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Grassland leafhoppers (Hemiptera: Auchenorrhyncha) as indicators of habitat condition – a comparison of between-site and between-year differences in assemblage composition

J.A. Hollier[1,2,*], N. Maczey[1], G.J. Masters[1] and S.R. Mortimer[3]
[1]*Ecology, Systematics & Biodiversity, CABI Bioscience, Bakeham Lane, Egham, Surrey, TW20 9TY, UK;* [2]*Current address: 42 Virginio Malnati, 1217 Meyrin, Switzerland;* [3]*Centre for Agri-Environmental Research (CAER), University of Reading, Earley Gate, P.O. Box 237, Reading RG6 6AR, UK; *Author for correspondence (e-mail: hollier-ja@hotmail.com; phone: (0041)22 783 0924)*

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Abstract

The Auchenorrhyncha (leafhoppers) show great potential as indicators of grassland habitat quality, which would make them useful as a conservation tool. However, they are known to have labile populations. The relative importance of site identity and the year of sampling in the composition of leafhopper assemblages on chalk grassland are assessed for two sets of sites sampled twice. The study included a total of 95 sites (one set of 54, the other of 41), and demonstrated that for both sets the vegetation community and geographical location had high explanatory value, while the influence of year was small. The conclusion is that, notwithstanding population fluctuations, the leafhopper assemblages are a good indicator of habitat quality, and represent a potentially valuable tool in grassland conservation and restoration.

Introduction

The Auchenorrhyncha (leafhoppers) are not only a diverse and species-rich group (Nickel 2003), but are often the most abundant insect herbivores in temperate grasslands (Waloff 1980). It has long been known that different grassland types have distinct leafhopper assemblages (Marchand 1953; Waloff and Solomon 1973). Since leafhoppers are very sensitive to vegetation structure (Andrzejewska 1965), differences between assemblages have often been explained in terms of this, and leafhopper assemblages have been shown to respond quickly to management by cutting (Morris 1971; Morris and Lakhani 1979) or grazing (Brown et al. 1992). However, the species composition of the vegetation can also be important (Novotný 1991). In practice however, the structure and composition of vegetation are inextricably linked (Liira et al. 2002), as well as being related to geophysical and ecophysiological constraints.

It was once thought that the majority of the leafhoppers of temperate grasslands were polyphagous, but more recent studies have found a range of specialisations (Nickel 2003). This, together with the richness of the group and its ready response to management, suggests that the leafhoppers would be valuable as indicators of habitat quality for conservation management purposes. A number of multi-site studies using various multivariate analysis techniques support this view (Cherrill and Rushton 1993; Eyre et al. 2001; Mortimer et al. 1998; Nickel and Hildebrandt 2003), finding that the distribution of leafhopper assemblages can be related to vegetation, soil and geographical factors, suggesting niche partitioning amongst the leafhopper species within particular vegetation types.

However, leafhopper populations are very labile (Waloff 1994; Waloff and Thompson 1980; Rombach 1999). While this helps to explain the rapid changes, which occur in response to succession (Hollier et al. 1994), as well as management (Morris 1981a, b) and even climate change (Masters et al. 1998), it might raise questions about the comparability of multi-site studies.

Lowland calcareous grasslands of Britain and other parts of north-western Europe are essentially a product of traditional agriculture (Duffey et al. 1974), and as such are vulnerable to changes in farming practice. Although the high diversity and richness in rare species of such grasslands has long been known (Tansley 1939) it is estimated that 85% of the area of these grasslands present in Britain in 1940 was lost in the subsequent 50 years (Keymer and Leach 1990). The remaining areas are threatened with degradation as a result of poor management, the biogeographical effects of fragmentation and the direct impacts of intensive agriculture such as spray drift and increased nutrient input due to run off (Jeanneret et al. 2003; Mortimer et al. 1998).

Lowland calcareous grassland, often referred to as 'chalk grassland', actually comprises several distinct plant communities within the UK's National Vegetation Classification (Rodwell 1992). There are geographical differences in the distribution of these communities, and of the subdivisions within them, which are related to management history, climatic and geological factors. The extent to which these differences are represented in the associated insect faunas is relatively unknown.

