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Ghyll woodlands of the Weald: characterisation and conservation

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Abstract. Ghylls are linear valley features cut into the sandy beds of the Weald of south-eastern England. The ghyll's indigenous woodlands are highly species rich at the small scale, support distinctive assemblages of cryptogamic plants, and are unique to south-east England. Field surveys were carried out for 48 ghyll woodlands in the Weald with a GIS used to examine the ecology, landform and conservation status of the ghyll woodlands. The data were analysed using spatial and multi-variate techniques in order to identify sub-groups or ghyll woodland communities based upon species composition, topography and geology. The ghylls are shown to be reasonably uniform for canopy vegetation type and structure and for their geological and soil characteristics. However, analysis shows that geomorphology, understorey and field layer variability may act as stronger indicators of site conditions and character. Further analysis focused on the level and extent of nature conservation protection that these unique and ancient systems receive. The study concludes that despite their ecological importance and potentially international significance, ghyll woodlands are poorly understood and protected.

Introduction

The Weald of southeast England supports woodland valley systems internationally distinct in both their ecology and geomorphology. The ghyll woodlands, around 1000 in total, are typically linear features occupying deep and narrow valleys cut into the sandy and silty Hastings Beds and the Weald and Wadhurst clays (Woolridge and Goldring 1962). The sheltered valleys occupied by ghyll woodlands buffer temperature fluctuations and maintain high humidity levels resulting in unusually oceanic micro-climatic conditions (Rose 1995). Elsewhere in northwestern Europe, ghyll-like valleys are rare, and thus the concentration of these features in lowland England has international geomorphological and ecological significance (Rose and Patmore 1997).

The Weald has retained extensive tracts of a variety of ecologically important woodland types, and notably the central High Weald (HW) is the most

wooded natural area in England (Countryside Commission 1994; Rose 1995; Reid et al. 1996; Forestry Commission 2001). Spatial and structural analyses suggest that the ghyll woodland systems are an important and significant landscape feature in the Weald and are of high conservation value (Rose 1995; Rose and Patmore 1997; Burnside et al. 2002). Yet, ghyll woodlands have received only scant attention in the past.

The international and national ecological significance of these ghyll woodlands is that they support a unique assemblage of cryptogamic plants with both oceanic and sub-oceanic affiliations (Ratcliffe 1968; Hodgetts 1997). The presence of rich liverwort and moss communities suggests that the ghyll woodlands are of considerable age, and are therefore also likely to support a high biodiversity of other species of conservation concern, particularly terrestrial invertebrates, which share similar micro-environmental requirements (Peterken 1993; Rose and Patmore 1997; Woodland Trust 2000). Most can be regarded as 'ancient woodland' (*sensu* Rackham 1980; Peterken 1981; Forestry Commission 2001), and Rose and Patmore (1997) suggest that field investigations may indicate that some fragments could represent actual remnants of prehistoric woodland.

Much of south-eastern and southern England underwent preferential exploitation of woodland following a phase of human expansion in the late Neolithic/early Bronze Age (Waller and Marlow 1994). From a land-use perspective, however, the steep slopes of the ghylls have meant that, for the most part, they have remaining relatively uncultivated and thus wooded. Historically, the Weald area, though difficult to cultivate, benefited from the iron industry with many woods managed (*coppiced*[1]) for charcoal production and subsequent iron smelting (Brandon 1977; Cleere and Crossley 1985; Sussex Biodiversity Partnership 2000). This provided early conservation of the woodlands, as the resource was managed on a long-term sustainable basis, and may have resulted in many ghylls maintaining 'old forest type epiphytic lichens and bryophytes' (Rose and Patmore 1997).

The geology and geomorphology of the ghylls is also distinctive. In the sandstone beds of the Weald, ghylls can take the form of narrow rock-walled gorges. Conversely, where rocks are softer, slopes tend to be shallower and the valleys less confined (Rose 1995). The Wealden ghylls differ from similar features in southwest England, as a result of greater continental climatic influences, and the presence of relatively clay-rich soils. Rose and Patmore (1997) report that similar ghyll-like features do occur in other parts of lowland Britain that were not blanketed by glacial drift. Most, however, are shallow with gentler relief and do not exhibit the steep morphology present in the Weald. Many ghyll valleys extend over 1 km in length and, as a result of the complexity of Wealden geology, traverse a number of different geological strata

[1]Coppicing is the productive management of woodland. Trees are cut down and encouraged to grow again from the stump. Coppicing produces a large number of thin stems, which are harvested on a regular cycle of about 5–15 years.

(Gallois 1965). This variability in geology and unusual micro-climate has clear implications for ecological diversity, and is considered to influence the high levels of bryophyte diversity observed in ghyll systems (Rose and Patmore 1997).

The study presented within this paper constitutes the first attempt to use geographical information system (GIS) approaches and contemporary surveys to analyse and characterise these unique systems. The analysis focuses on the geomorphological and ecological characteristics of the ghylls, but also considers how the ghyll systems relate to existing conservation provision. GIS-based cadastral approaches and multi-variate statistical techniques are used to compare and analyse environmental, management and species information derived from field surveys undertaken for a sample of ghyll woodlands within southeast England.

Methodology

GIS techniques coupled with recent field survey data and secondary data derived from digital maps have been used in an inductive study to analyse a range of environmental and ecological characteristics for ghyll woodlands within the central Weald.

Development of a GIS database

The study used boundary data for 1130 ghylls in the Weald. The development of the GIS required the collation of large amounts of secondary data held in digital and non-digital form. Data, such as ghyll woodland boundaries, nature conservation designations, topography and soil associations, were obtained in digital form. The ghyll woodland boundary data were compiled from field reports held at the regional Biological Records Centre. The statutory nature conservation designations examined included the boundaries of Sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC), National Nature Reserves (NNR), and also ancient woodland (AW). The resultant GIS was structured around geographic and ecological landscape features.

Field survey

This study has used data from field surveys of 48 ghyll woodland systems throughout East and West Sussex (Figure 1). Using a uniform walkover survey approach, field survey data recorded both biotic and abiotic characteristics of the ghylls (Table 1). The data were used to construct a GIS database containing site-specific information on the ecology, landform and management of

48 ghyll woodlands randomly selected from 1130 ghyll woodlands. Where there were substantial differences in the vegetational or geomorphological structure in individual ghylls, multiple surveys were undertaken so as to represent this internal variation. The variables included in the survey reflected those considered important in characterising ghylls (Table 1), and were integrated in a GIS and analysed using spatial and multi-variate techniques to identify sub-groups or types of ghyll systems.

Table 1. Field survey information for the ghyll woodland sample in the Weald.

