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FLORISTIC COMPOSITION AND ENVIRONMENTAL DETERMINANTS OF ROADSIDE VEGETATION IN NORTH ENGLAND

ABSTRACT: The roadside vegetation in some counties of north England (north and west Yorkshire) was studied to determine the community structure according to the British National Vegetation Classification (NVC) and main environmental factors influencing its composition. The data from Phytosociological survey (699 quadrats) and from the physico-chemical analyses of 233 soil samples from 35 sites were obtained. Both the classification (TWINSPAN & MATCH) and ordination programs (Canonical Correspondence Analysis) were used. The roadside vegetation is mainly dominated by few grasses (*Arrhenatherum elatius, Festuca rubra, Dactylis glomerata, Lolium perenne, Poa trivialis, Elymus repens, Holcus lanatus*) and their associated herbs (*Cirsium arvense, Heracleum sphondylium, Urtica dioica*). Five NVC Mesotrophic grassland communities (*Arrhenatheretum elatioris* community MG1, *Lolium perenne-Cynosurus cristatus* grassland MG6, *Lolium perenne* leys MG7, *Holcus lanatus-Deschampsia cespitosa* grassland MG9, *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland MG11) and one Upland *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland, U4 were identified which in general, exhibited good fit with the typical NVC units.

Altitude, pH, potassium, sodium and road age were found to be the main variables affecting the roadside vegetation. By relating the floristic composition with ecological characteristics of the roadside verges, three kinds of pattern of variation are observed. The first pattern is related to regional or geographical characteristics and the second pattern of variation exists across the width of the road verges showing a zonal pattern of plant distribution. The third scale of pattern is active at the local level including micro-environmental conditions, e.g., local edaphic variables.

KEY WORDS: roadside vegetation, British National Vegetation Classification, environmental factors, Canonical analysis

1. INTRODUCTION

Roadside vegetation, whether native or exotic, can make a major contribution to landscape character, pollution control, conservation and aesthetic beauty of roadside environment and their proper management is necessary for the achievement of sustainable road systems (Dolan *et al*. 2006). Management of roadside vegetation is important for its persistence and its proper management is dependent on the provision of meaningful scientific data. For 'ecologically sound management' of roadside verges, the knowledge of local conditions is necessary because roadside verges differ in their biological characteristics from place to place and also within the same region, mainly because of rapid changes in local geography and patterns of land use.

Roadside verges and their vegetation present a complex situation involving many factors and processes. Most of the previous studies of ecology of roadside verges and their vegetation have emphasized traditional aspects such as soil and air pollution (Feretti *et al.* 1995, Hafen and Brinkman 1996, Nabulo *et al.* 2006) or floristic surveys (Cilleres and Bredenkemp 2000, Harrison *et al.* 2002, Jantunen *et al.* 2006, Wróbel *et al.* 2006). Now as the list of road-related environmental problems is increasing, there is a need for studies of the various aspects of the roadside environment in an integrated manner. This research work was, therefore, undertaken to study the ecology of the roadside vegetation in some counties of northern England. The overall goal of the present work was to provide a holistic assessment of the ecology of roadside vegetation in the study area which is expected to provide a better understanding of the different aspects of the ecology and management of roadside vegetation. The results of some parts of this research dealing with assessment of scenic beauty of roadside vegetation (Akbar *et al.* 2003), comparison of de-icing salts (Akbar *et al.* 2006a) and distribution of heavy metals in roadside soils (Akbar *et al.* 2006b) have already been published.

In Britain, the National Vegetation Classification (NVC) describes plant communities from natural, semi-natural and common artificial habitats and classifies them into distinct categories (Rodwell 1991). It provides a comprehensive framework of classification within which the vegetation types found in Britain are presented in a systematic pattern. It also serves as a standard with which further studies can be compared. The NVC was produced by the Unit of Vegetation Science at Lancaster University under a research programme sponsored by the Nature Conservancy Council. It is based on the quantitative floristic records compiled from 35000 samples covering more than 80% of the 10 × 10 km grid squares of the British mainland and many islands (Rodwell 1992).

Each basic unit of the NVC classification is termed as a 'community'. The first order sub-group of a community is called 'sub-community' and for further divisions, are termed as variant. Every vegetation type or community has been assigned a code. This code consists of one or two letters related to the main category of the vegetation type named after its general vegetation or habitat type and a number that refers to the communities of that vegetation type. For example, *Arrhenatheretum elatioris* grassland is MG1 community; MG shows its place in the mesotrophic grasslands and one indicates that it is the first community of mesotrophic grasslands. A community is sometimes further subdivided into sub-communities which are denoted by letters such as a, b and c. For instance, *Arrhenatheretum elatioris* community has five sub-communities. Out of these five sub-communities, the *Festuca rubra* sub-community is described as the first sub-community and is denoted as MG1a.

This paper presents the results of a floristic survey of roadside vegetation, and its classification according to the British National Vegetation Classification (NVC) and exploration of relationships between its community structure and selected environmental variables. Our study was therefore, aimed at addressing the following questions:

1. What is the community structure of roadside vegetation according to the NVC and,

2. What are the main environmental factors affecting the floristic composition and community structure of roadside vegetation?