Lowland calcareous grassland is now covered at EU level by the Habitats Directive. In the UK, the Biodiversity Action Plan (UK Biodiversity Group 1998) has targets for the protection and restoration of existing areas and creation of new areas of this habitat. As the product of past agricultural practices, the conservation and restoration of this habitat depends upon provision of suitable land management. In practice, the agri-environment schemes funded through the EU Agri-Environment Regulation 2078/92 are the chief means of implementing conservation management (Ovenden et al. 1998). Measuring the success of such management in meeting the goals of conservation or restoration using insects as indicators of habitat condition can provide more information than the vegetation alone (Mortimer et al. 1998). While leafhoppers have been suggested as a suitable indicator group (Nickel 2003), the known labile nature of leafhopper populations represents a potential challenge. Although one study showed community stability over several years despite fluctuations in the populations of individual species (Müller 1978), leafhopper assemblages may change quickly (Huusela-Veistola and Vasarainen 2000). The example presented takes data from 95 calcareous grassland sites being managed as part of agri-environmental schemes in southern Britain, each of which was sampled twice. Under agri-environment scheme management prescriptions, these sites should have consistent management, thus between-year differences represent stochastic changes, while between-site differences reflect site identity. If these two kinds of difference are of the same order of magnitude then leafhoppers would not be effective indicators of habitat quality, but if site identity alone is important the case for using leafhoppers is strong.

Methods

The sites

The current study included 95 sites, comprising areas of existing chalk grassland, most of which were undergoing restoration management as part of an agri-environment scheme, and areas of newly-created grassland on ex-arable land on chalk soils. The sites were selected from those used in long-term monitoring programmes designed to test the efficacy of agri-environment scheme management, being categorised as agriculturally improved, semi-improved, unimproved or as arable-reversion (ADAS 1996, 1997; Carey et al. 2003). In the UK, two main agri-environment schemes have provisions for chalk grassland restoration and creation. The Environmentally Sensitive Area (ESA) scheme operates in defined geographical areas of high landscape value, whilst the Countryside Stewardship Scheme funds similar management options in the wider countryside outside of the ESA boundaries. The sites used in this study comprised two groups; one set from within the boundaries of the South Downs and South Wessex Downs (referred to as ESA sites), the other set from the areas of the chalk outcrop outside ESA boundaries, where chalk grasslands may be entered into Countryside Stewardship agreements (referred to as CS sites). Some differences between these two groups were expected because, the geographical spread of the CS sites was greater, and included more northerly sites which have somewhat different vegetation composition (Rodwell 1992). In addition, as a result of the criteria used to define ESAs, the sites within the ESA boundaries were generally larger, less isolated and in better condition than those outside the ESA boundaries.

Sampling

The ESA sites were sampled in 1998 and 2000 and the CS sites were sampled in 1999 and 2002 (originally intended to be 2001, but sampling was delayed because of restrictions imposed during the outbreak of foot and mouth disease in the UK).

Samples were taken in five plots within each site in a regular pattern, either on the longest diagonal or as a quincunx. The vegetation composition within a 2 m $\times$2 m quadrat at each sampling location was recorded in the first year, and assigned to a community within the National Vegetation Classification using the programme TABLEFIT (Ford 1995). Invertebrates were sampled three times in each year (mid May/June, Jul/mid Aug and Sept/mid Oct), using a 'Vortis' suction sampler (Burkhard Manufacturing, Rickmansworth, UK). At each visit 15 sucks of 10 s were collected within a radius of 3 m of the centre of the plots. In addition, the vegetation structure was measured using standard drop-discs (Stewart et al. 2001) on each sample date.

Invertebrates were stored in 70% alcohol, sorted to order, and subsequently the leafhoppers were identified to species (or genus for females which cannot be identified to species with certainty).

Analysis

The leafhopper data for the five plots at each site and three sample dates in a given year were combined to provide a bulk sample in order to characterise the assemblage present at each site. These data were then subjected to two multivariate approaches.