Characteristics	Descriptors
Geology	Predominant geological bed, geological beds in choronological sequence
Geomorphology	Valley form profiles, channel dimensions, height of ghyll,degree of fall, length of ghyll
Present land use	Coppicing, thinning/selective felling, clear felling, adjacent land use
Woodland type	Broadleaved, coniferous, mixed-woodland NVC – e.g. W6,W8,W10
Vegetation structure	Canopy, understorey, field layer vegetation composition using DAFOR scale, presence of alien species
Presence of important features	Geomorphology – waterfalls, sandstone outcrops Ecology – bryophytes, invertebrates

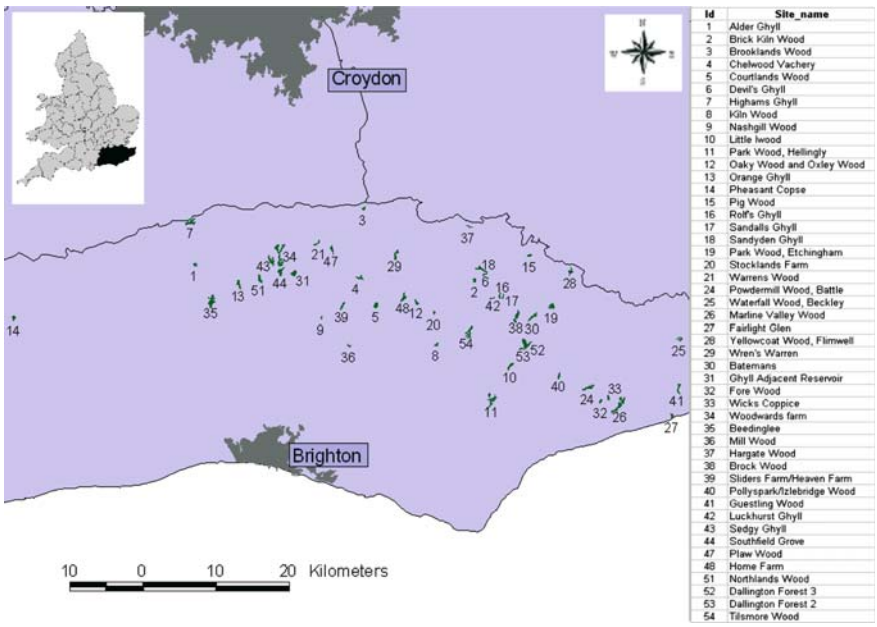


Figure 1. The location of the ghyll woodland field survey sites.

Spatial and statistical multi-variate analysis of the data

FragStats (McGarigal and Marks 1994) was used to measure area, perimeter length, and inter-patch distance for the ghyll woodlands. Additional spatial statistics were calculated for the digital boundary data of ghyll woodlands, to permit an assessment of the woodland pattern and physiognomy, relevant to the habitat and species of concern (Haines-Young and Choppin 1996; Gkaraveli et al. 2001). Using a cadastral approach, each ghyll woodland was examined to establish if it was either in [*within*] or abutted [*intersected*] one of the nature conservation designations (SSSI, SAC, NNR, AW) to facilitate examination of existing conservation designation for these sites. This analysis of ghyll woodland location was also undertaken for relevant English Nature landscape character areas, LCA (English Nature 2002). This analysis facilitated the classification of ghylls within broad-scale landscape management descriptions, for example, High Weald or Low Weald character areas (English Nature 2002).

The GIS was further utilised to examine the relationship between the ghyll woodland systems and soil associations using the woodland digital boundaries and digital soil information (SSLRC 2001). Soil associations known to be allied with ghyll woodlands were examined and proportional areas of ghyll woodlands situated in these soil types calculated using standard cadastral approaches (ESRI 1998).

Statistical analysis involved the application of multi-variate techniques to the field survey data. Cluster analysis and principal component analysis (PCA) were used to examine the differences in the ghyll woodlands for all major attributes recorded in the survey (the data format did not support detrended correspondence analysis) (Kent and Coker 1992; Everitt et al. 2001). The cluster analysis technique used average linkage and the Manhattan similarity index to describe the group of classification procedures (Waite 2000). In this analysis all ghyll woodland sites were initially considered to represent unique ghyll woodland systems or sites. A hierarchical classification was derived from a matrix, and based upon the values within that matrix samples were joined to form similar groups (Waite 2000). At each level, groups were joined based on their similarity. The process continued until all groups were joined to a common root.

PCA, was also used to assess the similarity or variation between these woodland systems based upon their vegetation and environmental features (Fowler et al. 1999; Waite 2000). A PCA ordination was undertaken to examine the gradients and variation in vegetation present within the ghyll systems. Analysis was undertaken collectively for the main canopy, understorey, and field layer vegetation data along with geological and environmental features (e.g. geological strata and valley form). This provided an initial analysis of a range of biotic and abiotic features associated with these distinct systems.

Results

Spatial patterns

Analysis indicates that ghyll woodlands cover 9332 ha of East and West Sussex, and are divided into 1130 patches (Table 2). The mean patch size (or habitat area) of ghyll woodland fragments is 8 ha. The ghyll woodlands have a high density of patches with 12 patches per 100 ha in the area of the Weald examined (Table 2). The mean patch shape calculations show that the ghyll woodland habitats (Shape Index = 17) are not uniform in shape (i.e. patch shapes move away from being regular shapes such as squares or circles). The calculation of mean nearest neighbour distance (NND) between ghyll woodland habitats gives values of 217 m ($\pm$250.5). A number of ghylls are however joined by contiguous areas of other woodland (managed and unmanaged). Thus, care must be taken to ensure that conclusions are not drawn regarding potential fragmentation effects (Wiens 1989; Bailey et al. 2002).

Conservation designations

Cadastral analysis of the ghyll woodland systems and national conservation designations indicate that the ghyll systems have not been a focus of conservation attention and on a site basis only 9% are included within SSSI. This proportion is also reflected in the sample of surveyed ghylls, where only 12% were identified as being associated with SSSIs. Furthermore, only 4% of ghyll woodland sites intersect the boundaries of SAC, and no ghyll woodlands are designated as NNR

The GIS analysis shows, however, that on a site basis 85% of the ghyll woodland systems are associated with areas of AW(both semi-natural and replanted) in East and West Sussex. Additionally, a substantial number of ghyll woodlands are included in the locally designated sites of nature conservation interest (SNCI), and a number fall within important landscape

Table 2. Spatial statistics for the Ghyll woodlands within the Central Weald of East and West Sussex (raster format).