2. STUDY AREA

The data described here have been derived from the survey of roadside verges mostly from north and west Yorkshire (Fig. 1). The study area comprises of two main geological formations; Carboniferous Rocks and Permian Trias (Rayner and Heminway 1974). The principal soils covering the greater part of the area are lithomorphic soils, brown soils, gley soils and peat soils (Avery 1990). The climate of the study area can be described as follows: cool, wet winters with little snowfall, then dry springs followed by warm summer and warm, wet late summers and autumns. Overall the area receives a moderate rainfall i.e.; 620–1150 mm (Smith

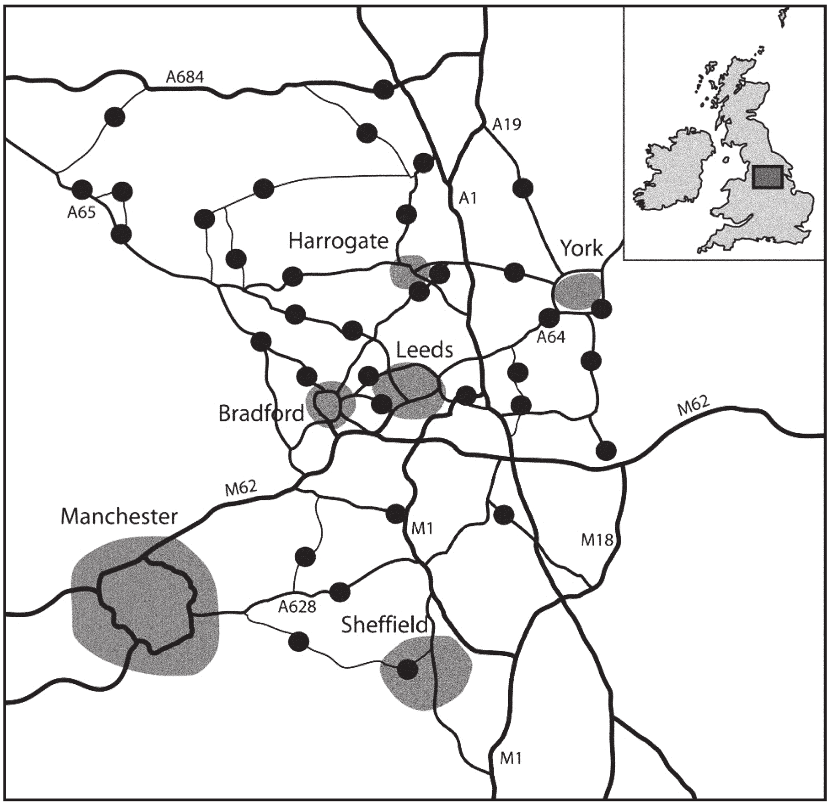

Fig. 1. Location the study area (small map) of the surveyed roadside verges. Black circles indicate the location of surveyed sites.

1984). Mean monthly air temperatures range from 1.7°C to 16°C. The duration of bright sunshine varies from 1 sun hours/day to 7 sun hours/day. The main motorways which pass through the study area are the M1, M62, and A1(M). The major trunk roads in the study area are A19, A59, A61, A65, and A650. Agriculture is the most extensive land use in the study area. The study area also includes some important industrial cities of the UK, including Leeds and Sheffield. These cities along with their neighbouring small cities comprise one of the most populous urban areas in the UK.

3. METHODS

3.1. Field Survey

In total, thirty five sites along A and B class roads (notified by local highway authority) in the study area were surveyed for their floristic composition. The sites were selected to cover different ranges of road verges with respect to road age, verge size, traffic volume and geography etc. The width of the verges ranged from 2–20 meters. At each site, within each verge, distinct vegetation zones (border, verge, slope, ditch/fence) were identified and roadside vegetation was recorded in these zones across the verge. During the survey, however, it often happened that not all the four zones (particularly slope) were present at each site. A 50 metres long tape was laid down parallel to the road in each arbitrary zone of the verge at each site. Three 0.5 × 4 m quadrats were placed at equal distances along the 50 m tape in each zone. Within each quadrat, vascular plants and their estimated cover were recorded by visual estimation according to Domin Cover Scale (Kent and Coker 1995). Both sides of the road at each site were sampled. Nomenclature of vascular plants follows Stace (1991).

In addition, a set of environmental descriptors for each verge such as width, aspect and angle of slope (if slope present) were also recorded. The aspect was determined by a compass whereas the angle of a slope was measured with a clinometer. The information

about altitude, age of the road and traffic volume was solicited from the literature. For road type, roads were divided into three classes, class 1 (B road), class 2 (A road single) and class 3 (A-road with dual carriage way). For road age, roads were placed into one of the following five classes:
Class 1: <10 years, Class 2: 10–19 years, Class 3: 20–29 years, Class 4: 30–39 years, Class 5: ≥40 years.

3.2. Collection and analysis of soil samples

From each quadrat, a soil sample (5–15 cm depth) was taken from two points with a stainless steel trowel. Three samples from three quadrats in a zone at each site were mixed together to make a composite sample representative of that zone. In total, 233 composite soil samples were collected. The soil samples were analyzed for pH, total nitrogen, phosphorus and exchangeable cations (calcium, magnesium, potassium, sodium) following Allen (1989). Organic matter was determined gravimetrically by using the loss on ignition method (Rowell 1994). Soil fertility was determined by phytometric assessment method using net above-ground biomass production of tomato (*Lycopersicum esculentum var. Alicante)* as being indicative of soil fertility (Wheeler *et al*. 1992).

3.3. Classification and ordination of data

The whole floristic data set consisting of 699 quadrats, was classified using Two-Way Indicator-Species Analysis (TWINSPAN) (Hill 1979). The data were classified up to five levels and 32 small groups were produced. For NVC community analysis, the floristic data of each group produced by TWINSPAN were entered into MATCH (Malloch 1992) which compared them to the plant communities described by the NVC system by determining the similarity of the data to the recognised National Vegetation Classification (NVC) community. After examining the similarity coefficient values of different groups with the NVC types, it was found that many groups scored their highest similarities for the same NVC community and sub-community. The data from the groups showing similarity to the same NVC unit were combined and these combined data were entered into MATCH again resulting in the recognition of six NVC communities.

The information from NVC classification of roadside vegetation, physico-chemical analyses of roadside soils and other environmental variables was used in a direct gradient analysis technique, Canonical Correspondence Analysis (CCA) to determine main environmental variables influencing the composition and distribution of roadside flora. This analysis (CCA) was carried out with CANOCO (ter Braak 1988) using default options.