The first was TWINSPAN (Hill 1979), a divisive classification method. TWINSPAN was chosen because it is a robust method emphasising site identity (Wright et al. 1984). The analysis performs hierarchical division of the total pool of sites on the basis of species composition. An analysis of each set of sites was carried out for each year and direct comparisons of the objective groupings of sites were assessed using the Kappa measurement of concordance (Cherrill et al. 1997) with significance tests carried out using SPSS. Only the first two levels of division were examined because of the low eigenvalues associated with subsequent levels. The groupings produced were interpreted in terms of site parameters such as vegetation type as a check of the biological validity of the analysis.

The second approach used Redundancy Analysis (RDA) performed using the CANOCO software package (ter Braak and Smilauer 1998) to explicitly test the explanatory power of the site variables used to interpret the TWINSPAN groupings. Using RDA, a number of constrained ordinations were performed to test the proportion of the species–environment relationship explained by various variables both in isolation and after the effects of the other variables had been accounted for. The analysis used log-transformed leafhopper data, excluding species that were present in fewer than 10% of samples. The explanatory variables tested included NVC community, botanical diversity, vegetation height, heterogeneity in vegetation height and geographical region, along with year of sampling. RDA was performed using each set of variables, with and without the other variables employed as covariables in the analyses. The main focus of the analysis was to quantify the proportion of the explained variance that could be attributed to each set of factors, and to examine the relative magnitude of variability between years compared to the explanatory power of the variables describing site characteristics.

Results

Vegetation

The vegetation classification showed that the sites spanned a range of grassland communities described as mesotrophic and calcicolous grasslands in the National Vegetation Classification (Rodwell 1992), representing variation in soil type and management history.

Site groupings

The two sets of year to year comparisons are presented separately because the nature of the relevant agri-environmental schemes could engender differences in the factors which give rise to the groupings.

The results of the TWINSPAN classification of the ESA sites are expressed in Figure 1. In both years the results were similar, with the resulting groupings being easily explained in terms of the botanical composition of the vegetation. At the first division the sites classified as calcicolous grasslands in the NVC were separated from those classified as mesotrophic grasslands, although there are a number of exceptions. At the second division, the group composed largely of mesotrophic grasslands were sub-divided such that the improved permanent pastures and newly created grassland sites tend to be segregated, although this was less clear cut. The group composed largely of calcicolous grasslands were separated according to turf height, which was significantly different between the two groupings (in 1998, endgroup 1 mean 15.96 cm, endgroup 2 mean 6.73 cm; $F = 4.77$, $p = 0.0066$: in 2000, endgroup 1 mean 11.48 cm, endgroup 2 mean 7.46 cm; $F = 5.24$, $p = 0.0045$).

The results of TWINSPAN for the CS sites are shown in Figure 2. Once again the results for the 2 years are similar, and can be interpreted in much the same way as the ESA data. The first division separates calcicolous and the mesotrophic grasslands, with few exceptions. The second division tends to segregate the newly created grasssland sites from the others, although this effect is more obvious in 2002. The calcicolous grassland sites are not separated by sward height, but seem to show a regional difference at the second division, with the most northerly grasslands from sites in the Chiltern Hills tending to be grouped together in endgroup 1. This effect is not clear-cut, and could possibly represent differences in management practices rather than biogeographical differences *per se*.

As will be already clear, the TWINSPAN results demonstrate a high degree of consistency between years and the kappa values reflect this. The kappa coefficient varies between 1 (perfect agreement) and -1 (perfect disagreement); the significance test compares the experimental value with a null hypothesis of 0 (no agreement) (Bishop et al. 1976).

For the ESA sites, kappa values were 0.815 at the first division ($T = 6.025$, $p < 0.001$), and 0.546 at the second ($T = 7.027$, $p < 0.001$). For the CS sites, kappa values were 0.853 at the first division ($T = 5.471$, $p < 0.001$), and 0.669 at the second ($T = 7.364$, $p < 0.001$). The significance tests do not, perhaps, tell the whole story: these values of kappa are very high, especially at the first TWINSPAN division. It is considered that values > 0.75 indicate excellent agreement (Fleiss 1981).

Site factors

The use of Redundancy Analysis to test the explanatory power of the factors used in the interpretation of the TWINSPAN analyses confirmed both that the year of sampling had only a small impact on the results, and that the vegetation composition was the most important variable (see Table 3).