Raster indices	Ghyll woodland
Total area (ha)	9332
Mean area (ha)	8
Mean area std dev	13.3
Patch number	1130
Patch density (#/100 ha)	12
Mean Shape Index	2.17
Mean NND (m)	217
Mean NND std dev	250.5

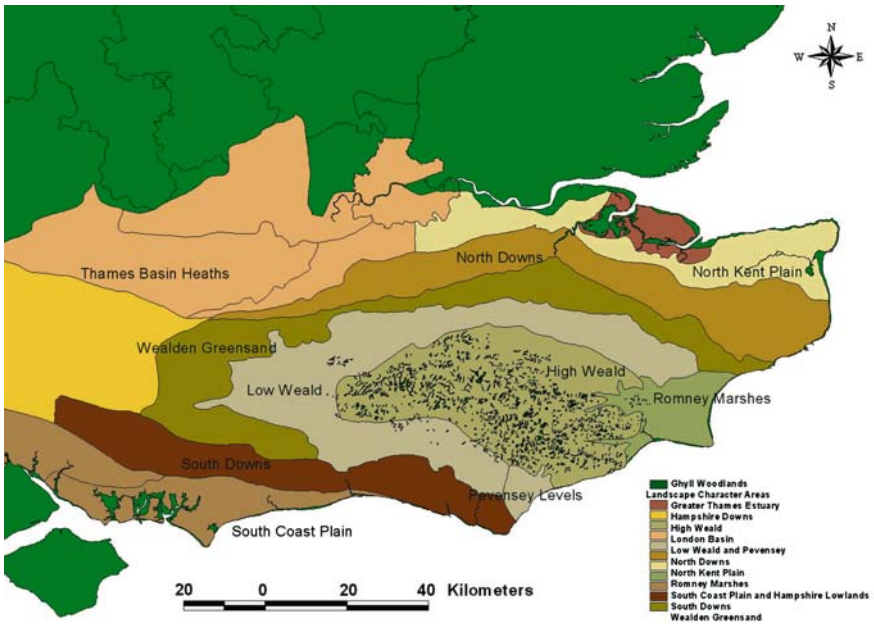


Figure 2. The relationship between ghyll woodland systems and English Nature landscape character areas.

designations such as area of outstanding natural beauty (AONB) and the HW. Comparison of the distribution of ghyll woodlands and LCA classification (English Nature 2002) reveals that 92% of ghyll systems are associated with the HW LCA. A further 6% are found in the Low Weald LCA and, as might be anticipated, only 2% are found in the Romney Marsh LCA (Figure 2).

Plant community characteristics

GIS data and field surveys revealed that *Quercus robur – Pteridium aquilinum – Rubus fruticosus* woodland (NVC – W10) and *Fraxinus excelsior – Acer campestre – Mercurialis perennis* woodland (NVC – W8) were the most common woodland community types found. Of the woodland surveyed, 47% was found to be predominantly W10, and a further 43% dominated by W8 woodland. The remaining areas were comprised of W7, W12, W15 and some pockets of W4, W6 and W16 woodland (Rodwell 1998). Analysis using multivariate statistical approaches (Cluster analysis and PCA) was performed on the digital survey records. This provided a descriptive means of assessing similarity and differentiation both within individual ghylls and between different ghyll woodland sites. Cluster analysis was initially undertaken for the

three vegetation components surveyed; the canopy, the understorey and the field layer.

The canopy

The canopy data shows that overall there is a moderately good level of similarity in the composition of the canopy within the sampled ghyll woodland systems (Figure 3a). Values of between 38 and 55% similarity were obtained when comparing the overall data set and the various sub-groupings. When clusters were grouped, analysis showed an increase in the similarity values with groups 1–3 and 8 between 50 and 60% similar whilst groups 4–7 showed similarity values greater than 60% (see appendices). Within these groups, one major anomaly was seen at Fairlight Glen, Hastings which was clearly identified as an outlier. This is because the canopy of this southern, more coastal, section of Fairlight Glen ghyll is solely dominated by *Salix* species.

Further analysis identified some clear ghyll woodland associations, all showing comparatively high similarity values ($>64\%$). The data may suggest that there are some 'canopy' based associations within these ghyll woodlands. For example, Group 1 is shown to be 42% similar to the other ghyll woodlands surveyed yet, there is a moderately high level of canopy similarity within the group itself (56%) (see appendices).

More specifically, two classes are identified and, of these, the two Brick Kiln ghyll woodland areas are identical in canopy structure. Furthermore, the analysis picks out two, somewhat individual, ghyll woodlands based upon canopy composition, Kiln Wood (Lower ghyll) (no. 11) and Sandyden Wood (no. 49). These woodlands are shown as only 38% similar to all other ghyll woodlands surveyed and have no comparative ghylls at the group or class level (Figure 3a).

The understorey

The data shows that, generally, there is similarity in the composition of the understorey within the ghyll woodland systems (Figure 3b). Values of between 31 and 61% similarity were obtained when comparing the overall data set and the various sub-groupings provided through cluster analysis. The analysis at the group level showed a substantial increase in the similarity values with all groups, apart from group 1, greater than 60% similar. These findings may indicate some potential categories or communities.

Analysis at the class level shows strong association within the ghyll woodland systems, with similarity values around 75–100%. The analysis shows that when the understorey vegetation is examined many of the ghyll sites display little difference (e.g. Marline Valley, Batemans and Northlands

