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A functional classification of herbaceous hedgerow vegetation for setting restoration objectives

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Abstract Hedgerows are valuable habitats for biodiversity in farmed landscapes. The herbaceous vegetation at the hedge base is an important component of this habitat but its condition in Britain has deteriorated due to a combination of nutrient and pesticide contamination, and inappropriate management or neglect. The condition of herbaceous hedgerow vegetation is included in policy targets for biodiversity conservation, so a strategy is required for its restoration. This vegetation can be highly variable, so a classification of the main types is required to set realistic objectives. Vegetation classifications based on species' functional characteristics can have more general application that those based on species identity. Using existing datasets from a countrywide survey, a functional classification of herbaceous vegetation from hedgerows in Britain was developed. Cluster analysis of vegetation plots, based on attributes of the species present, produced thirteen vegetation types in six broad groups. These were differentiated by the association of the component species with woodland, grassland or arable habitats and by gradients of soil nutrient status and pH, light availability, disturbance and grazing tolerance. By using species' ecological characteristics as a basis for the classification, the condition of vegetation can be established and the prevailing environment predicted. From this information, a realistic strategy for restoration can then be determined.

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Introduction

Hedgerows are important semi-natural habitats in farmed landscapes, providing shelter, food resources and potential routes of dispersal for a wide range of farmland wildlife (Baudry et al. 2000). Intensification of farming in the last century in western Europe (Stoate et al. 2001; Robinson and Sutherland 2002) and more recently, lack of suitable hedgerow management have caused a substantial decline in the extent of hedgerows and the condition of those remaining (Petit et al. 2003; Carey et al. 2008). A significant element of the biodiversity value of hedgerows is the herbaceous vegetation which grows under the woody shrubs and trees of the hedge itself and on adjacent features influenced by the presence of the hedge, including banks, ditches and verges (Smart et al. 2002; Roy and de Blois 2008). This vegetation is of conservation value in its own right but also provides foraging resources and shelter for fauna, including invertebrates, birds and mammals. Because of its importance in the UK, the condition of the hedgerow ground flora is a Biodiversity Indicator for achieving European and UN targets (Defra 2012). However, in Britain there has been a decline in the species diversity of this herbaceous vegetation over the last 20 years, an increase in the ratio of grasses to forbs, and an increase in competitive species and those associated with high soil fertility and lower light levels (Carey et al. 2008). This deterioration in condition is thought to be a consequence of close cultivation, fertiliser enrichment and drift, inappropriate application of pesticides, intensive grazing or lack of management. In order to meet international targets for biodiversity, it will be necessary to set policy objectives and priorities at a national level for the restoration of herbaceous hedgerow vegetation. At this spatial scale, however, there is considerable variation in species composition associated with climate and landscape structure, as well as more local influences such as adjacent land use, soil properties and management practices (French and Cummins 2001; Deckers et al. 2004a; Ernoult and Alard 2011). The need for, and ultimate objectives of, restoration are likely to differ markedly among vegetation types with varying characteristics. In order to set national objectives for restoration of the herbaceous hedgerow flora, it will therefore be necessary as a first step to identify the broad vegetation types present and the ecological characteristics of the component species.

Identification of vegetation types presents a challenge because, in addition to the aforementioned variation associated with environmental factors, the species composition of the herbaceous vegetation associated with hedgerows shows considerable spatial variation within individual sites due to the structural complexity and associated variation in microclimate, shading, soil nutrients and moisture. Vegetation classifications based on species identity are often only locally relevant due to regional variation in species composition (Díaz and Cabido 1997). An alternative is to base the classification on functional types of plant species that share sets of morphological and physiological traits associated with the environmental conditions of interest (Rutherford et al. 1995). The classification of vegetation according to emergent functional groups therefore has the advantage of not only having general application irrespective of local variation in floristics, but also of having predictive value in terms of the prevailing environment in which each functional group exists (McIntyre et al. 1999). It can also provide a more informative basis for assessing the nature conservation value of vegetation, than measures of diversity based simply on species richness. Altering the prevailing environment will change the environmental filters operating on the vegetation, and consequently the functional groups that are likely to prevail at a particular site (Mayfield et al. 2010). Knowledge of the functional type of vegetation already present will enable the current condition of the vegetation to be determined and whether restoration might be an appropriate course of action. Where restoration is deemed to be desirable, the functional characteristics of the vegetation can also indicate the trajectory along which it would be desirable to steer vegetation change. Furthermore, information about the prevailing environment, as predicted from the vegetation functional characteristics, will enable restoration objectives to be set in terms of the type of vegetation that can realistically be maintained or re-established. Where the realised niche of species in the field is well documented, species traits can be supplemented by information on their recorded association with particular habitats or environmental factors (Critchley 2000; Deckers et al. 2004b). This is a useful approach if trait data are lacking or if their functional relationships with particular environments are uncertain.