The year of sampling accounted for only 1.5% of the variance in the species–environment relationship explained in these analyses, whether analysed alone or with co-variables. All of the other variables were more important than year when tested alone, but the importance of botanical diversity, vegetation height and height heterogeneity were much reduced when the co-variables were included. Interestingly, geographical region remained important even in the analyses using co-variables, indicating that there are biogeographical differences which are not solely an artefact of the differences in site management and farming practice between regions.

Between-year differences in species abundance

Whilst the mesotrophic and newly-created grasslands are relatively consistently characterised by species typical of these habitats such as *Deltocephalus pulicaris* and *Psammotettix confinis*, it is

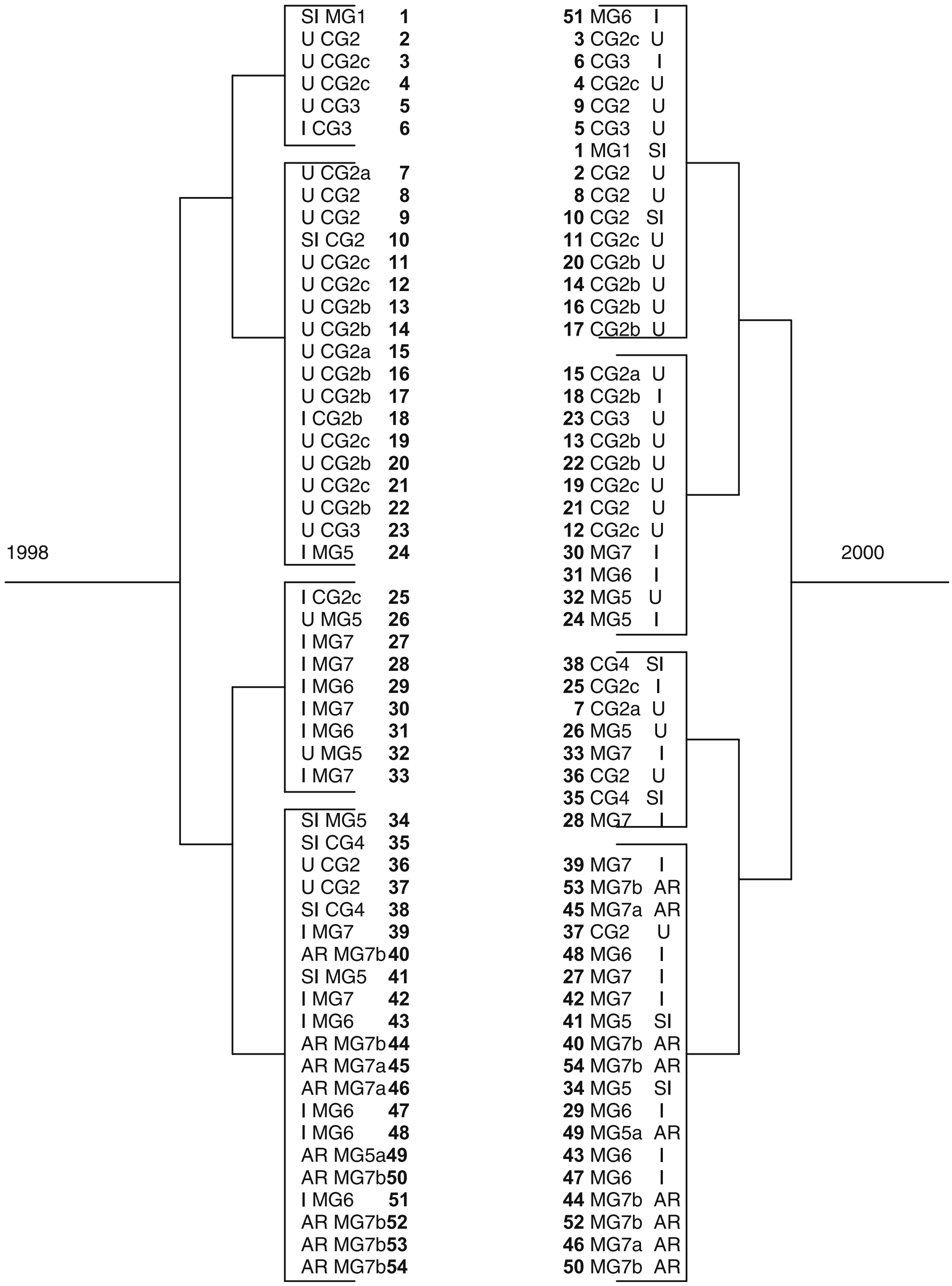

Figure 1. Classification of ESA sites using TWINSPAN for leafhopper assemblages. Site category (U unimproved; SI semi-improved; I improved; AR arable reversion) and vegetation (NVC code) are shown. (Endgroups numbered 1 (top) to 4 (bottom)).