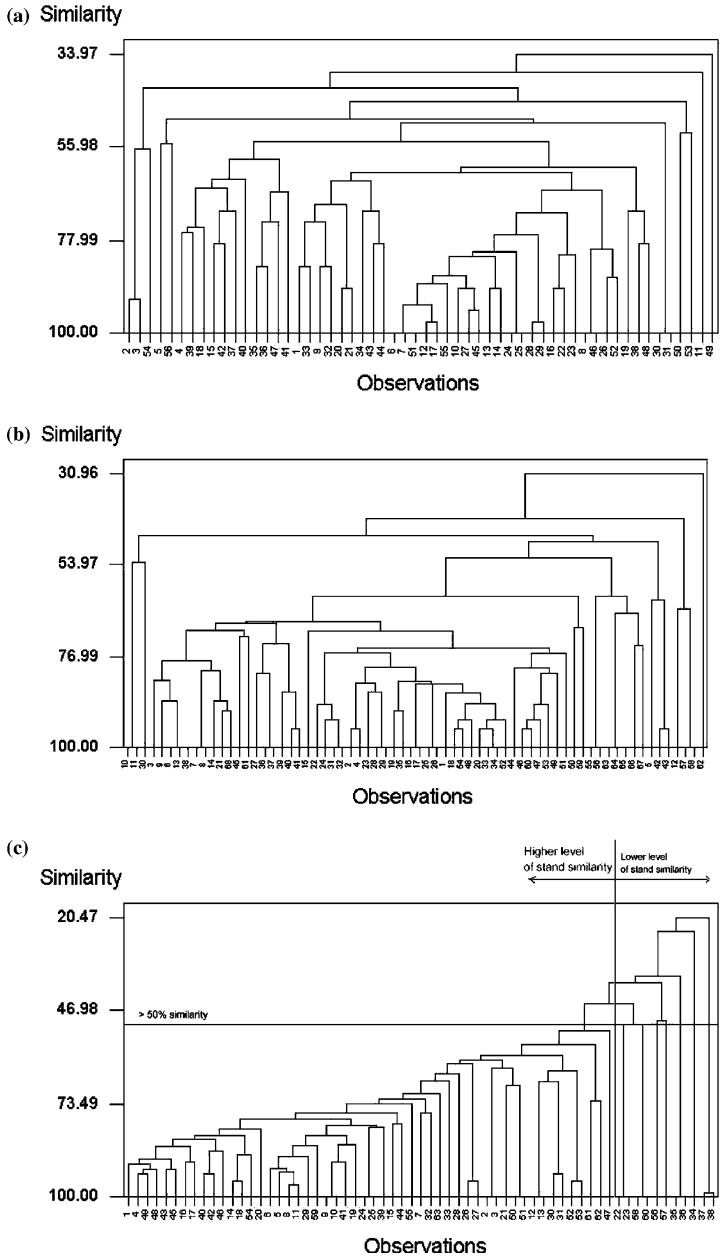


Figure 3. Cluster analysis dendrogram of the ghyll woodland canopy (a), under-storey (b), and field (c) survey data. A complete table of percentage similarity values derived from cluster analysis is provided in the appendix.

Wood). It is, however, interesting to note that the analysis shows that Marline valley does have some zonation within the ghyll – reflected in the fact that two surveys were conducted at the site. Marline valley (away from stream) and Marline Valley (near stream) are identical, as are Marline Valley (by watercourse) and Marline Valley (away from watercourse). When comparing these two groups the analysis only shows a similarity value of 47% between them (Figure 3b).

The analysis isolates Waterfall Wood as relatively distinctive. When the GIS database and survey sheets are examined, this separation appears to be an artefact of the understorey composition. Waterfall wood is the only ghyll with the understorey solely dominated by *Alnus* species. Highams Ghyll and Sandyden Wood also have *Alnus* species present within the understorey; however, closer inspection shows that Highams also has *Crataegus monogyna* dominant and *Ilex aquifolium* occasional within the understorey, whilst Sandyden Ghyll has *Sambucus nigra* frequent within the understorey and *Corylus avellana* occasional.

The field layer

The analysis of the field layer data using cluster analysis shows that some data sets appear very dissimilar with values ranging from 21 to 39% similarity (derived from 11 site surveys). In contrast, 48 of the remaining sites show high levels of similarity (Figure 3c). When considering the cluster analysis for field data, the dendrogram clearly shows that those sites to the right of the figure are on the whole largely dissimilar whilst those sites to the left of the figure reveal moderately good levels of similarity, $>50\%$ (Figure 3c).

When grouped, over half of the sites show similarity levels of 62%. Furthermore, within group 1, for example, the associations show 13 sites with 80% similarity and a further 15 sites with 81% similarity (see appendices). Despite these high levels of field layer similarity within the majority of ghyll systems, there are additional ghyll systems which are shown to be relatively distinctive in character and field layer composition. Sandyden Wood and Waterfall Wood are shown to be 50% similar to each other in presence/absence, but are only 39% similar to all other ghyll woodlands surveyed. Wicks Copse and Tilsmore Wood are also outliers with similarity values of 25 and 21% respectively (Figure 3c). Wren's Warren is also distinct, separated from other ghylls by the presence of *Vaccinium* spp. within the field layer (see appendices).

Ghyll woodlands and soils

Cadastral analysis via the GIS demonstrates that the ghyll woodlands occupy a range of soil types. At a general level, GIS analysis indicates that 85% of the

ghyll woodlands are associated, to some extent, with brown soils and particularly with argillic brown earths of the Curtisden association (Association 5.72i of Jarvis et al. 1984). This association is widespread throughout the HW, occurring on siltstones and sandstones. In this association, slope relief is typically strong with moderately to steeply sloping valleys [ghylls] separated by gently sloping interfluves. Soils of the Curtisden association are usually moderately deep on gentle or moderate slopes. Characteristically, the soils comprise slowly permeable compact subsoil, which is subject to seasonal water logging. Springs and flushes are often common on the sloping ground of permeable and impermeable strata (Jarvis et al. 1984).

Ghyll woodlands are also commonly found on surface-water gley soils (Stagnogley Associations 7.11e, 7.11i and 7.12b of Jarvis et al. 1984), which are linked, again to varying degrees, with 55% of ghyll systems. The Wickhams 1 and 5 Associations are extensive on the Low Weald. The Wickham Associations have slowly permeable subsoils and are often waterlogged for prolonged periods in winter. Often heavily wooded, these soils are naturally acidic and can have good reserves of available water (Jarvis et al. 1984). Other associations are linked with the ghyll systems but their importance is low. Podzolic soils, in particular gley podzolic soils, are associated with 4% of the ghyll systems. Only 1% are associated with ground water gley soils.

Cluster analysis of geological and topographical data

Cluster analysis was undertaken for the geological components of the surveys, including surrounding geology, 1st, 2nd, 3rd Geological Beds (in chronological sequence), height at top of ghyll, and height difference within the ghyll valley. The geological and topographical data shows substantial level of similarity within the ghyll woodland systems with 89% of the sites being $>68\%$ similar (Figure 4). All reside on the clays and sands of the Hastings Beds. Beyond this level of similarity there are some additional sub-groupings with particularly strong associations yielding similarity values $>80\%$ (Figure 4), which reflect the presence of ghylls on Ashdown sands, Tunbridge sands, Wadhurst clays and Fairlight clays.