The aim of this study was to determine whether a functional classification of hedgerow herbaceous vegetation could be created that would have practical application for setting realistic objectives for a national strategy of vegetation restoration. Using existing datasets from a countrywide survey in Great Britain, a classification was developed based on species' ecological characteristics and habitat preferences. The resulting classes were then examined to see if they had distinctive sets of species attributes that could be used to determine whether restoration might be desirable. Assuming that the detrimental national trends identified previously (Carey et al. 2008) might be reversible, the ideal goals for restoration were identified for the respective classes. Specifically, the following questions were addressed:

(i) What are the main types of herbaceous hedgerow vegetation in Britain based on attributes of the component plant species?
(ii) Which attributes best distinguish the resulting classes?
(iii) Where are the different classes most likely to be found in terms of adjacent land type and geographic location?
(iv) Does this approach to vegetation classification provide a meaningful basis to guide a national restoration scheme?

Methods

Dataset

Data were used from Countryside Survey (CS), which is a long-term ecological surveillance programme to measure change in condition and extent of common habitat types in Great Britain (Carey et al. 2008). The first stratified random survey of 1 km sample squares was conducted in 1978. Subsequent surveys were carried out in 1984, 1990, 1998 and 2007, with original sample locations revisited to enable analyses of change. The scope and sample size of the survey has progressively increased, with more sample squares added each time. The 1 km sample squares in CS were stratified to provide a statistical representation of all major habitats in Great Britain. Within each 1 km square, a range of randomly located fixed vegetation plots was sampled in which presence and cover of all vascular plant species were recorded. To sample vegetation at the base of hedgerows, 10×1 m plots were located alongside the hedge such that one long side of the plot was as close as possible to the base of the hedge (hedgerow and boundary plots; Carey et al. 2008). For the purposes of this study, data from these plots surveyed in 1990, 1998 and 2007 were used, totalling 3,065 samples.

Species attributes

Species attributes were selected that indicated prevailing environmental conditions that would be relevant to a restoration scheme for hedgerow vegetation. Attributes were a combination of their preferred habitats and species traits or indicator values relating to resource availability and environmental stresses.

A complete list of vascular plant species recorded from all plots was compiled. Tree and shrub species were excluded but dwarf shrubs, non-woody and woody climbers and scramblers were included because they can form an important part of the basal vegetation. A matrix of the plant species with their habitat preferences (Hill et al. 2004), Ellenberg fertility (N), light (L) and soil pH (R) values (Hill et al. 1999), competitor (C), stress (S) and ruderal (R) radii (Thompson 1994; Grime et al. 2007), grazing indicator (G) status (Critchley et al. 1996; ADAS 2006) and life histories was then constructed (Table 1). Twelve habitat types were derived from the Broad Habitat preferences of species in the PLANTATT database (Hill et al. 2004), in which each species can be associated with up to four habitat types. The Ellenberg system allocates a value from 1 to 9 to each species for a range of habitat properties with which the species is associated. CSR radii are scaled from 1 to 5, representing the proximity of a species to each of the three primary strategies (competitor, ruderal, stress-tolerator) in the triangular model of Grime (1974). Ellenberg values and CSR radii were expressed as either high or low values, the cut-off levels being specified after examination of the frequency distributions of the values across all species to ensure that approximately equal numbers of species were in each category. The grazing indicator status denotes those species tolerant of either extreme of the continuum from high to low grazing intensity, based on traits including growth form, canopy structure and life history.

Classification

For each attribute, the cover of species possessing the attribute was summed for each plot. Each of these 28 attributes was then expressed as the percentage of total vegetation cover in the plot. Cluster analysis was then performed on these cover-weighted attributes; the total vegetation cover in each plot was also included as a variable in the cluster analysis. Preliminary data exploration using Tree-joining cluster analysis indicated that there were 13 distinctive groups in the dataset. The classification was then performed using K-means cluster analysis specifying 13 groups. The K-means clustering algorithm first allocates samples randomly to the specified number of clusters and then moves the samples between these clusters to minimise variability within, and maximise variability between, clusters. Cluster analyses were performed using Statistica v.6.0 (Statsoft Inc, Tulsa, Oklahoma, US).

To determine the relation between clusters and attributes, clusters from the K-means analysis were subjected to Principal Components Analysis (PCA) of $\log(x + 0.1)$ transformed attribute means for each cluster. A preliminary Detrended Correspondence Analysis showed gradients were short (<4 SD), indicating that a linear model was suitable. PCA was performed using Canoco v.4 software (Ter Braak and Šmilauer 1998).