4. RESULTS

4.1. Floristic composition

Two hundred and twelve plant species were recorded indicating the richness of roadside flora and proving that roadside verges are an important habitat for the conservation of flora (Way 1977, Bennett 1991).

Despite the large number of species recorded on the road verges, the number of dominant and frequent species is small. In general, roadside plant species could be divided into two groups, one mainly on the border zone and another one on the rest of the verge. The border zone was dominated by *Lolium perenne* L., *Poa annua* L., *Plantago major* L., *Taraxacum officinale* agg. Web., and *Elymus repens* L.. The second group includes *Arrhenatherum elatius* (L.) J &C. Prest., *Cirsium arvense* L., *Festuca rubra* L., *Holcus lanatus* L., *Dactylis glomerata* L., *Poa trivialis* L., *Heracleum sphondylium* L. and *Urtica dioica* L. as dominants which are distributed over the verge, slope and ditch (Table 1).

4.2. NVC classification of roadside data

Six different NVC (Rodwell 1992) communities were recognized in the road verge data (Table 2). These communities are the *Arrhenatheretum elatioris* community (MG1), *Lolium perenne-Cynosurus cristatus* grassland (MG6), *Lolium perenne* leys (MG7), *Holcus lanatus-Deschampsia cespitosa* grassland (MG9), *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland (MG11) and *Festuca ovina-Agrostis capillaris-*

Table 1. Frequency (%) and mean cover (%) of the ten most frequent species in different zones of the road verges.

Species	Total frequency	Mean cover	Border		Verge		Slope		Fence	
			Number of quadrats							
	699	699	204		204		99		192	
			Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
Arrhenatherum elatius (L.)P.B. ex J. et C.Presl	53	19	18	4	62	21	69.0	26	74	24
Cirsium arvense (L).Scop.	53	2	39	1	61	3	64	17	53	3
Festuca rubra L.	46	12	37	10	54	14	69	17	35	8
Dactylis Glomerata L.	44	3	25	1	52	3	55	6	49	3
Lolium perenne L.	39	8	79	20	38	6	19	1	8	0.1
Holcus lanatus L.	37	3	11	0.5	42	3	59	5	47	6
Poa trivialis L.	33	2	8	0.2	41	4	40	3	48	3
Elymus repens (L.)Desv.ex Neuski.	29	4	40	9.0	28	2	20	2	24	2
Urtica dioica L.	28	1.0	5	0.1	20	2	26	3	60	9
Heracleum sphondylium L.	27	3	12	0.1	31	1.0	32	0.5	35	1

Galium saxatile grassland (U4). Out of these communities, three sub-communities were recognised in MG1 namely, *Arrhenatheretum-Festuca rubra* sub-community (MG1a), *Arrhenatheretum-Urtica dioica* sub-community (MG1b) and *Arrhenatheretum-Filipendula ulmaria* sub-community (MG1c). MG6 and MG7 were represented by the *Lolium perenne-Cynosurus cristatus* pasture typical sub-community (MG6a) and the *Lolium perenne-Poa pratensis* sub-community (MG7f) respectively. Two sub-communities, MG1c and MG7f comprised of seven and nineteen quadrats only. These results show that except for the upland sites, the road verges in the study area are dominated by mesotrophic grassland communities.

Rodwell (1992) has described some variants of different vegetation types which sometimes, attain abundance at local levels. In the present study, some variants of the NVC sub-communities were recorded. In addition, the frequent occurrence and local abundance of *Equisetum arvense* on the road verges suggested that it might be considered as another variant of MG1a. Sargent (1984) described it as a separate sub-community of *Arrhenatheretum elatioris* in British railway vegetation. She described *Alopecurus pratensis, Anthriscus sylvestris*, *Elymus repens, Lathyrus pratensis* and *Poa trivialis* as its differential species. In the present work, most of these species were recorded along with *Equisetum arvense*. Lavin and Willmore (1994) described *Linaria vulgaris, Plantago lanceolata, Reseda luteola* and *Senecio jacobaea* as associated species of *Equisetum arvense*. Among them, *Plantago lanceolata* and

Table 2. British National Vegetation Classification (NVC) communities and sub-communities recognized in the road verge data.

NVC community/ sub-community	No. of quadrats	Similarity coefficient (%)
Arrhenatheretum elatioris: MG1		
Festuca rubra sub-community MG1a	191	64
Urtica dioica sub-community MG1b	174	61
Filipendula ulmaria sub-community MG1c	7	64
Lolium perenne-Cynosurus cristatus pasture: Typical sub-community MG6a	94	60
Lolium perenne: *Lolium perenne-Poa pratensis* sub-community MG7f	19	50
Holcus lanatus-Deschampsia cespitosa grassland MG9	60	63
Festuca rubra-Agrostis stolonifera-Potentilla anserina grassland MG11	135	48
Festuca ovina-Agrostis capillaris-Galium saxatile grassland U4	19	55

Senecio jacobaea were found commonly associated with *Equisetum arvense* in the present study. These observations suggest that *Equisetum arvense* may be considered as a distinct variant of the *Festuca rubra* sub-community (MG1a) in the NVC classification.

4.3. Grouping of plant species

All the recorded plant species (212) were used in the CANOCO analysis to find patterns of grouping among the species. However, only plant species with more than 10% frequency of occurrence are shown in the Fig. 2.