Figure 4a also shows that some sites appear relatively distinctive in comparison to the majority of ghylls surveyed. Site 41 (Guestling Wood) shows low similarity values of 28% to all other ghyll systems examined. Two of the Fairlight Glen surveys (Sites 46 and 27) show good similarity when compared to each other (87%), but are only 41% similar to all other systems. Equally, Courtlands Wood (Site 5) and Little Iwood (Site 10) are similar to one another (90%) but are only 54% similar to all other survey sites. Examination of the GIS database and survey sheets suggests that these differences are related to surrounding geology, strata and average levels of fall along the ghyll. Further cluster analysis was undertaken for the geological components

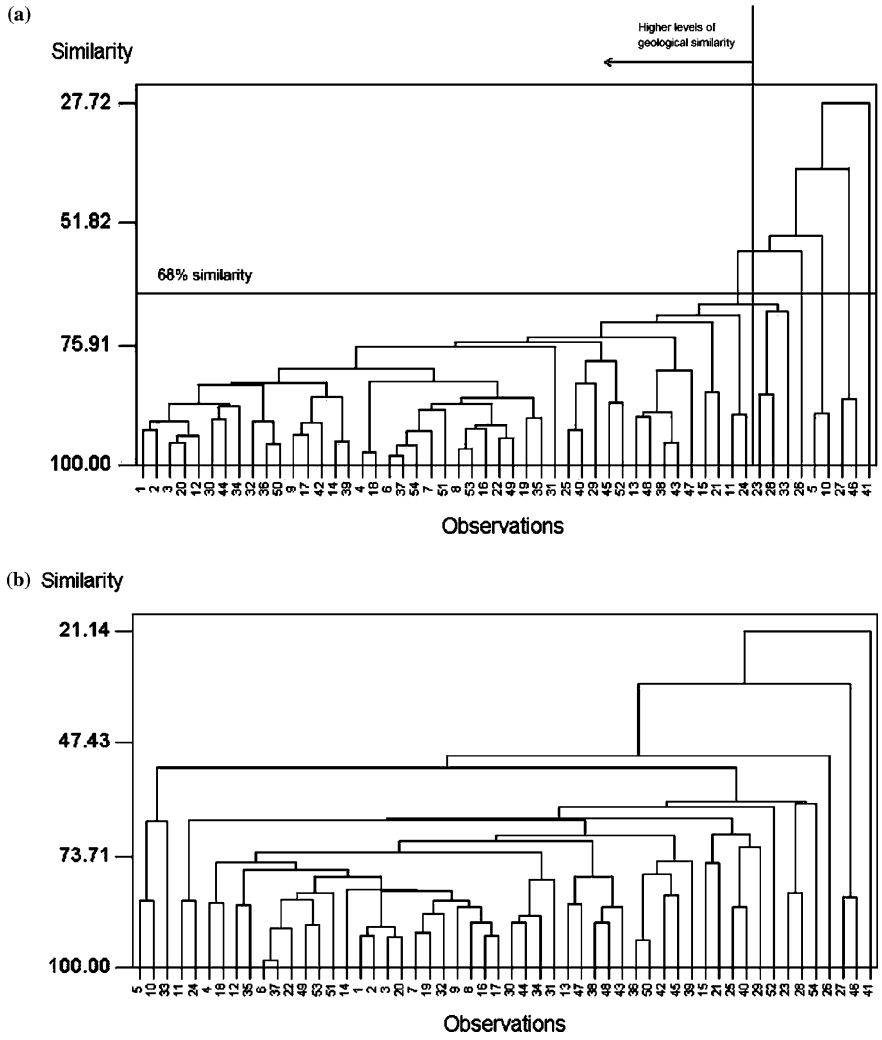


Figure 4. Cluster analysis dendrogram of the ghyll woodland geological (a) and geological and vegetation survey data combined (b).

and the vegetational data from the ghyll woodland surveys combined (Figure 4b). The dendrogram repeats patterns observed within the previous cluster analysis showing a strong association ($>62\%$) between the majority of ghyll woodland sites surveyed (over 80% of sites). In addition, the dendrogram isolated the same sites as being distinctive including Fairlight Glen, Guestling Wood, Courtlands Wood, Little Iwood and Marline Valley (Figure 4b). This similarity of outcomes may be associated with the dominance of geological data within the analysis of both data matrices and the relatively weak

contribution of the vegetational components to the geology and vegetational matrix.

PCA of geological and vegetational data

PCA analysis of the geological and vegetational survey data reinforces the conclusions drawn from the cluster analysis. Analysis shows high levels of association between the majority of ghyll systems based upon the variables (shown by the main grouping on the ordination, Figure 5). This suggests that the majority of ghyll systems have similar geological and vegetational characteristics and little or no separation is present along either axis.

It is however, interesting to note that there are two ghylls separated from the main grouping along the first component showing 24% of the variation (*eigenvalue = 2.419*) (Figure 5). Both Fairlight Glen and Marline Valley (near watercourse) are separated along this axis and examination of the GIS database suggests that this relates to strong differences in their geological

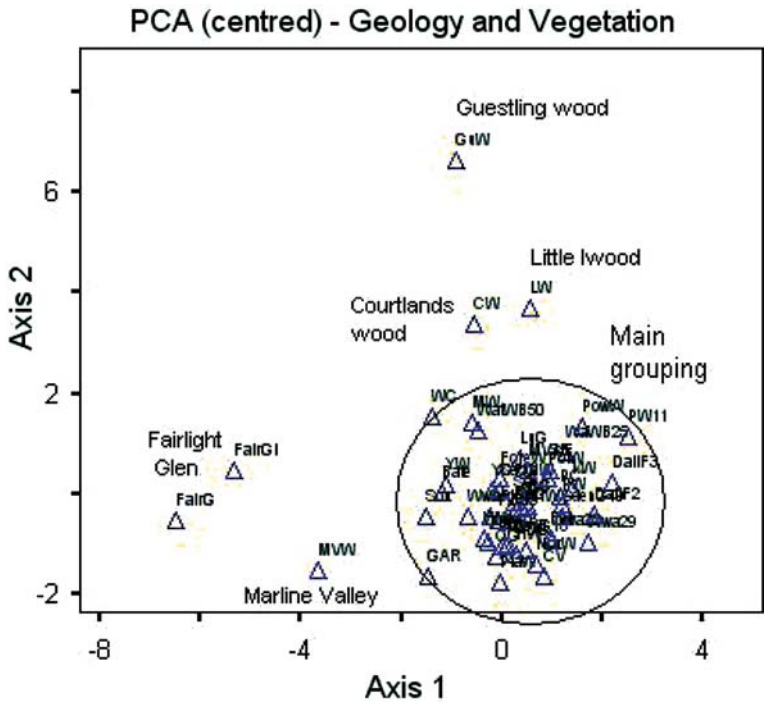


Figure 5. PCA analysis ordination of the ghyll woodland geological and vegetational survey data.

beds, valley form and average degree of fall along the ghyll. Equally, a further three ghylls are separated from the main grouping along the second component showing 20% of the variation (*eigenvalue = 2.002*). Guestling Wood, Courtlands Wood and Little Iwood are separated here and the survey data again points to geological conditions although some differences are evident within their National Vegetational Classifications (Rodwell 1998) (Figure 5).