Land types adjacent to the hedge plots recorded as part of CS were classified into eight broad types; arable, grassland, linear (i.e. roads, tracks, railways, embankments, etc.), bracken, urban, water body, wetland or woodland. Each plot was also assigned to the

Table 1 Plant species attributes used and data sources

Attribute	Source
Habitat	Hill et al. (2004), updated November 2008
Woodland	
Boundary and linear	
Arable and horticultural	
Improved grassland	
Neutral grassland	
Calcareous grassland	
Acid grassland	
Dwarf shrub heath	
Wetland	
Water	
Inland rock	
Coastal	
Ellenberg values	Hill et al. (1999)
High fertility (6–9)	
Low fertility (1–5)	
High light (7–9)	
Low light (1–6)	
High pH (7–9)	
Low pH (1–6)	
CSR radii	Thompson (1994), Hodgson et al. (1995), updated by Grime et al. (2007)
High competitor (3–5)	
Low competitor (1–2)	
High stress (3–5)	
Low stress (1–2)	
High ruderal (3–5)	
Low ruderal (1–2)	
Grazing indicator status	ADAS (2006)
Grazing tolerant	
Grazing intolerant	
Life history	Hodgson et al. (1995), updated by Grime et al. (2007)
Annual	
Biennial/perennial	

Ranges specified for high and low Ellenberg values and CSR radii shown in parentheses

geographic area in which it was located (Scotland, Wales and eight English administrative regions). A weighted index was calculated for each land category and geographic area for each cluster as

$$\frac{\sum \frac{p}{d}}{n}$$

where p = presence (1 or 0), d = plot Euclidean distance from cluster centre and n = total number of plots in the cluster. The relationships between CS clusters and adjacent land

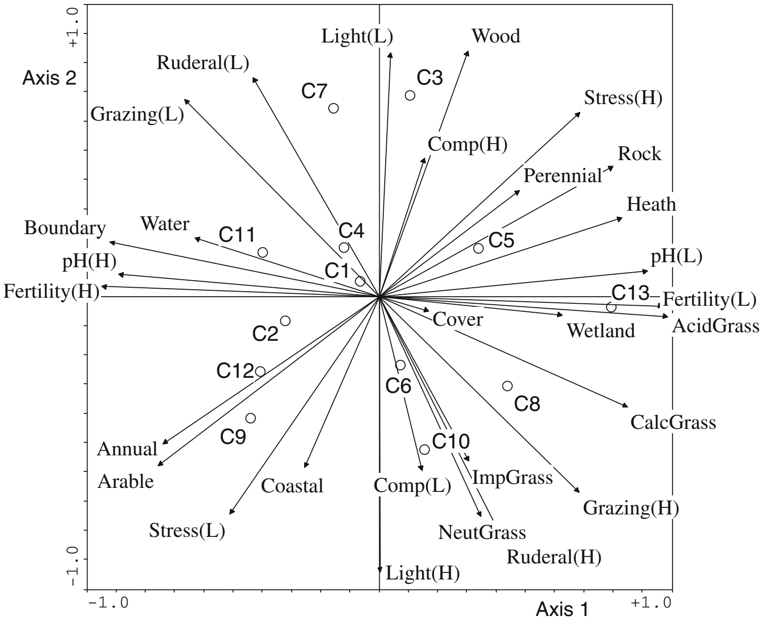

Fig. 1 PCA biplot of first two axes of variation showing the 13 clusters (C1–13) and species attributes. *AcidGrass* acid grassland, *Boundary* boundary & linear habitats, *CalcGrass* calcareous grassland, *Comp(H)* high competitor radius, *Comp(L)* low competitor radius, *Fertility(H)* high Ellenberg fertility, *Fertility(L)* low Ellenberg fertility, *Graze(H)* high grazing tolerance, *Graze(L)* low grazing tolerance, *ImpGrass* improved grassland, *Light(H)* high Ellenberg light, *Light(L)* low Ellenberg light, *NeutGrass* neutral grassland, *pH(H)* high Ellenberg pH, *pH(L)* low Ellenberg pH, *Ruderal(H)* high ruderal radius, *Ruderal(L)* low ruderal radius, *Stress(H)* high stress radius, *Stress(L)* low stress radius, *Wood* woodland

categories and geographic areas were then analysed using PCA on log(x + 0.1) transformed indices.

Results

Species attributes

The first axis of the PCA of the 13 clusters (eigenvalue 0.41) represented a clear gradient of nutrient status and pH, with low Ellenberg fertility and pH values and acid grassland at the positive end and high Ellenberg fertility and pH at the negative end (Fig. 1). Boundary & linear habitat was also associated with high nutrients and pH. The second PCA axis (eigenvalue 0.29) represented a clear gradient of light availability and canopy structure. The positive end had low Ellenberg light values and woodland habitat with, to a lesser extent, low ruderal radius and grazing scores, indicating relatively closed and undisturbed vegetation. The negative end had high Ellenberg light values and ruderal radii indicating more open and disturbed conditions. Arable habitat, annual life history and low stress radius occupied the zone combining high nutrient and light availability. Axis 3 (eigenvalue 0.12) was a gradient of competitor radius and axis 4 (eigenvalue 0.06) a relatively weak gradient of wetland habitat.

Two clusters (C3, C7) had a strong affinity to woodland (Fig. 1; Table 2). C3 ($n = 159$) represented the most typical woodland conditions, with low Ellenberg light value and grazing tolerance and high stress and competitor radii. C7 ($n = 277$) was associated with more alkaline conditions, having higher Ellenberg pH values than C3. A third cluster (C5, $n = 228$) was also associated with woodland but with higher values for neutral and improved grassland and lower Ellenberg fertility than the other woodland clusters.