Four arbitrary main species groups were recognised on the basis of their positions in the Figure 3 and are designated as A, B, C and D. The group A consists of plant species (*Bellis perennis*, *Elymus repens*, *Lolium perenne*, *Plantago major*, *Poa annua*, *Polygonum aviculare* and *Taraxacum officinale* agg.) typically associated with the first zone of the road verges. It also includes salt tolerant species such as *Chenopodium album*. *Poa annua* has been reported as a common species of road verges and its associated species include *Agrostis stolonifera, Lolium perenne, Matricaria matricarioides, Plantago major* and *Polygonum aviculare* (Hutchinson and Seymour 1982). Since the first zone of a road verge undergoes extensive levels of trampling and compaction, the high frequency species of this zone (*P. major, L. perenne* and *P. annua)* are expected to be able to tolerate these conditions. These species exhibit morphological modifications such as low and compact growth form (Frenkel 1970) or prostrate genotypes (Grime 1979) which are advantageous to their survival in trampled and disturbed conditions.

The group B consists of *Anthriscus sylvestris, Arrhenatherum elatius, Galium aparine, Rubus fruticosus* agg. and *Urtica dioica.* Some of these species, *Galium aparine*, *Rubus fruticosus* agg. and *Urtica dioica* have been reported to colonise organically rich, moist and fertile habitats (Grime *et al.* 1988) and these habitat conditions can be observed in the last zone of the road verges. This zone is relatively protected from the effects of traffic and mowing and usually there is a hedge on the outer side. Ellenberg (1988) described *Urtica dioica* and *Galium aparine* as

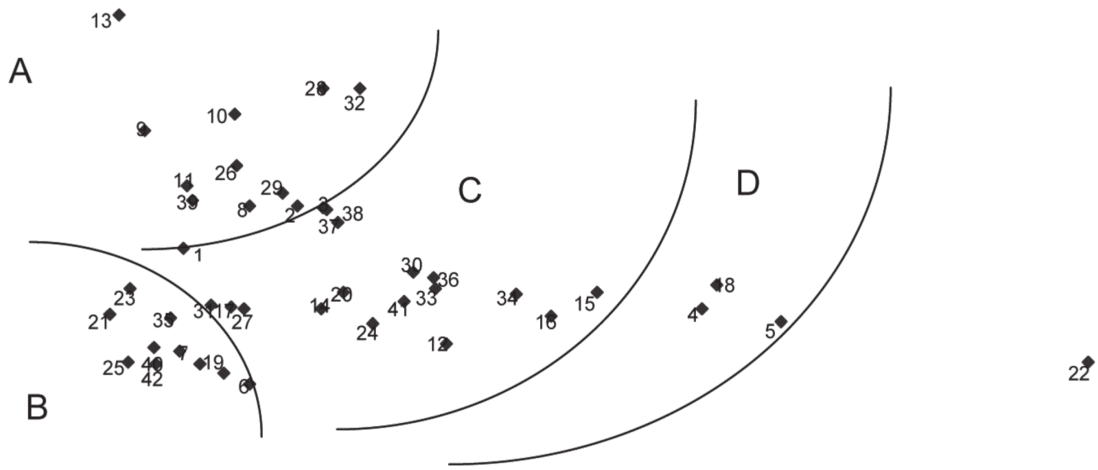

Fig. 2. CCA ordination of roadside species (frequency >10%). Species groups: A – species associated with the zone of the road verges; B – species associated with the last zone of the road verges; C – species which have a wide range of distribution on different zones of road verges; D – species which grow on damp or wet soils.

Explanations: Number and names of species shown in Fig. 2.

1. *Achillea millefolium* L.
2. *Elymus repens* (L.) Gould
3. *Agrostis stolonifera* L.
4. *Agrostis capillaris* L.
5. *Anthoxanthum odoratum* L.
6. *Anthriscus sylvestris* (L.)Hoffm
7. *Arrhenatherum elatius* (L.) J&C. Presl.
8. *Artemisia vulgaris* L.
9. *Atriplex patula* L.
10. *Bellis perennis* L.
11. *Bromus hordeaceus* L.
12. *Cerastium fontanum* Baumg.
13. *Chenopodium album* L.
14. *Cirsium arvense* (L.). Scop.
15. *Cirsium vulgare* (Sari.) Ten.
16. *Cynosurus cristatus* L.
17. *Dactylis glomerata* L.
18. *Deschampsia cespitosa (L)P. Beauv.*
19. *Equisetum arvense* L.
20. *Festuca rubra* L.
21. *Galium aparine* L.
22. *Galium saxatile* L.
23. *Heracleum sphondylium* L
24. *Holcus lanatus* L.
25. *Lathyrus pratensis* L.
26. *Lolium perenne* L.
27. *Plantago lanceolata* L.
28. *Plantago major* L.
29. *Poa annua* L.
30. *Poa pratensis* L.
31. *Poa trivialis* L.
32. *Polygonum aviculare* L.
33. *Ranunculus acris* L.
34. *Ranunculus repens* L.
35. *Rubus fruticosus* agg. L.
36. *Rumex acetosa* L.
37. *Rumex obtusifolius* L.
38. *Senecio jacobaea* L.
39. *Taraxacum officinale agg.* Web.
40. *Trifolium pratense* L.
41. *Trifolium repens* L
42. *Urtica dioica* L.