Discussion

Using a GIS-based spatial approach and multi-variate statistical techniques, this inductive study has provided an initial analysis of a sample of ghyll woodlands within the Weald of southeast England which suggests the significance of these important ecosystems within the broader landscape context. Biological Records Centre digital data sets identify 1130 ghyll woodlands in the High and Low Weald LCA. Spatial analysis suggests that, on an area basis, these ghylls comprise 23% of the woodland within East Sussex alone. This, however, is likely to be an over-estimate due to boundary issues, and the previous classification of substantial woodland areas as ghylls beyond the confines of the characteristic valley systems (Burnside et al. 2002). This latter point is of particular relevance to area calculations, as ghyll systems are normally regarded as restricted to small linear valley features.

The analysis of the composite GIS survey database and field surveys using multi-variate techniques has shown that the vegetation within the ghyll woodlands is relatively similar in the canopy, understorey and field layers with similarity values of around 50–60%. The similarity reflects the common occurrence of NVC type W10 and W8 woodlands and a dominance of *Quercus* sp. and *Fraxinus* sp. respectively in the canopy. Equally, within the understorey and field layer the often widespread incidence of *Ilex aquifolium* and *Corylus avellana*, and in other cases of *Rubus fruticosus* and *Pteridium aquilinum*, provided good similarity levels.

In some cases, however, the vegetation within particular ghylls does appear distinctive with percentage similarity values dropping to 20–30%. In relation to the canopy this reflected cases whereby the vegetation was solely dominated by *Salix* species. In relation to the understorey layer, the distinctive nature of some ghylls reflected the strong presence of *Castanea sativa* and the management practice of rotation coppicing.

Analysis of the geological data also illustrates that the ghylls are undifferentiated at the general level. Cluster analysis identified that around 90% of sites were 70% similar for geological beds (e.g. Ashdown beds or Tunbridge Wells sands) and topographic characteristics (e.g. depth of ghyll and degree of fall). However, as shown by the vegetational analysis, some of the ghylls do remain relatively distinctive in topography (levels including 30–40%

similarity), which reflects the importance of landscape influence. The PCA shows, from a geological, geomorphological and ecological perspective that valley form, underlying geology and woodland type (*sensu* NVC) can be used to differentiate some ghyll woodlands (Figure 5). For example, Fairlight Glen and Marline valley are shown to be representative of steep-sided, confined valleys, on harder Wadhurst clays with a dominance of traditional *Quercus robur – Pteridium aquilinum – Rubus fruticosus* woodland (NVC – W10). Whilst Guestling wood, Little Iwood and Courtlands wood, are representative of more open valleys on unconsolidated and unlithified head-material. The latter ghylls exhibit a strong presence of *Fraxinus excelsior – Acer campestre – Mercurialis perennis* woodland (NVC – W8), vegetation more characteristic of base-rich soils (Rodwell 1998). In comparative terms, many of the 'main groupings' display less distinctive traits and exhibit the more general characteristics, which include Ashdown or Tunbridge geology, a moderate depth of ghyll (*circa* 20 m) and more than one woodland community along the entire valley profile.

Comparison of the ghyll woodland data and nature conservation designation confirms that in many cases the ghyll systems have received little protection. It is apparent that a substantial number of the ghyll woodlands fall within the broad remit of landscape designations, such as AONB, but on a site-by-site basis only about 10% have benefited from a nationally recognised conservation designation. This may result from the small size and linear character of individual ghyll woodlands when placed in the context of the broader wooded landscape. Effectively, ghyll woodlands represent small pockets of exceptionally high diversity, but often occur in broader woodlands that do not warrant designation. The analysis presented here may well indicate an under-representation of these intrinsically small and fragmented sites within existing statutory protection (Kirby 2003).

These linear and fragmented sites may also be susceptable to the negative aspects of edge effect and incursion by more robust and competitive species (Harrison and Bruna 1999). Alterations to the understorey and canopy layers as a result of species change could have severely detrimental effects to the structure of the woodland systems (Burke 1998), and may result in a reduction in biodiversity and the loss of more specialised species indicative of the ghyll woodland habitats.

The study emphasises the importance of developing appropriate management plans for these sites, and the need to set appropriate nature conservation designation. As stated earlier, many of the ghyll woodlands are AW and have for the most part remained relatively undisturbed (Hodgetts 1997; Rose and Patmore 1997). This is an important consideration in relation to both biodiversity management and biological conservation. In many cases, whilst maintaining rich (and often locally rare) cryptogamic communities, ghyll valleys have no prescribed management plans and are under private ownership. Sustaining and promoting biodiversity at the

landscape scale requires the characterisation and maintenance of pockets of high biodiversity (Ernoult et al. 2003). In the case of some ghyll woodlands, this may only involve non-interventionist management but, nevertheless, designation must be secured. Some ghylls have been given regional status via SNCI designation, but this is a local designation and provides only limited protection.

Conclusion

GIS database and multi-variate statistical approaches have been used to investigate ghyll woodland systems of the Sussex Weald. The ghylls have been shown to be a reasonably uniform vegetation type in terms of the canopy and their geological and soil characteristics. Yet, the variation in geology and climate, along with historical factors creates a system which is very species rich at the small scale (Waller and Marlow 1994; Rose and Patmore 1997; Sussex Biodiversity Partnership 2000). Analysis shows that the ghyll woodlands offer substantial opportunity for analysis of woodland characterisation and diversity. Some workers consider that bryophyte species occurrence and frequency may be the key to the systematic differentiation of ghyll woodland communities (Rose 1995; Rose and Patmore 1997), whilst others propose a more balanced approach looking at both ecological and landscape factors together (Burnside et al. 2002). However, this study shows that the geomorphology, understorey and field layer may act as an initial indicator of site conditions and character.

The research has also demonstrated that ghylls have relatively weak levels of habitat protection in respect of their known conservation value for lower plants. Addressing this protection is of critical importance given the national, and potentially international, significance of the ghyll woodlands of the Weald. Further GIS investigations linking surveys of mosses and lichens with climatic and aspect data could provide a means to identify noteworthy ghyll woodlands for conservation targeting.

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GIS analysis was performed on ArcView 3.x software, Environmental Systems Research Institute and FragStats (ver 2), McGarigal and Marks (1992).

Statistical analysis performed using WinSTAT 3.1, Kalmia Co. Inc., 1995. Terrain data supplied by EDINA Edinburgh University, 2002; soil data supplied by SILSOE, Cranfield University, 2002; forestry and woodland data supplied by Forestry Commission, 2002; English Nature GUI, 2002, and Sussex Biological Records Centre, 2001.

