.214***
	Brd, ASNW	.256**	*Brd, ASNW*			-.357***
	Brd, PAWS					
	Cons, PAWS		*PAWS*			
	Mix, PAWS					
Area of clough habitat in 1km	*All data*	-.171**	*All data*			-.152**
	Brd, ASNW	-.189*	*Brd, ASNW*			.264**
	Brd, PAWS	-.277*				
	Cons, PAWS		*PAWS*		-.291***	
	Mix, PAWS					
Structural isolation S1	*All data*	-.121*	*All data*	.181**	-.195**	-.120*
	Brd, ASNW		*Brd, ASNW*		.294**	-.395***
	Brd, PAWS					
	Cons, PAWS	.282*	*PAWS*	-.242**		
	Mix, PAWS					
Structural isolation S2	*All data*	.132*	*All data*		.182*	
	Brd, ASNW		*Brd, ASNW*	.193*		
	Brd, PAWS					
	Cons, PAWS		*PAWS*			
	Mix, PAWS					
Structural isolation S3	*All data*		*All data*			
	Brd, ASNW		*Brd, ASNW*			
	Brd, PAWS					
	Cons, PAWS		*PAWS*			
	Mix, PAWS					

Appendix 10.11
Reduced variables for PAWS and ASNW data regressions

3 groups of landscape variables were produced. One condensed and theory based selection of variables was used to represent the landscape where only few variables could be permitted in model testing. Larger sets of variables were available for use with the larger data sample for exploratory analysis. Knowledge used in the formulation of the research hypothesis was used to detail key landscape variables considered to affect woodland biodiversity and found to be critical in previous studies. For PAWS multiple regression models, a reduced list of predictors was developed, omitting the structural variables (**Table A10.6.1**). For the more limited ASNW data, several key theory selected variables were used (**Table A10.6.2**).

Table A10.11.1
Sequential regression order of addition. All PAWS compartment data. N = 184.

Block		Variables
1	Habitat type	Presence / absence of separate PAWS habitat Coniferous PAWS as the reference habitat
2	Site quality	PCA A3 – topographic diversity PCA A2 – elevation mean and slope mean Grazing Stream distance Clough distance
3	Area , Shape	Area PCA A1 – shape complexity and elongation
4	Structural area	Core area index
5	Historic connected area	AW site area
6	Historic isolation indicator	Area of clough in 1km
7	Functional connectivity	PCA1 SF =least cost prox AW/ SN 1km, 500m and low contrast 1km PCA2 SF=low contr 20m 100m, and high least cost prox SN500m, 1km PCA3 SF =high contrast at patch and at 100m,

Table A10.11.2
Sequential regression order of addition. ASNW data. N = 114.

Block		Variables
1	Site quality	PCA A3 – topographic diversity PCA A2 – elevation mean and slope mean Grazing Stream distance Clough distance
2	Area , Shape	Area PCA A1 – shape complexity and elongation
3	Historic connected area	AW site area
4	Historic isolation indicator	Area of clough in 1km

Appendix 10.12
Multiple regression models: PAWS and ASNW data subsets

Table A10.12.1
Sequential multiple regression results of NMS Biodiversity ordination score 1: Botanical richness / ha and ground flora cover (tree cover, NVC, layers, woody species richness), by habitat and abiotic values. PAWS data, N = 184.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	-.206	.099	-.198	-2.092*	.0176	.025
	Mix, PAWS	N/A	-.264	.090	-.258	-2.949**	.0353	
2	Grazed	N/A	.104	.089	.092	1.166	.0062	.097**
	Topo diversity	.077	-.021	.045	-.039	-0.467	.0009	
	Elevation, slope	.125	.052	.042	.107	1.238	.0054	
	Stream distance	.209**	.117	.036	.249	3.206**	.041	
	Clough distance	.145*	.057	.033	.123	1.749	.0125	
3	Area	.366***	.314	.060	.600	5.2521***	.1108	.160***
	Shape	.006	-.019	.040	-.036	-0.467	.0009	
4	Core area index	.238**	-.118	.064	-.236	-1.814	.0136	.001
5	AW site area	.255***	-.007	.045	-.015	-.163	.0001	.004
6	Clough area in 1km	-.063	-.015	.045	-.033	-.388	.0004	.001
7	Functional isolation 1	.158*	.028	.044	.053	.640	.0016	.030
	Functional isolation 2	-.018	.106	.073	.130	1.440	.0084	
	Functional isolation 3	-.145	-.129	.049	-.259	-2.608**	.0275	
	Residuals: Moran I =	0.02					R^2 =	.317
	Z score =	1.44					Adj R^2 =	.256
	p =	>0.1					R =	.563***