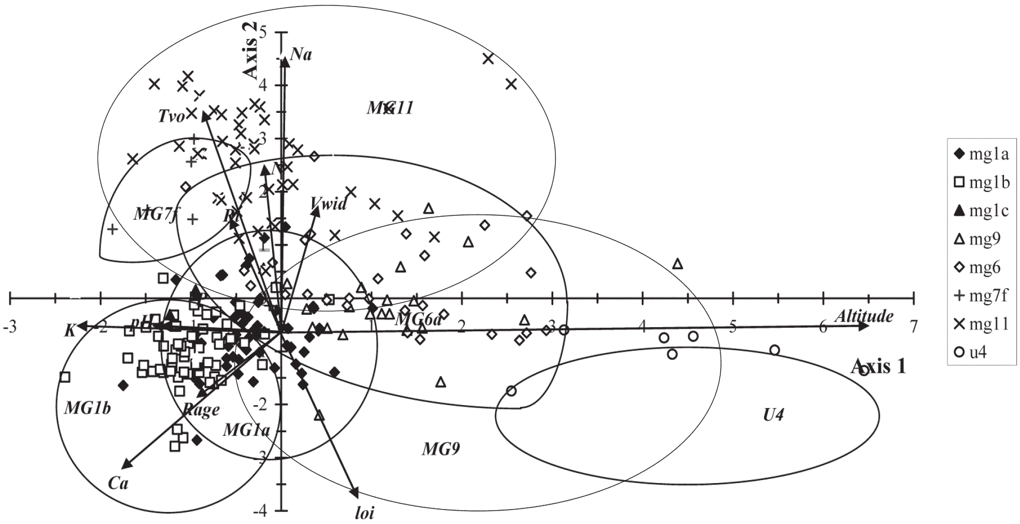

Fig. 3. CCA ordination of roadside quadrats and biplot scores of environmental variables.

Explanations:
MG – mesotrophic grassland communities,
U4 – upland community (see Section 4.2).

Loi	Loss on ignition	Ca	exchangeable calcium
Rage	Road age	K	exchangeable potassium
Vwid	Verge width	Mg	exchangeable magnesium
Tvo	Traffic volume	Na	exchangeable sodium
P	phosphorus	N	total nitrogen

common plants of 'fringe communities requiring nitrogen and high humidity in central Europe. Greig-Smith (1948) reported that *Urtica dioica* cannot withstand repeated cutting and one reason for its abundance in the last part of the verge may be relative protection from mowing. Although *A. elatius* is one of the dominant species across three zones (verge, slope and ditch) it showed the highest frequency of occurrence of 74%, in the last zone and is placed in the ordination diagram near *Urtica dioica* which is the codominant of this zone.

The third group, C consists of species which have a relatively wide range of distribution on different zones of road verges. The species of this group are placed in the centre of the ordination diagram and include *Cirsium arvense, Dactylis glomerata, Festuca rubra, Plantago lanceolata, Poa trivialis, Trifolium repens* and *Rumex* spp. The majority of these plants are rhizomatous or stoloniferous and show a capacity for rapid vegetative spread. Though *Festuca rubra* is more frequent and abundant in the verge and slope, this is commonly distributed throughout all the zones. However, its abundance is at a minimum in the ditch zone. By considering the extent of disturbance, the second zone occupies an intermediate position between the border and ditch zones.

The fourth group D includes the species which grow on relatively damp or wet soils. This group includes species such as *Agrostis capillaris*, *Deschampsia cespitosa* and *Juncus effusus*. These species have been recorded as the frequent species of marshlands (Grime 1979). In central Europe, *D. cespitosa* has been recorded as a common species of damp sites whereas *Juncus effusus* is the common plant of moderately wet sites (Ellenberg 1988). At the extreme positive end of the first axis are found the common species of heaths and upland habitats, such as *Galium saxatile*.

Table 3. Summary of Canonical Correspondence Analysis results.

	Axis 1	Axis 2	Axis 3	Axis 4
Eigen values	0.26	0.21	0.17	0.10
Percentage variance of species-environment relationship :				
For each axis	18.5	15.3	12.8	7.9
Cumulative	18.5	33.8	46.6	54.5

Table 4. Canonical coefficients of environmental variables with the four CCA axes (with levels of significance). The bold values show the maximum coefficient value for each variable. No star, $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Variable	Axis 1	Axis 2	Axis 3	Axis 4
Altitude	**0.56***	0.01	0.14	–0.33***
pH	**–0.38***	0.01	–0.15	0.27**
Loss on ignition	0.23*	**–0.28**	–0.09	–0.12
Na	0.01	**0.46***	0.03	0.11
K	**–0.61***	0.01	0.09	–0.13
Mg	–0.30**	0.11	0.01	**–0.52***
Ca	**–0.47***	–0.23*	–0.38***	–0.40***
N	–0.05	0.28**	0.06	**–0.39***
P	**–0.36***	0.01	–0.13	0.04
Soil fertility	–0.05	0.09	–0.05	**–0.49***
Verge width	0.11	0.21*	**–0.35***	–0.10
Road type	–0.15	**0.196***	–0.192	0.07
Road verge age	–0.25**	–0.11	**–0.89***	–0.07
Traffic volume	–0.23*	0.37***	–0.18	**0.48***

4.4. Ordination of quadrats

To differentiate the quadrats into the NVC communities and sub-communities recognised by TWINSPAN and MATCH analyses, the quadrats falling into different NVC communities and sub-communities are delineated in Fig. 3. This diagram shows two clear patterns of distribution of the NVC groups. Along the first axis, the NVC communities exhibit a distinct grouping of quadrats with a minor overlap. All these NVC types are mainly composed of the quadrats from the verge, ditch and slope zones of the road verges. This can be explained by relating it to the actual road verge situation where these zones share common species and are strongly linked. These vegetation types show a parallel trend along the first axis starting from MG1b sub-community at the left end of the axis, MG1a sub-community in the centre, MG9 community towards the right side and the upland community, U4 grassland at the extreme right side. Other NVC groups which mainly consist of the quadrats from the first zone of the road verges are clustered along the second axis with considerable overlap. These NVC units are MG6a, MG7f) and MG11.

4.5. Roadside vegetation and environmental factors

The application of canonical correspondence analysis (CCA) proved successful in highlighting the important environmental variables affecting the roadside vegetation in the study area. The eigen values for the four CCA axes are given in Table 3. This table shows that 55% of the total variation in the data set is explained by the four axes. The first two axes are by far the most important in explaining the variation in floristic data because these explain 34% of the total variation.