Four clusters (C6, C8, C10, C13) were most associated with grassland habitats. Of these, C10 ($n = 212$) had the highest values for improved and neutral grassland and for Ellenberg light, grazing tolerance and ruderal radius, all suggesting relatively open conditions and high grazing intensity. C6 ($n = 313$) was similar to this but had lower grazing tolerance, Ellenberg light value and ruderal radius, indicating less disturbed and more closed or rank vegetation. C8 ($n = 263$) had lower Ellenberg fertility and pH values and a relatively high value for wetland habitat, suggesting an affinity with potentially more species-rich grassland. C13 ($n = 116$) was a distinctive cluster with high values for acid grassland, grazing tolerance and stress radius and low Ellenberg fertility and pH. None of these clusters had high values for calcareous grassland. Calcareous grassland was located between neutral and acidic grassland in the PCA ordination (Fig. 1), which might be attributable to the bimodal distribution of some species in both acidic and calcareous habitats (e.g. *Festuca ovina*) and the scarcity of these species in the sample.

There were four clusters with characteristics of arable habitat (C2, C9, C11, C12). Of these, C9 ($n = 243$) had the highest proportion of annuals and was the only cluster where the mean score for annuals was higher than that for biennials/perennials. This cluster also had high values for arable & horticultural habitat, Ellenberg fertility and pH, and low stress radius. C12 ($n = 185$) was intermediate between C9 and C2 but with a higher value for coastal habitat. C2 ($n = 287$) had a relatively high value for neutral grassland habitat and a much lower value for arable & horticultural habitat than the two previous clusters. However, in the PCA analysis its location in ordination space was closer to arable than grassland. Together these results suggest that this was an intermediate type between the grassland and arable cluster types, and might have been related to the presence of set-aside vegetation. Cluster C11 ($n = 260$) had some association with water habitat, suggesting the presence of drainage ditches or watercourses beside the hedge.

There were two clusters (C1, C4) that did not fall clearly into any of the preceding groups in the PCA and had high values for a range of habitats and other species attributes. This suggests that these were generalist clusters containing plots with a range of species types. However, C1 ($n = 236$) had high total cover (128 %), suggesting a dense, closed and possibly layered vegetation, which was also indicated by a combination of high competitor radius and Ellenberg fertility and pH values. In contrast, C4 ($n = 286$) had the lowest total vegetation cover of any clusters (49 %) suggesting a high percentage of bare ground or non-herbaceous vegetation.

Adjacent land type

The first PCA axis (eigenvalue 0.82) mainly separated adjacent arable land from adjacent grassland (Fig. 2). Woodland was correlated with bracken, while urban showed some relation with arable. Relatively little variation was explained by subsequent axes. Axis 2 (eigenvalue 0.16) did not show a clear gradient of adjacent land categories but axis 3 (eigenvalue 0.11) was related to the presence of woodland and bracken.

Table 2 Mean (±standard deviation) values of the most important attributes differentiating the 13 CS clusters

Cluster	*n*	Habitats			Ellenberg values			CSR radii			Grazing intolerance
		Woodland	Neutral grassland	Arable	N (low)	L (low)	R (low)	C (high)	S (high)	R (high)	
1	236	30 ± 14.9	34 ± 16.5	18 ± 12.5	14 ± 12.8	54 ± 15.8	31 ± 15.6	94 ± 7.5	31 ± 17.0	34 ± 16.4	55 ± 15.3
2	287	9 ± 9.0	61 ± 19.1	18 ± 12.2	5 ± 7.3	22 ± 13.8	11 ± 10.0	94 ± 7.3	9 ± 9.0	22 ± 14.7	69 ± 16.8
3	159	79 ± 12.7	7 ± 7.8	5 ± 6.2	13 ± 15.4	89 ± 10.8	69 ± 19.2	94 ± 9.6	77 ± 13.9	12 ± 10.1	80 ± 16.4
4	286	44 ± 14.7	22 ± 14.6	17 ± 13.5	8 ± 9.6	66 ± 15.1	29 ± 16.3	91 ± 10.4	43 ± 15.5	34 ± 17.2	60 ± 19.2
5	228	54 ± 18.4	26 ± 15.9	8 ± 8.8	48 ± 18.5	67 ± 16.6	67 ± 15.8	89 ± 13.5	42 ± 22.6	31 ± 16.3	33 ± 18.6
6	313	13 ± 12.2	62 ± 17.3	23 ± 18.2	18 ± 12.3	26 ± 14.5	36 ± 14.3	92 ± 8.8	22 ± 13.5	53 ± 16.6	29 ± 14.7
7	277	75 ± 14.4	7 ± 8.1	7 ± 7.8	6 ± 9.5	87 ± 10.3	21 ± 16.7	95 ± 7.4	74 ± 14.5	13 ± 11.2	83 ± 13.8
8	263	12 ± 10.8	70 ± 16.6	11 ± 11.1	50 ± 13.5	23 ± 13.7	70 ± 15.4	90 ± 10.4	51 ± 14.0	73 ± 14.8	15 ± 13.6
9	243	8 ± 9.7	15 ± 13.9	60 ± 21.5	4 ± 7.8	43 ± 26.8	10 ± 11.6	66 ± 25.6	7 ± 9.4	69 ± 18.3	44 ± 24.8
10	212	11 ± 16.0	82 ± 12.5	18 ± 19.0	12 ± 11.0	12 ± 12.1	72 ± 17.7	89 ± 14.2	13 ± 11.1	84 ± 11.5	10 ± 11.9
11	260	10 ± 10.8	15 ± 13.2	16 ± 13.8	3 ± 6.8	75 ± 16.0	10 ± 9.8	96 ± 6.4	9 ± 10.8	23 ± 14.7	78 ± 15.0
12	185	6 ± 8.0	22 ± 17.1	65 ± 16.9	4 ± 7.3	18 ± 13.7	9 ± 10.1	90 ± 11.4	7 ± 8.1	25 ± 13.7	27 ± 15.0
13	116	19 ± 17.8	36 ± 16.8	3 ± 4.2	76 ± 12.6	57 ± 18.2	88 ± 9.9	88 ± 12.7	67 ± 17.0	70 ± 17.4	11 ± 12.4