* p < .05, ** p < .01, *** p < .001, **** p < .0001

Table A10.12.2
Sequential multiple regression results of NMS Biodiversity score 2: General naturalness, richness and interest, by habitat and abiotic values. PAWS data, N = 184.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	.701	.126	.457	5.584***	.0942	.291***
	Mix, PAWS	N/A	.880	.114	.584	7.707***	.1797	
2	Grazed	N/A	-.208	.114	-.125	-1.829	.0102	.122***
	Topo diversity	.275***	.037	.057	.047	.660	.0012	
	Elevation, slope	-.212**	-.004	.054	-.006	-.079	.0000	
	Stream distance	-.307***	-.142	.046	-.205	-3.056**	.0282	
	Clough distance	-.046	-.049	.042	-.071	-1.175	.0042	
3	Area	.326***	.047	.077	.061	.619	.0012	.022*
	Shape	.233**	.083	.051	.107	1.624	.0079	
4	Core area index	.115	.180	.082	.244	2.203*	.0145	.001
5	AW site area	.033	-.098	.057	-.139	-1.706	.0088	.018*
6	Clough area in 1km	-.270***	-.137	.057	-.205	-2.416*	.0176	.019*
7	Functional isolation 1	-.109	-.019	.056	-.024	-.334	.0003	.019
	Functional isolation 2	.265***	-.196	.093	-.163	-2.096*	.0132	
	Functional isolation 3	.120	.125	.063	.170	1.982*	.0118	
	Residuals: Moran I =	0.02					R^2 =	.491
	Z score =	1.59 SD					Adj R^2 =	.445
	p =	> 0.1					R =	.701

* p < .05, ** p < .01, *** p < .001, **** p < .0001

Table A10.12.3
Sequential multiple regression results of NMS Biodiversity score 3: General naturalness by habitat and abiotic values. PAWS data, N = 184.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	-.051	.108	-.049	-.474	.0011	.018
	Mix, PAWS	N/A	.039	.098	.038	.395	.0008	
2	Grazed	N/A	-.087	.098	-.077	-.891	.0040	.104**
	Topo diversity	.010	.036	.046	.075	.789	.0030	
	Elevation, slope	.262	.088	.049	.165	1.798	.0159	
	Stream distance	-.132	-.021	.040	-.044	-.519	.0013	
	Clough distance	-.180	-.057	.036	-.123	-1.592	.0125	
3	Area	.283	.104	.066	.200	1.583	.0123	.032*
	Shape	.010	-.054	.044	-.104	-1.237	.0076	
4	Core area index	.175	-.055	.070	-.111	-.787	.0030	.000
5	AW site area	.173	.034	.049	.073	.700	.0024	.007
6	Clough area in 1km	-.003	.017	.049	.038	.355	.0006	.000
7	Functional isolation 1	.089	.008	.048	.016	.171	.0001	.012
	Functional isolation 2	.173	.120	.080	.147	1.490	.0110	
	Functional isolation 3	-.082	-.047	.054	-.095	-.873	.0037	
	Residuals: Moran I =	0.01					R^2 =	.172
	Z score =	0.75 SD					Adj R^2 =	.099
	p =	> 0.1					R =	.415

* p < .05, ** p < .01, *** p < .001, **** p < .0001

Table A10.12.4
Sequential multiple regression results of NMS Biodiversity score 1: Botanical richness per compartment by habitat and abiotic values. ASNW data, N = 114.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Grazed	N/A	.022	.087	.022	.259		.173**
	Topo diversity	-.374***	-.085	.055	-.192	-1.537		
	Elevation, slope	-.034	-.029	.045	-.059	-.637		
	Stream distance	.257**	.070	.053	.127	1.332		
	Clough distance	.009	.009	.043	.017	.209		
2	Area	-.472***	-.130	.051	-.294	-2.552*		.097**
	Shape	-.066	.070	.043	.151	1.635		
3	AW site area	-.267**	-.068	.049	-.134	-1.391		.028*
4	Urban area in 10km	.286**	.000001	.000	.194	2.149*		.030*
	Residuals: Moran I =	0.06					R^2 =	.329
	Z score =	1.56 SD					Adj R^2 =	.270
	p =	> 0.1					R =	.573***