Table 4 shows the canonical coefficients of different environmental variables with the four principal CCA axes. Axis 1 most closely corresponds to potassium and altitude with canonical coefficient values of –0.61 and 0.56 respectively. Other variables, which out of the four axes have their highest correlation coefficients with the first axis are calcium (–0.47), pH (–0.38) and phosphate (–0.36). Axis 2 is most strongly related to sodium (0.46) and other variables having maximum correlation with this axis are loss on ignition (–0.28) and road type (0.19). Two factors, road age (–0.89) and verge width (–0.35) appeared to be highly correlated with the third axis. As for magnesium (–0.52), soil fertility (–0.49), traffic volume (0.48) and total nitrogen (–0.39) have their highest coefficient values with the fourth axis. Since the first two axes are the principal axes for explaining the variation in the data, the variables which correspond strongly with these axes are considered as the most important environmental variables.

The most important factors recognised by CANOCO were altitude, pH, exchangeable sodium and calcium, verge age and macro-nutrients particularly nitrogen and potassium. Ordination analysis also highlighted the existence of factors which were not measured or recorded in the field such as the effects of trampling or the nature and extent of management activities including mowing.

The wide altitudinal variation within the sites (6–480 m above the sea level) appeared to be an important factor affecting the distribution of plant communities in the study area. Though the dominant species of the roadside vegetation have wide ecological amplitude and are distributed ubiquitously, nevertheless, the composition of the road verge vegetation at upland sites was significantly different from that at lowland sites. However, the change in species composition seemed gradual without distinct boundaries. The NVC communities ordered along the first axis suggest organisation by the location of the sites, the communities located in lower, warmer and relatively drier areas ordinating negatively, and the communities located at higher elevations (with presumably more moisture) ordinating positively. The subcommunities of *Arrhenatheretum* community are mainly distributed below the altitude of 200 metres. *Arrhentherum elatius* can not tolerate low temperatures because its sexual reproduction is severely affected (Pfitzenmeyer, 1962). Ellenberg (1988) reported that *Arrhenatheretum* is absent from the coolest parts of south-west Germany which have the highest rainfall. MG6a showed a fairly wide distribution with respect to altitudinal variation while MG7f and MG11 are distinctly concentrated below 200 metres. MG9 and U4 are common on the upland sites.

Exchangeable potassium had the strongest negative correlation with the first axis. By

Table 5. Mean values (± S.E) of some edaphic variables of the roadside British National Vegetation Classification (NVC) plant communities. (see Section 4.2.)

Variable	MG1a	MG1b	MG6a	MG7f	MG9	MG11	U4
pH	7.5± 0.1	7.2± o.1	7.1± 0.2	8.1 ± 0.2	7.2 ± 0.2	8.1 ± 0.1	5.5 ± 0.3
LOI (%)	10.5±0.4	11.0±0.4	9.4 ± 0.5	7.7 ± 1.4	11.6 ± 0.6	8.2 ± 0.5	13.6 ± 1.6
N (%)	0.4 ± 0.1	0.6 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.5 ± 0.1
K (μg g^{-1})	148±7.9	188±10.3	117.9± 8.5	156.5±25.8	103.7± 11.8	125 ± 10.0	74.6± 3.4
P (μg g^{-1})	22.5 ± 1.7	22.2 ± 1.9	14.3 ± 1.5	14.6 ± 1.3	19.5 ± 2.1	25.2 ± 2.6	12.7 ± 2.1
Mg(μg g^{-1})	145 ± 13.8	164.6 ± 13.8	113.5 ± 22.9	93.1 ± 18.3	91.4 ± 12.0	88 ± 12.9	57.1± 10.5
Ca (μg g^{-1})	4869 ± 405	3344 ± 188	2547 ± 413	3763± 789	2691± 295	3226 ± 360	830.8± 147.5
Na (μg g^{-1})	215.8 ± 15.5	217.7 ± 20.1	408.6± 96	668± 194	422 ± 93.2	1430 ± 121	215.4± 46.4
Fertility (% of control)	43 ± 3.9	49.9± 2.3	31.6± 3.0	28.5 ± 3.3	19.6± 2.1	23.1± 2.4	34.3± 4.4

using ANOVA analysis on the data in Table 5, a significant variation ($P < 0.001$) was observed between the potassium concentration of soils associated with different NVC plant communities. The *Urtica dioica* sub-community (MG1b) of the *Arrhenatheretum* showed the closest correspondence with potassium in the ordination diagram and had the highest mean potassium concentration (188 μg g^{-1}) in its soils. The *F. rubra* sub-community (MG1a) had relatively lower concentration of potassium in its soils (148 μg g^{-1}) and was positioned near the centre of the ordination diagram. On the positive side, *Holcus lanatus-Deschampsia cespitosa* grassland (MG9) soils contained intermediate value of potassium (103 μg g^{-1}) while soils from the U4 community had the lowest potassium concentration (74.6 μg g^{-1}). This negative relationship of exchangeable potassium with increasing altitude may be due to increased leaching of potassium. At high altitude, precipitation is higher and topography favours fast runoff and both these conditions may deplete the soils of potassium. This is supported by the fact that most of the quadrats of the *Festuca rubra* sub-community which are from the verge and slope zones and which are better drained than the soils from the *Urtica dioica* sub-community (mainly from the ditch zone), have lower potassium concentration than that of the latter community.

After potassium, other chemical variables which have the highest correlation with the first axis are pH and phosphate. Calcium showed significant correlation with all the four CCA axes. The high to very high levels of calcium in the roadside soils may be one of the reasons for the high frequency of neutral soils in the study area. For pH, the U4 community with a mean pH of 5.5 is placed near the negative end. *Arrhenatheretum* sub-communities are placed near the positive end of the pH gradient and had circumneutral soils. With respect to phosphate, the U4 soils had the lowest phosphate concentration and there was a gradient of gradual increase from MG9 to the MG1 sub-communities. There was no significant difference between MG1a and MG1b sub-communities with respect to the concentration of phosphate of their soils.