Data are the proportion of total vegetation cover in a plot occupied by species possessing the specified attribute

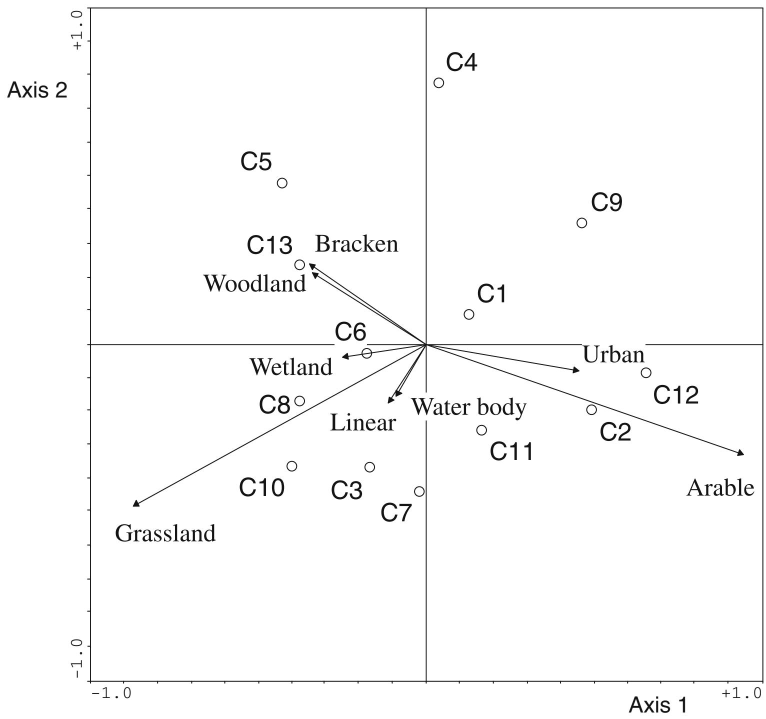

Fig. 2 PCA biplot of first two axes of variation showing the 13 clusters (C1–13) and adjacent land categories

Of the woodland-type clusters, neither C3 nor C7 was related to adjacent woodland but both were mostly likely to occur adjacent to grassland. C5 was related to adjacent woodland in the PCA although grassland was still its commonest adjacent land category.

The grassland-type clusters C8 and C10 were strongly related to adjacent grassland. C6 was also related to adjacent grassland, but to a lesser extent. Cluster C13 was strongly related to woodland and bracken, although grassland was still its commonest adjacent land category.

The four arable-type clusters were all much more likely to be adjacent to arable land than grassland, woodland or bracken. C12 and C2 also had some relation with adjacent urban land.

Wetland, linear and water body land categories did not show a strong relationship with clusters.

Geographic location

The biplot of PCA axes 1 (eigenvalue 0.60) and 2 (eigenvalue 0.25) showed a distinct separation of three regions, being the north and west (Wales, North-west England and Scotland), the east (East England, East Midlands, Yorks/Humber and North-east England) and the south and west (South-east England, South-west England and West Midlands) (Fig. 3). Clusters with a tendency to occur in the north and west were the grassland-type clusters C13 and C8 and the woodland-type cluster C5. The remaining woodland-type