* p < .05, ** p < .01, *** p < .001, **** p < .0001

Table A10.12.5
Sequential multiple regression results of NMS Biodiversity score 2: Botanical richness per compartment by habitat and abiotic values. ASNW data, N = 114.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Grazed	N/A	.042	.085	.032	.499	.0009	.157**
	Topo diversity	-316**	.053	.053	.093	1.011	.0037	
	Elevation, slope	-.014	-.042	.044	-.067	-.957	.0033	
	Stream distance	.020	-.074	.051	-.103	-1.460	.0077	
	Clough distance	.004	-.035	.043	-.051	-.800	.0023	
2	Area	-.711***	-.446	.045	-.784	-10.012***	.367	.383***
	Shape	-.146	.014	.041	.024	.344	.0004	
3	Structural isolation S1	.296**	.120	.041	.191	2.943**	.0316	.040**
4	Urban area in 10km	-.156	.00001	.000	-.213	-3.250**	.0388	.039**
	Residuals: Moran I =	0.06					R^2 =	.618
	Z score =	1.58 SD					Adj R^2 =	.585
	p =	> 0.1					R =	.786***

* p < .05, ** p < .01, *** p < .001, **** p < .0001

Table A10.12.6
Sequential multiple regression results of NMS Biodiversity score 3: Botanical richness and ground flora by habitat and abiotic values. ASNW data, N = 114. Low NMS3 scores indicate higher compartment interest.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Grazed	N/A	.069	.122	.051	.566	.0023	.060
	Topo diversity	-.110	-.003	.074	-.005	-.040	.0000	
	Elevation, slope	.116	-.074	.067	-.115	.276	.0084	
	Stream distance	.198*	.177	.072	.243	2.465*	.0428	
	Clough distance	-.108	-.055	.060	-.080	-.924	.0060	
2	Area	.029	.076	.063	.131	1.207	.0104	.054*
	Shape	-.201*	-.075	.060	-.124	-1.262	.0112	
3	Functional isolation SF3	-.342***	-.164	.056	-.266	-2.905**	.0595	.156***
	Area of clough in 1km	.344***	.242	.075	.327	3.233**	.0739	
4	Urban area in 10km	-.137	.0000	.000	.012	.122	.0001	.000
	Residuals: Moran I =	0.08					R^2 =	.271
	Z score =	4.74 SD					Adj R^2 =	.200
	p =	< 0.001					R =	.520***

* p < .05, ** p < .01, *** p < .001, **** p < .0001

Table A10.12.7

Sequential multiple regression results of summary Biodiversity score. PAWS data, N = 184.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Brd, PAWS	N/A	8.385	1.583	.419	5.298***	.0789	.275***
	Mix, PAWS	N/A	10.245	1.446	.521	7.085***	.1413	
2	Grazed	N/A	-1.823	1.451	-.084	-1.256	.0044	.176***
	Topo diversity	.374***	1.344	.723	.131	1.859	.0098	
	Elevation, slope	-.204**	.112	.683	.012	.163	.0000	
	Stream distance	-.355***	-1.811	.592	-.201	-3.059**	.0262	
	Clough distance	-.082	-.731	.533	-.081	-1.372	.0053	
3	Area	.423***	2.224	.973	.221	2.285*	.0146	.037**
	Shape	.203**	.093	.663	.009	.140	.0000	
4	Core area index	.175*	.953	1.041	.099	.915	.0024	.001
5	AW site area	.069	-1.581	.720	-.173	-2.197*	.0136	.014*
6	Clough area in 1km	-.261***	-1.1817	.745	-.208	-2.440*	.0166	.018*
7	Functional isolation 1	-.052	.615	.724	.061	.850	.0020	.004*
	Functional isolation 2	.313***	-1.374	1.219	-.088	-1.127	.0036	
	Functional isolation 3	.077	.293	.828	.031	.354	.0003	
8	Urban area in 1km	.182*	.167	.091	.118	1.845	.0096	.010
	Urban area in 10km	.202**	.0000	.000	-.004	-.057	.0000	
	Residuals: Moran I =	0.04					R^2 =	.533
	Z score =	2.55 SD					Adj R^2 =	.485
	p =	< 0.005					R =	.730***

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$

Table A10.12.8

Sequential multiple regression results of summary Biodiversity interest score. ASNW data, N = 114.