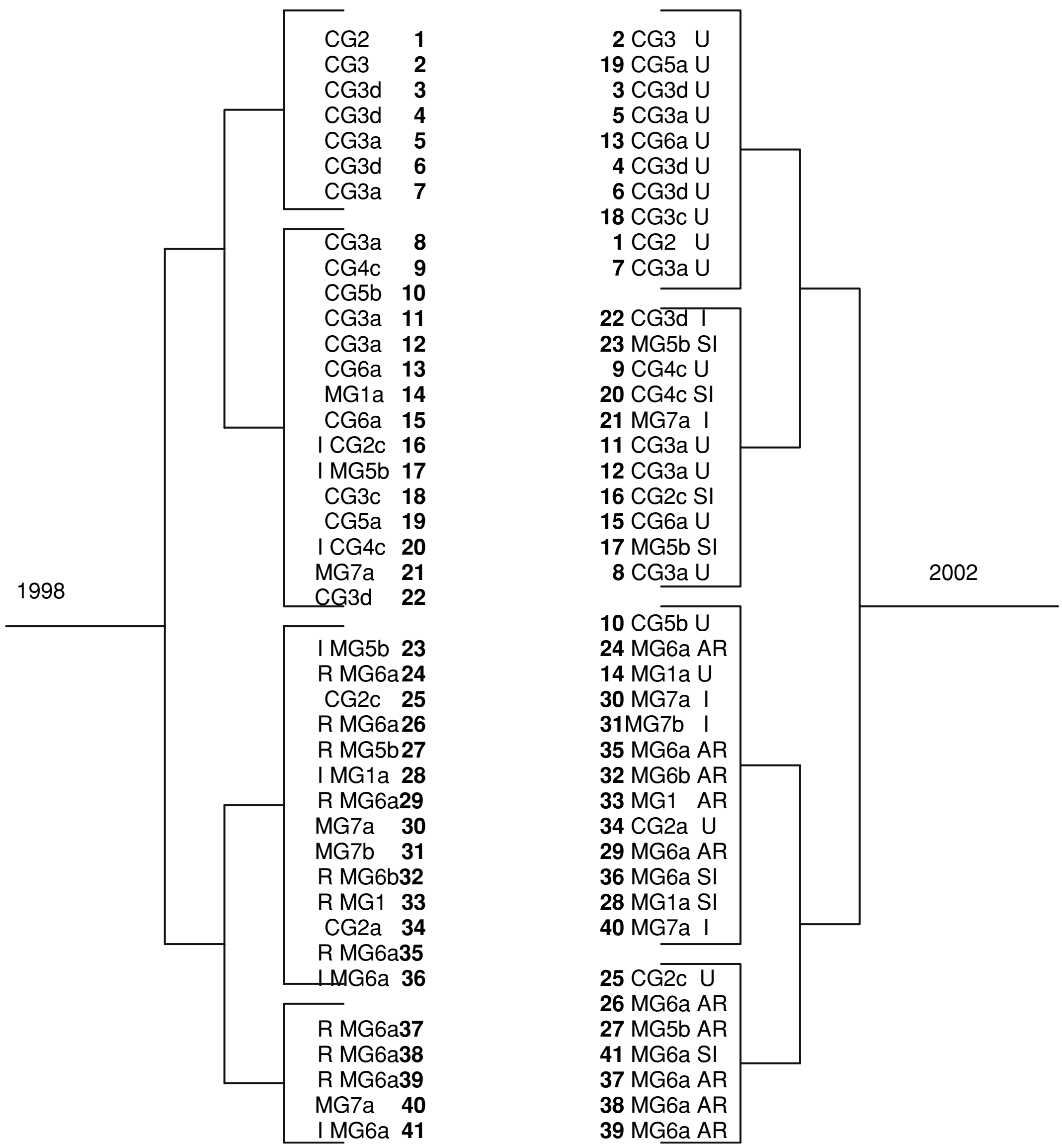

Figure 2. Classification of CS sites using TWINSPAN for leafhopper assemblages. Site category (U unimproved; SI semi-improved; I improved; AR arable reversion) and vegetation (NVC code) are shown. (Endgroups numbered 1 (top) to 4 (bottom)).

notable that many of the abundant species in the calciclous grassland endgroups are not calcicolous grassland specialists. More interesting is the fact that, notwithstanding the excellent agreement between the TWINSPAN analyses of the leafhopper assemblages, there were considerable differences in species abundance between sampling years, as Tables 1 and 2 demonstrate. The most extreme case is *Xanthodelphax stramineus*, which was the most abundant species in endgroup 3 in 2002, despite not having been recorded at all in the 1999 samples.

Discussion

The results highlight the importance of botanical composition in explaining leafhopper communities. The diversity and structure of the vegetation, whilst important to leafhoppers, are largely autocorrelated with vegetation community, as is shown in Table 3.

The exceptions to this general interpretation of the TWINSPAN groups in terms of the vegetation type are interesting. Firstly, the leafhopper

Table 1. The five most abundant species in each of the ESA TWINSPAN endgroups (rank abundance). (Nomenclature follows Holzinger et al. 1997).

TWINSPAN Endgroup	1998				2000			
	1	2	3	4	1	2	3	4
Arboridia parvula	1							
Zyginidia scutellaris	2	1			1	1	4	
Hyledelphax elegantulus	3	5	5		4			
Eupteryx notata	4	3				5		
Megophthalmus scanicus	5							
Kosswigianella exigua		2	4	4		3		
Neophilaenus exclamationis		4			5			
Deltocephalus pulicaris			1	1			1	1
Psammotettix confinis			2	2			2	2