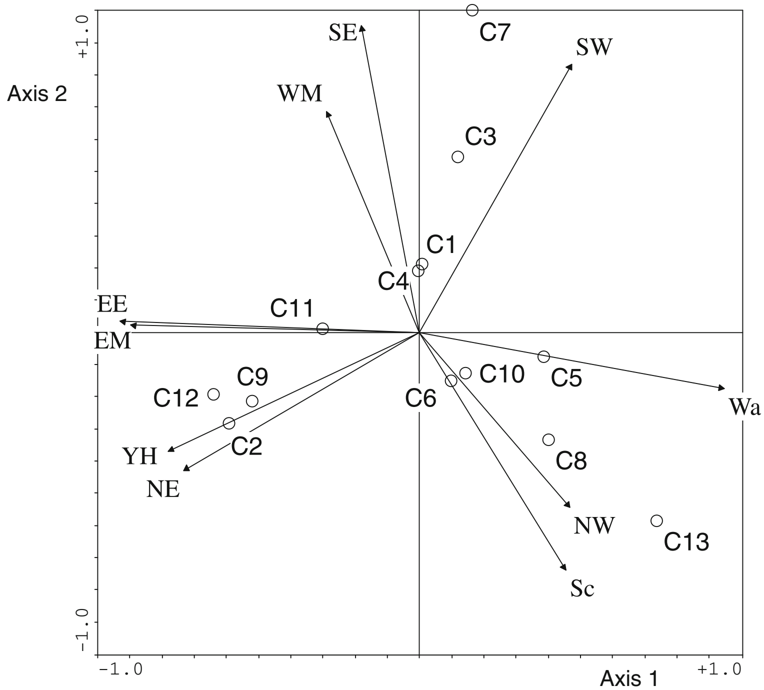

Fig. 3 PCA biplot of first two axes of variation showing the 13 clusters (C1–13) and geographic areas. *Sc* Scotland, *Wa* Wales. English regions: *NE* North-east, *NW* North-west, *EM* East Midlands, *WM* West Midlands, *EE* Eastern, *SE* South-east, *SW* South-west

clusters C7 and C3 had a generally southern distribution. The arable-type clusters C2, C9 and C12 had a relatively strong eastern bias. The remaining clusters showed weaker relationships with particular regions.

Plant species

Most species with the highest cover values were common and widespread across many clusters, while individual clusters also tended to have a characteristic suite of species that reflected its particular set of attributes. For example, widespread species such as *Arrhenatherum elatius*, *Urtica dioica* and *Galium aparine* occurred at relatively high cover in the woodland-type clusters, but in association with more typical species such as *Mercurialis perennis*, *Brachypodium sylvaticum* and *Dryopteris felix-mas*. This reflected the heterogeneous structure of the hedgerow base at many sites, but also the widespread occurrence of species associated with disturbance and high nutrient levels.

Discussion

Classification

The classification identified woodland, grassland and arable vegetation types, with variants of each type distinguished by differing levels of soil nutrient status and pH, light availability and disturbance. The data on species' habitat preferences distinguished the main groups to a large extent but the Ellenberg values, life histories and ruderal and stress radii identified important environmental gradients that not only confirmed the characteristics of clusters in each main habitat group, but also differentiated clusters within these main groups. This confirms the value of using a range of species' attributes in the classification to provide information on different levels of community assembly.

The PCA showed clear environmental gradients that differentiated the clusters. Despite this, some attributes had relatively high values across most clusters, even although the clusters were well distributed along that particular gradient. For example, most clusters had relatively high competitor radius, including those with more stable vegetation characteristic of woodland or grassland. Species associated with relatively undisturbed conditions under or near a hedge in good condition would tend to be those with high competitor radius. Many clusters also had relatively high values relating to nutrients and disturbance. To some extent this will be attributable to the heterogeneity of the hedge base, which can include the relatively undisturbed conditions close to the hedge itself or on features such as hedgebanks, ditch sides and grass verges and a zone of greater disturbance and nutrient input adjacent to intensively managed arable land or grassland. However, the widespread indication of these conditions among clusters also indicates a degraded state, which reflects the condition of the hedges themselves, less than half of which were assessed to be in good condition in 2007, and only 10 % on arable land (Carey et al. 2008).

The association of clusters with arable, grassland or woodland as the adjacent land type, was also reflected in their geographical distribution. Some of the arable-type clusters had an affinity with eastern regions, which have a drier climate and a greater proportion of arable land. Similarly, the north and west of Britain is wetter, with more pastoral landscapes, where some of the grassland and woodland-type clusters tended to be located. Relationships of hedgerow vegetation types with land type and landscape structure will be due partly to climatic and edaphic factors influencing hedgerow vegetation and land use in similar ways, but also to direct effects of adjacent land management practices on hedgerow vegetation. This has been shown in other studies where landscape structure and adjacent land use were related to hedgerow species richness and composition (Deckers et al. 2004a), but with local management practices and hedge structure having a greater influence at individual sites (Ernoult and Alard 2011).

The CS data are representative of the most common and widespread hedgerow types in Great Britain. Local hedgerow types with unique combinations of structure, management and environment were not specifically targeted in CS and might be under-represented in the sample. For example, species associated with calcareous grassland were scarce in the dataset, reflecting the scarcity of calcareous habitats nationally, and a calcareous grassland vegetation type was not distinguished here. Despite this, the classification based on species attributes produced a series of clusters that were, for the most part, relatively distinctive and the PCAs accounted for a relatively high percentage of the variation between clusters.