Axis 2 most closely corresponds to exchangeable sodium. Nitrogen and organic matter had the second position with respect to level of correlation with the second axis, the former with a positive and the latter with a negative correlation. Among the non-chemical variables, traffic volume showed a high correlation with the second axis. This correlation may, however be related to exchangeable sodium which in roadside soils is related to de-icing activities during winter. The road verges along the roads with a large traffic volume are supposed to receive greater quantities of de-icing salt as well as larger quantities of de-icing salt being splashed off. With respect to sodium, the NVC communities including quadrats mainly from the border zone (MG7f and MG11) are placed near the top end of the second axis showing a strong correspondence with sodium. MG1a and MG1b are placed near the centre with lowest mean values of sodium along the second axis.

Organic matter had the strongest negative correlation with the second axis. The MG7f and MG11 are placed near the opposite end of the axis with respect to organic matter and had lowest mean loss on ignition percentages (7.7 and 8.0%) whereas MG1a and MG1b are placed near the centre with intermediate values (10.5 and 11%). MG9 and U4 have relatively higher percentages of loss on ignition (11.6 and 13.6%) but they do not seem to be related to the second axis.

5. DISCUSSION

On the whole, the roadside flora is quite rich in species with the recording of 212 plant species from the road verges supporting this point. A relatively small number of dominant or very frequent species in the roadside flora shows that these species are found in a wide range of ecological conditions and are present throughout the study area. The dominance of the roadside flora by a limited number of species is also supported by other studies, such as Ulmann and Heindl (1989) in temperate Europe where the roadside flora is dominated by the species of just a few families such as Poaceae, Asteraceae and Apiaceae.

Considering the general origin of the roadside species, the roadside vegetation has been reported as consisting of two main components: 1) the species present in the seed bank of the road area, and 2) the invading species introduced and spread by traffic or other human activities (Ullmann and Heindl 1989). In the author's view, the roadside species in the study area could be divided into three broad categories according to their origin. The first group of species includes the seed-mixture species which are fast growing plants and help in the rapid stabilisation of soil to decrease soil erosion on the verges. With the passage of time, their abundance or frequency may change, but three of them, *Festuca rubra*, *Lolium perenne* and *Trifolium repens* remain as major constituents of the roadside flora. The second group consists of the species of the local flora which also are present on road verges. The roadside vegetation has been shown to exhibit affinities with the regional or local flora (Ahmad *et al.* 2004). The third component of the roadside flora includes introduced or alien species. This is mainly facilitated by dispersal of species with construction material, by vehicles and changes in habitat conditions. The most evident example of this phenomenon is the spreading of some maritime, salt tolerant species such as *Puccinellia distans, Cochlearia officinalis, C. danica* and *Spergularia marina* along the British roads, following the application of de-icing salts (Scott and Davison 1982). In the present study, *Puccinellia distans* and *Spergularia marina* were recorded at a few sites.

The comparison of the floras of eight NVC vegetation units reveals that a majority of the roadside plant communities show a good fit with the typical NVC units. However, the situation in the communities mainly comprising data from the first zone is not as clear. The three grassland types (*Lolium perenne-Cynosurus cristatus* grassland, MG6, *Lolium perenne* leys, MG7, *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland, MG11), recognised mainly in the first zone showed a lot of variation in their composition and constituted species which are not described as the common species of these communities by the NVC. The most abundant group among them is the *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland, MG11 community which comprised 60% of the total quadrats (204) from the first zone. It lacks most of the constant species of the defined NVC community. A greater floral diversity and a low constancy of the dominant species might be the reasons for a low similarity coefficient exhibited by this group (48.5%). Furthermore, the presence of the species which are characteristic species of other NVC groups complicated the situation. The fitting of the roadside plant communities from the border zone into NVC types proved to be difficult in this case. This observation also exhibits the common problem with hierarchical classification systems. These systems do well in the situations where the vegetation is predominantly homogeneous and is characterised by few dominant species. In situations where patterns of floral diversity are not uniform and exhibit considerable variation from place to place, these systems have problems. The presence of groups of species which are typical species of different communities further complicates the situation. Similar difficulties were experienced by Ulmann and Heindl (1989) in the application of the syntaxonomic system of Braun-Blanquet to roadside flora in temperate Europe. This situation is also common in the case of other anthropogenic vegetation such as urban areas and railways where there are many species without a clear dominance structure. This issue needs further study.

By analysing the patterns of species and community distribution and relating them with ecological characteristics of the habitats supporting them, three kinds of pattern of variation are evident in the roadside vegetation. A large scale pattern of differentiation exists involving variations according to regional or geographical location. Though roadside vegetation is strongly determined by anthropogenic activities, regional differences are however just as important. This has also been shown by other workers in other countries. In California, distinct regional differences were found in the floristic composition of roadside vegetation and the composition of roadside plant communities was found to vary according to the regional vegetation (e.g. grasslands, forest) and surrounding areas (Frenkel 1970). In Denmark, many roadside species were recorded to exhibit an appreciable affinity to different pedological regions (Hansen and Jansen 1972).

In West Yorkshire, Rodwell (1994) described the main grassland types and reported that mesotrophic grassland communities are the common grassland types of meadows and pastures. The complete dominance of road verges in the present study by mesotrophic grassland communities, with the exception of a few upland sites, indicates the influence of the regional flora on the roadside vegetation.

In Britain, water regime, management, soil and geographical location are the four main factors which determine the botanical composition of neutral grasslands (Duffey *et al.* 1974). In the present study, the appearance of altitude as a major factor affecting the roadside vegetation indicates the significance of geographical location because with an increase in altitude, precipitation usually increases which in turn increases the moisture content of soils.