Appendices

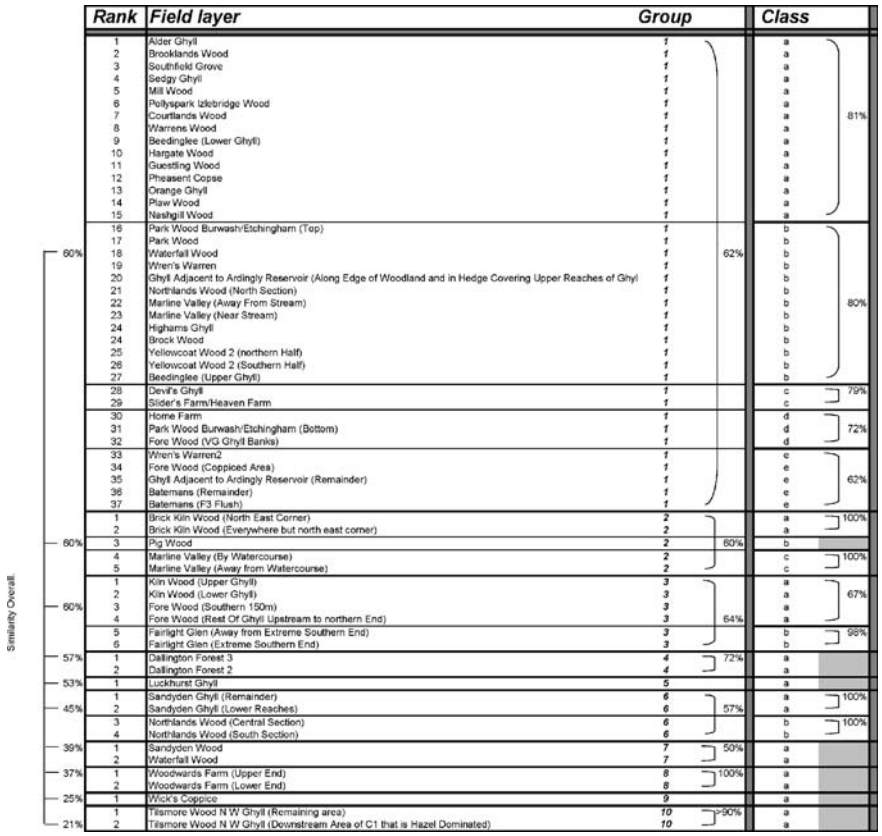
Table A1. Percentage Similarity of cluster analysis for Canopy data.

Similarity Overall	Rank	Canopy	Group		Class	
	1	Brick Kiln Wood (North East Corner)	1		a	90%
42%	2	Brick Kiln Wood (Everywhere but north east corner)	1	56%	a	
	3	Dallington Forest 3	1		b	
49%	1	Waterfall Wood	2	55%	a	
	2	Wren's Warren2	2		a	
	1	Brooklands Wood	3		a	
	2	Guestling Wood	3		a	
	3	Stocklands Farm (Remainder)	3		a	
55%	4	Orange Ghyll	3		a	64%
	5	Southfield Grove	3		a	
	6	Slider's Farm/Heaven Farm	3	59%	a	
	7	Luckhurst Ghyll	3		a	
	8	Hargate Wood	3		b	
	9	Mill Wood	3		b	67%
	10	Plaw Wood	3		b	
	11	Sodgy Ghyll	3		b	
	1	Alder Ghyll	4		a	
	2	Beedinglee (Lower Ghyll)	4		a	
	3	Wren's Warren	4		a	
	4	Beedinglee (Upper Ghyll)	4		a	70%
55%	5	Sandyden Ghyll (Remainder)	4	64%	a	
	6	Sandyden Ghyll (Lower Reaches)	4		a	
	7	Brock Wood	4		b	
	8	Marline Valley (By Watercourse)	4		b	71%
	9	Marline Valley (Away from Watercourse)	4		b	
	1	Marline Valley (Away From Stream)	5		a	
	2	Marline Valley (Near Stream)	5		a	
	3	Northlands Wood (Central Section)	5		a	
	4	Pheasent Copse	5		a	
	5	Nashgill Wood	5		a	
	6	Dallington Forest 2	5		a	
	7	Kiln Wood (Upper Ghyll)	5		a	
	8	Wick's Coppice	5		a	
	9	Fairlight Glen (Section Next to Beach)	5		a	71%
55%	9	Fairlight Glen (Away from Extreme Southern End)	5		a	
	10	Courtlands Wood	5		a	
	11	Warrens Wood	5	66%	a	
	12	Ghyll Adjacent to Ardingly Reservoir (Remainder)	5		a	
	13	Ghyll Adjacent to Ardingly Reservoir (Along Edge of Woodland and in Hedge Covering Upper Reaches of Ghy	5		a	
	14	Woodwards Farm (Upper End)	5		a	
	15	Woodwards Farm (Lower End)	5		a	
	16	Highams Ghyll	5		a	
	17	Batemans (Remainder)	5		a	
	18	Batemans (F3 Fluth)	5		a	
	20	Fairlight Glen (Extreme Southern End)	5		b	
	21	Fore Wood (Coppiced Area)	5		b	79%
	22	Northlands Wood (North Section)	5		b	
	1	Pig Wood	6		a	
55%	2	Pollyspark Izlebridge Wood	6	71%	b	77%
	3	Home Farm	6		b	
55%	1	Tilsmore Wood N W Ghyll (Remaining area)	7	100%	a	
	2	Tilsmore Wood N W Ghyll (Downstream Area of C1 that is Hazel Dominated)	7		a	
45%	1	Waterfall Wood	8	53%	a	
	2	Northlands Wood (South Section)	8		a	
38%	1	Kiln Wood (Lower Ghyll)	9		a	
38%	1	Sandyden Wood	10		a	

Table A2. Percentage Similarity of cluster analysis for Understory data.