Earlier analyses of CS hedgerow basal data based on plant species identity had produced four classes related to arable land, arable/rotational, grassland and woodland (French and Cummins 2001) or eight groups (four woodland and four grassland) which were subsequently amalgamated into three main groups (woodland, grassland and tall herb/disturbed) (Stuart et al. 2005). A functional classification of the herbaceous species in hedgerows from a region of Belgium produced four groups of species related to woodland, arable, wetland and pasture/wasteland habitats (Deckers et al. 2004b). In that study, variation in the species composition of hedgerows, including herbaceous vegetation, was largely explained by abiotic environmental factors, management and hedge structure (Deckers et al. 2004a). Whilst Stuart et al. noted that it was difficult to identify clear environmental gradients that would explain differences between their species-based groups, Deckers et al. (2004b) achieved this by relating species' traits to environmental factors. This lends some support to the approach used here, where the classification was based a priori on species attributes that reflected their ecological preferences.

Functional classifications are increasingly being used to explore ecological processes and to make predictions about the response of vegetation to specific perturbations (e.g. Díaz et al. 2007). The approach does have limitations if general models are applied to specific local conditions (Anderson and Hoffman 2011) but with the CS data the use of broad sets of species traits to tease out general distinctions between heterogeneous samples does have some merit.

Restoration

From the classification, it is possible to identify various levels of intervention needed for restoration and management of the herbaceous vegetation. Where a class exhibits an undesirable set of attributes, then the aim would be to try and rectify these vegetation characteristics. For example, vegetation with high Ellenberg fertility values and low Ellenberg light values, but with a low incidence of woodland species, would possess characteristics reflecting the detrimental national trends highlighted by Carey et al. (2008), and signifying that remedial action would be desirable. Therefore, where relatively stable, semi-natural vegetation types predominate, such as those similar to woodland or forb-rich grassland, the objective would be to maintain these elements and active restoration measures will not normally be required. In contrast, to reverse the detrimental national trends, restoration will need to be focussed on rank, eutrophic vegetation, which will require more intensive management to promote the export of nutrients from the system. Finally, highly disturbed vegetation types will require more severe intervention to re-establish more stable, perennial vegetation. On this basis, six broad groups of clusters have been identified, each group having similar attributes, from which the restoration objectives were determined (Table 3).

The approach applied for restoration at individual sites will be dependent primarily on the type of vegetation present, its extant value for wider biodiversity, the adjacent land use and the intended endpoint of restoration. Some management practices are universally applicable in order to avoid damaging relatively intact sites or contributing further to deterioration of others. These would include preventing contamination from fertilisers and herbicides and avoiding high levels of grazing intensity. Where the existing vegetation is considered to be of high conservation value as signified by its functional characteristics, then the overall objective would normally be to maintain its characteristics. This would also apply to sites with degraded vegetation types where the existing vegetation provided significant foraging resources or breeding or wintering habitat for fauna. The endpoint for other vegetation types will depend upon what can be realistically achieved, taking into account the presence of competitive species and having some knowledge of the soil nutrient status. The prevailing environmental conditions will also influence the likelihood of maintaining the target vegetation after the initial restoration phase.

In the current classification, each cluster is a synthesis of information from a large number of plots and an identical set of attribute values or species is unlikely to be encountered at any individual site within the sample or elsewhere. However, in common with other vegetation classifications, the aim was to enable a sample or set of samples to be placed in context within a wider framework, in this case for the purpose of setting

Table 3 Broad cluster groups with their restoration objectives

Group	Clusters	Restoration objectives
Woodland herbs	Typical woodland (C3) Alkaline woodland (C7) Woodland and grassland (C5)	Maintain woodland element; reduce competitive woodland species if dominant
Species-rich or semi-improved grassland	Mesotrophic grassland (C8) Acidic grassland (C13)	Maintain or increase diversity of grassland element and retain any woodland element
Rank grassy vegetation	Closed grassland (C6) Closed arable (C2) General closed (C1)	Reduce nutrient status and increase incidence of woodland and grassland forbs
Species-poor pasture	Disturbed grassland (C10)	Re-establish perennial vegetation containing common grassland and woodland forb species
Disturbed arable	Disturbed arable (C9) Intermediate arable (C12) Arable complex (C11)	Re-establish perennial vegetation
Sparse vegetation	Typical sparse (C4)	Re-establish woodland vegetation if none present

Group and cluster names relate to the type of species present in the hedgerow vegetation and not necessarily the habitat or landscape in which they occur

restoration objectives. Individual plots could contain species associated with a range of habitats and this was reflected to some extent in the attributes and species composition of the clusters. However, it is possible that vegetation typical of more than one cluster might be present at one site in a series perpendicular to, or along the line of the hedgerow. In some cases, multiple objectives for restoration, and a range of restoration techniques might need to be applied. For example, the aim might be to retain a woodland type flora if it existed near to the hedge but to restore a forb-rich grassland sward at the field edge if it was highly disturbed.

Management of the shrub component of the hedge itself will have an effect on the herbaceous vegetation. For example, periodic removal of the canopy by coppicing will result in cyclical changes in microclimate and light availability, which will affect the relative abundance of species associated with woodland or more open habitats. In contrast, a hedge maintained by frequent trimming is likely to produce more consistent conditions over a period of years. Restoration of the herbaceous vegetation will therefore need to be considered, and possibly implemented, concurrently with the hedge management regime.