Geology is also considered as an important factor affecting the colonisation and development of roadside vegetation (Thomas 1992). Due to difficulties in the categorisation of different geological substrates, geology could not be included as an environmental variable in the CCA analysis. However, it was found that though the study area includes a variety of geological substrates and soils, the main community structure of the roadside vegetation does not appear to be affected by these differences. Roadside vegetation is under the continuous influence of human use and management and under these conditions, the effects of geology in determining the community structure of roadside vegetation may not be fully expressed. With the exception of the upland sites, the verge and ditch zones and slopes of nearly all the sites were occupied by *Arrhenatheretum sub*-communities.

The second pattern of variation exists across the width of the road verges showing a zonal pattern of plant distribution. It is expressed in the form of distinct vegetation zones and in the diversity of plant communities occurring in the specific road verge zone. The distribution of specific roadside plants in different zones has been observed and reported by different authors (Hansen and Jansen 1972, Dowdeswell 1987). This differentiation is mainly dependent on the nature and extent of anthropogenic disturbance, management and the surrounding environmental conditions. Regarding the zonation of roadside vegetation in the present study, two patterns were observed. Near the metalled road, plant cover is usually low, the dominant species have a generally prostrate growth form and low stature and the proportion of therophytes is relatively high. In the other zones of the verge, tall, perennial and dense grasses with a few tall herbs are predominantly abundant. However, there were differences in the frequency and abundance between the dominant species of verge and ditch zones. The second zone and slope were predominantly covered by *Festuca rubra, Arrhenatherum elatius, Holcus lanatus, Heracleum sphondylium* and *Anthriscus sylvestris*. The vegetation of the last zone showed a greater variation than the second zone and its composition showed some influence of the surrounding habitats. Along with *Arrhenatherum elatius* and tall umbellifers, the ditch zone was dominated by the plant species commonly associated with woody and scrub habitats. These include *Urtica dioica, Rubus fruticosus* agg. and *Galium aparine*.

As the habitat conditions of a road verge show a gradual change in the extent and nature of anthropogenic influence (mowing, trampling, de-icing salt), the plant species also show a change in composition from the border zone to the outer boundary of the verge. The pattern of species composition near the road is influenced by the factors relating to mechanical disturbance and management while, in relatively distant zones (slope and ditch), other ecological factors become important in defining the character of roadside vegetation. Common rock salt (NaCl) is an important factor affecting the plant growth conditions of roadside soils because its accumulation in roadside soils gives rise to unfavourable conditions for the growth of glycophytes. High levels of sodium and chloride ions in the roadside soils affect the distribution of plant species in the verge vegetation and salt tolerant or annual species are abundant near the road margin. In the present study, the patterns of the grouping of species in the ordination diagram (Figure 2) and the distribution of different NVC plant communities in different road verge zones also supports this view.

The type of the surrounding habitat or area also affects the composition of different zones of road verges. The frequency of therophytes in the border zone of roadside verges is relatively higher than in other zones (Frenkel 1970, Hansen and Jansen 1972) but this may change with changes in surrounding habitats or flora. The effect of adjacent areas on the species composition of various verge zones was also investigated in this study. The road verges in urban or sub-urban areas had a higher proportion of annual species (21%) as compared to verges from rural sites (13%). Similarly, the extent of the species characteristic of border zone was increased in urban areas. In verges from rural areas, the plants resistant to disturbance were mainly confined to the border zone and other zones were occupied by the species of more permanent grassland.

The third scale of pattern is active at the local level including micro-environmental conditions, e.g., local edaphic variables. Although, each community has a homogeneous physiognomy, nevertheless these variations in local edaphic conditions also result in phytosociological variation. For example, in the case of *Arrhenatheretum,* Rodwell (1992) stated that pH, nitrogen, phosphorus, potassium and drainage are the important factors affecting the variation within the community. In the present study, pH and nitrogen and potassium concentrations of *Arrhenatheretum-Festuca rubra* sub-community (MG1a) and *Arrhenatheretum-Urtica dioica* sub-community (MG1b) soils showed significant differences between the two communities (Table 4). *Arrhenatheretum-Festuca rubra* sub-community (MG1a) soils had significantly higher ($P < 0.05$) mean pH value than *Arrhenatheretum-Urtica dioica* sub-community MG1b soils. On the other hand, *Arrhenatheretum-Urtica dioica* sub-community MG1b soils had significantly higher ($P < 0.001$) amounts of potassium and nitrogen than *Arrhenatheretum-Festuca rubra* sub-community (MG1a) soils. The two sub-communities, however, showed no significant difference in their phosphate concentration in soils. The present results therefore, partly support the view of Rodwell (1992) by showing that pH, nitrogen and potassium are important nutrients in affecting the floristic variation within the roadside *Arrhenatheretum* community. However, the role of phosphate in influencing the variation within the roadside MG1 community is not evident.

Management is considered as the major factor affecting the composition of grasslands, particularly in the case of anthropogenic grasslands. According to Ausden and Treweek (1995), all grasslands in Britain require some management to prevent succession if they are to remain as grassland. The methods which form the basis of grassland management mainly involve the removal of vegetation (grazing, cutting, burning). The main management techniques used for roadside verges include regular or irregular mowing, scrub removal and application of herbicides. In Britain, mowing is the most extensively used management method and the majority of the highway authorities cut a swathe once or twice a year. Usually mowing is restricted to the first 1 to 2 metres of the road verge and this practice shows considerable effects on the floristic composition of road verges. One reason for the absence of *Arrhenatheretum* grassland from the border zone is its intolerance to mowing (Pfitzenmeyer 1962). In Netherlands it was found that in the absence of mowing and shade, species diversity declined on roadside verges and competitive grasses such as *Festuca rubra* and *Agrostis capillaris* became dominant (Melman *et al.* 1988). In shady habitats without mowing, *Urtica dioica* became dominant. In this study, the dominance of *Festuca rubra* on the second zone of the verges which is relatively unshaded and mowed occasionally and the dominance of *Urtica dioica* in the last zone, which is shadier due to the presence of hedges and protected from mowing supports that study.

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