Block	Variable	r	B	seB	β	t value	sr^2	sr^2 Incremental
1	Grazed	N/A	-1.138	1.476	-.069	-.771	.0042	.177**
	Topo diversity	.388***	1.327	.915	.186	1.450	.0148	
	Elevation, slope	-.124	0.662	.837	.084	.791	.0044	
	Stream distance	-.287**	-1.558	.888	-.174	-1.755	.0219	
	Clough distance	-.043	-0.198	.734	-.023	-.270	.0005	
2	Area	.367***	1.432	.778	.201	1.841	.0240	.032
	Shape	.228*	0.474	.722	.063	.656	.0030	
3	Area of clough in 1km	-.190*	-1.643	.892	-.181	-1.842	.0243	.033*
4	Urban area in 5km	.117	0.001	.000	.139	1.489	.0158	.016
	Residuals: Moran I =	0.04					R^2 =	.258
	Z score =	2.61					Adj R^2 =	.194
	p =	< 0.001					R =	.508***

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$

Appendix 11

Appendix 11.1

LBAP Objective 4: Identification of potential priority woodland creation area polygons

The methodology involved several data sources and stages. The source data was the mapped clough landscape zone and the habitats occurring within it, created in **Chapter 8**. The analysis was conducted using 10m grids giving each habitat a value indicative of its value for conversion to a new native woodland. A 75m neighbourhood mean grid cell analysis was then conducted. A cut off value was selected above which grid cells were selected as priority areas for creation. The aim was identification of broader amalgamated creation areas where smaller pocket of suitable sites would merge when they occurred separated by areas of moderately suitable habitat but not when they were separated by highly unsuitable habitat. The scores therefore gave large values to high priority sites and small values to areas of habitats considered less suitable for conversion. A cut of value of 60 was selected above which grid cells would be considered high priority sites. Intermediate habitats were given a value just below the cut off value (e.g. 55, 59) such that they would return a value above 60 and be selected for creation when they occurred within the proximity of high priority sites. When such intermediate priority habitat did not occur near high priority sites the neighbourhood mean process resulted in values which did not mean they were picked for high priority creation sites. The effect of this analysis was such that where pockets of high quality creation habitats such as bracken, scattered trees or scrub occurred close together they would merge to form a single polygon. Final priority areas were converted to a polygons file which was unioned with urban areas to remove roads and urban areas, before being exported as a cleaned and exploded file.

Table A11.1
Dark Peak woodland creation LBAP Obj 4a priority site calculation. Values for conversion of habitats within cloughs values, to identify clusters of habitat suitable for conversions. Applied to a 75m neighbourhood mean.

Phase 1 habitat	Phase 1 habitat code	Value
Broadleaved woodland, semi-natural	A111	65
Scrub, dense and Scrub, scattered	A21, A22	500
Bracken	C11	150
Scattered trees, dense and Scattered trees, open	A3 (2), A3 (3)	500
All plantation woodland	A1 (Yng) A11, A112, A122 A132	65
Felled woodland	A4	65
Introduced shrub: rhododendron	J14	59
Acid grassland, unimproved	B11	59
Acid grassland, semi-improved (Rough)	B12 (Rough)	59
Acid grassland, semi-improved	B12	55
Improved / Semi-improved grassland	B4/Bx2	55
Dry dwarf shrub heath	D, D11	55
Marshy grassland (Soft rush or purple moor grass dominant)	B5 (Je), B5 (Mc)	55
Neutral grassland, semi-improved (Rough)	B22 (Rough)	55
Neutral grassland, semi-improved	B22	55
Cliff, Scree and Quarry	I1, I12, I21	55
Marshy grassland / Wet modified bog	B5 / E17 (Mc)	55
Bare ground	J4	55
Improved	B4	55
Acid grassland / heathland mosaic	D6	55
Acid flush	E21	20
Arable	J1	20
Amenity grassland	J12	20
Eroding moorland	Eroding moorland	20
Bare peat	E4	20

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