Maintaining the shrub component of the hedge and its associated microclimate and shade will be critical for preserving the woodland element in the Woodland Herbs cluster group (Table 3). However, if this element is lost completely, its reinstatement will present a particular challenge. Woodlands can act as a colonisation source for hedgerows up to 100 m along the hedge (Wehling and Diekmann 2009) but in general, Woodland Herbs have low fecundity and dispersal capability (Verheyen et al. 2003). Hedgerows tend to support species that are more similar to those of the woodland edge than woodland interior, being suited for example to higher nutrient availability and lower acidity and moisture (McCollin et al. 2000). Early spring flowering species and those dispersed by myrmecochory (ants) are among those least likely to colonise hedgerows (Roy and de Blois 2006); some woodland plants can colonise more quickly, but even those can take a matter of decades (Roy and de Blois 2008). Restoration of a woodland flora will therefore probably require positive re-introduction of plant species. Species with a high competitor radius (e.g. *Rubus fruticosus*) which were prominent in the Woodland Herbs group might need to be controlled as they are associated with a decline in vulnerable species when present at high cover levels (Stuart et al. 2005).

Management regimes developed for species-rich grasslands will have some relevance to hedgebanks and verges in the Species-rich or Semi-improved Grassland cluster group (Table 3), as long as there is access for machinery, or livestock access can be controlled. However, restoration of the Rank Grassy Vegetation cluster group to species-rich herbaceous vegetation presents a more difficult challenge due to the high soil fertility, as implied by the Ellenberg N values. Turf-stripping can remove nutrient pools in the upper layers of soil and is the most successful method for establishing target plant species (Tallowin and Smith 2001; Pywell et al. 2007). This technique is unlikely to be acceptable in agricultural grassland but on hedgebanks and verges it might be a practical proposition if the source of eutrophication was also controlled. Alternatively, cutting alone or in combination with grazing can reduce soil fertility and vegetation biomass as long as cuttings are removed, but only over long timescales (Walker et al. 2004). If the vegetation has a substantial tall herb or wetland component with high value for fauna (e.g. Asteraki et al. 2004), this relatively benign management could be applied in order to conserve the vegetation structure.

Vegetation in the Disturbed Arable group (Table 3) is indicative of high levels of disturbance, most likely from past or recent herbicide applications or cultivation close to the hedge base, and suggests that any precursor perennial vegetation has been severely modified. The high nutrient status of this vegetation could also be a consequence of fertiliser contamination. Given that nationally scarce annual arable plants are unlikely to exist in this highly eutrophic vegetation (Walker et al. 2007), the optimum course would probably be to re-establish perennial vegetation, as has been done widely on field margin strips adjacent to the permanent hedge base or field boundary (Critchley et al. 2006). Successful restoration of species-rich perennial vegetation is only likely to be achieved by destroying the existing vegetation, creating a seedbed and re-introducing seed of the target species. Sites dominated by well-established populations of *Galium aparine* or *Urtica dioica* will present a particular challenge as they will need to be controlled before ground preparation. Even if these species can be controlled, success will be dependent on high germination and establishment rates of sown species, which will be influenced by various factors including soil nutrient status, weather conditions and management in both short and long-term. In highly eutrophic and disturbed conditions, the best that can be achieved might be to establish a verge of perennial grasses which will protect the hedge base from adjacent agricultural activities (Marshall 2009).

A functional classification of vegetation can be used in this way to predict the prevailing environment, and leading from this, the objectives for restoration in terms of a realistic endpoint and the most appropriate management strategies. Reference sites with the desired vegetation characteristics could be selected to represent the targets for restoring degraded sites. However, in following a prescriptive approach, there is a risk of steering a large number of sites towards a relatively homogenous type of vegetation and it will therefore be essential also to take account of the individualistic character of each site in terms of its species composition, prevailing environment and geographic location. Although the general principles for restoration of habitats such as woodlands, grasslands and field margins might be applicable to hedgerows containing similar herbaceous vegetation types, research is still required to refine the detail and practicalities of applying these principles to hedgerows. Some of this is related to the problems of managing or restoring the hedge itself concurrently with the herbaceous vegetation, for which better knowledge about the interactions between the woody and herbaceous components is required.

Conclusion

Returning to the original questions, six broad vegetation groups were identified, which ranged from relatively intact semi-natural vegetation to highly eutrophic and disturbed types, although there were elements of disturbed or eutrophic vegetation within all groups. Variants were identified within the broad groups, differentiated primarily by gradients of soil nutrient status and pH, light availability and disturbance. The broad groups were typified partly by the habitat associations of the component species and in some, but not all cases the habitat associations were similar to the adjacent land type and its prominence in different geographic locations. The functional classification provided a meaningful insight for formulating general restoration objectives at a national level but variation within the vegetation classes means that individual sites will need to be treated on a case by case basis.

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