Similarity Overall	Rank	Understory	Group		Class	
	1	Marline Valley (Away From Stream)	1		a	100%
46%	2	Marline Valley (Near Stream)	1	54%	a	
	3	Yellowcoat Wood 2 (Southern Half)	1		b	
	1	Brick Kiln Wood (Everywhere but north east corner)	2		a	
	2	Waterfall Wood	2		a	
	3	Park Wood	2		a	
	4	Fairlight Glen (Section Next to Beach)	2		a	
	5	Fore Wood (Coppiced Area)	2		a	
	6	Powdermill Wood (North)	2		a	78%
	7	Powdermill Wood (South)	2		a	
	8	Wren's Warren	2		a	
61%	9	Warrens Wood	2	69%	a	
	10	Wren's Warren2	2		a	
	11	Beedinglee (Lower Ghyll)	2		b	72%
	12	Sandyden Wood	2		b	
	13	Pig Wood	2		c	
	14	Fore Wood (Rest Of Ghyll Upstream to northern End)	2		c	
	15	Fore Wood (VG Ghyll Banks)	2		c	74%
	16	Wick's Coppice	2		c	
	17	Woodwards Farm (Upper End)	2		c	
	18	Woodwards Farm (Lower End)	2		c	
	1	Oaky Wood and Oxley Wood	3		a	
	2	Orange Ghyll	3		a	
61%	3	Nashgill Wood	3	89%	a	
	4	Batemans (Remainder)	3		b	100%
	5	Batemans (F3 Flush)	3		b	
	1	Brick Kiln Wood (North East Corner)	4		a	
	2	Brooklands Wood	4		a	
	3	Highams Ghyll	4		a	84%
	4	Sandyden Ghyll (Remainder)	4		a	
	5	Sandyden Ghyll (Lower Reaches)	4		a	
	6	Devil's Ghyll	4		b	
	7	Fore Wood (Southern 150m)	4		b	
	8	Kiln Wood (Upper Ghyll)	4		b	
	9	Kiln Wood (Lower Ghyll)	4		b	
61%	10	Stocklands Farm (Remainder)	4	80%	b	
	11	Stocklands Farm (Upper Reaches)	4		b	
	12	Alder Ghyll	4		b	83%
	13	Pheasent Copse	4		b	
	14	Southfield Grove	4		b	
	15	Mill Wood	4		b	
	16	Courtlands Wood	4		b	
	17	Ghyll Adjacent to Ardingly Reservoir (Remainder)	4		b	
	18	Ghyll Adjacent to Ardingly Reservoir (Along Edge of Woodland and in Hedge Covering Upper Reaches of Ghy	4		b	
	19	Luckhurst Ghyll	4		b	
	1	Beedinglee (Upper Ghyll)	5		a	
	2	Brock Wood	5		b	
	3	Home Farm	5		b	
61%	4	Hargate Wood	5	76%	b	89%
	5	Sedgy Ghyll	5		b	
	6	Slider's Farm/Heaven Farm	5		b	
	7	Guestling Wood	5		c	
61%	1	Pollyspark (Glebridge Wood	6	70%	a	
	2	Plaw Wood	6		a	
	1	Marline Valley (By Watercourse)	7		a	100%
	2	Marline Valley (Away from Watercourse)	7		a	
	3	Northlands Wood (Central Section)	7		b	
52%	4	Northlands Wood (North Section)	7	62%	b	100%
	5	Northlands Wood (South Section)	7		b	
	6	Dallington Forest 3	7		c	74%
	7	Dallington Forest 2	7		c	
	1	Chelwood Vachery	8		a	
48%	2	Tilsmore Wood N W Ghyll (Remaining area)	8	63%	b	
	3	Tilsmore Wood N W Ghyll (Downstream Area of C1 that is Hazel Dominated)	8		b	
	1	Fairlight Glen (Remainder)	9		a	circa
42%	2	Fairlight Glen (Away from Extreme Southern End)	9	65%	a	60%
	3	Fairlight Glen (Extreme Southern End)	9		a	
31%	1	Waterfall Wood	10		a	

Table A3. Percentage similarity of cluster analysis for Field data.



Similarity Overall	Rank	Field layer	Group		Class	
	1	Alder Ghyll	1		a	
	2	Brooklands Wood	1		a	
	3	Southfield Grove	1		a	
	4	Sedgy Ghyll	1		a	
	5	Mill Wood	1		a	
	6	Pollyspark Idlebridge Wood	1		a	
	7	Courtlands Wood	1		a	81%
	8	Warrens Wood	1		a	
	9	Beedinglee (Lower Ghyll)	1		a	
	10	Hargate Wood	1		a	
	11	Guestling Wood	1		a	
	12	Pheasent Copse	1		a	
	13	Orange Ghyll	1		a	
	14	Plaw Wood	1		a	
	15	Nashgill Wood	1		a	
	16	Park Wood Burwash/Etchingham (Top)	1		b	
	17	Park Wood	1		b	
60%	18	Waterfall Wood	1	62%	b	
	19	Wren's Warren	1		b	
	20	Ghyll Adjacent to Ardingly Reservoir (Along Edge of Woodland and in Hedge Covering Upper Reaches of Ghyl	1		b	
	21	Northlands Wood (North Section)	1		b	
	22	Marline Valley (Away From Stream)	1		b	80%
	23	Marline Valley (Near Stream)	1		b	
	24	Highams Ghyll	1		b	
	24	Brock Wood	1		b	
	25	Yellowcoat Wood 2 (northern Half)	1		b	
	26	Yellowcoat Wood 2 (Southern Half)	1		b	
	27	Beedinglee (Upper Ghyll)	1		b	
	28	Devil's Ghyll	1		c	79%
	29	Slider's Farm/Heaven Farm	1		c	
	30	Home Farm	1		d	
	31	Park Wood Burwash/Etchingham (Bottom)	1		d	72%
	32	Fore Wood (VG Ghyll Banks)	1		d	
	33	Wren's Warren2	1		e	
	34	Fore Wood (Coppiced Area)	1		e	
	35	Ghyll Adjacent to Ardingly Reservoir (Remainder)	1		e	62%
	36	Batemans (Remainder)	1		e	
	37	Batemans (F3 Flush)	1		e	
	1	Brick Kiln Wood (North East Corner)	2		a	100%
	2	Brick Kiln Wood (Everywhere but north east corner)	2		a	
60%	3	Pig Wood	2	60%	b	
	4	Marline Valley (By Watercourse)	2		c	100%
	5	Marline Valley (Away from Watercourse)	2		c	
	1	Kiln Wood (Upper Ghyll)	3		a	
	2	Kiln Wood (Lower Ghyll)	3		a	67%
60%	3	Fore Wood (Southern 150m)	3		a	
	4	Fore Wood (Rest Of Ghyll Upstream to northern End)	3	64%	a	
	5	Fairlight Glen (Away from Extreme Southern End)	3		b	98%
	6	Fairlight Glen (Extreme Southern End)	3		b	
57%	1	Dallington Forest 3	4	72%	a	
	2	Dallington Forest 2	4		a	
53%	1	Luckhurst Ghyll	5		a	
	1	Sandyden Ghyll (Remainder)	6		a	100%
45%	2	Sandyden Ghyll (Lower Reaches)	6	57%	a	
	3	Northlands Wood (Central Section)	6		b	100%
	4	Northlands Wood (South Section)	6		b	
39%	1	Sandyden Wood	7	50%	a	
	2	Waterfall Wood	7		a	
37%	1	Woodwards Farm (Upper End)	8	100%	a	
	2	Woodwards Farm (Lower End)	8		a	
25%	1	Wick's Coppice	9		a	
	1	Tilsmore Wood N W Ghyll (Remaining area)	10	>90%	a	
21%	2	Tilsmore Wood N W Ghyll (Downstream Area of C1 that is Hazel Dominated)	10		a	

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