Macrosteles spec.			3					
Anaceratagallia ribauti				3				
Anoscopus serratulae				5				
Mocydia crocea					2			
Stenocranus minutus					3			
Euscelis incisus						2	3	
Turrutus socialis						4		
Javesella dubia							5	
Euscelis lineolatus								3
Arthaldeus pascuellus								4
Psammotettix spec.								5

Table 2. The five most abundant species in each of the CS TWINSPAN endgroups (rank abundance). (Nomenclature follows Holzinger et al. 1997, and Remane and Guglielmino 2002).

TWINSPAN Endgroup	1998				2000			
	1	2	3	4	1	2	3	4
Arboridia parvula	1				1			
Batracomorphus irroratus	2							
Zyginidia scutellaris	3	1	4		2	2	5	
Stenocranus minutus	4							
Eupelix cuspidata	5	3						
Turrutus socialis		2				1		
Mocydia crocea		4				3		
Anaceratagallia ribauti		5						
Deltocephalus pulicaris			1	1				1
Psammotettix confinis			2	2				2
Anoscopus serratulae			3				2	
Arthaldeus pascuellus			5	4			3	3
Euscelis incisus				3				4
Javesella pellucida				5				5
Recilia coronifera					3			
Kelisia occirrega					4	5		
Megophthalmus scanicus					5			
Anoscopus albifrons						4	4	
Xanthodelphax stramineus							1	

Table 3. The percentage of total variance explained by the chosen variables analysed using Redundancy Analysis with each factor considered either independently or with all other factors as co-variables.

	Explanatory variable analysed independently	Explanatory variable analysed with All other factors as co-variables
Year of sampling	1.4	1.5
NVC category	17.3	8.9
Botanical diversity	6.0	0.7
Vegetation height	7.1	0.9
Heterogeneity in height	7.2	0.8
Geographical region	11	6.7

assemblages of some semi-improved and improved sites were classified among those from calcicolous grasslands, and are grouped here with the unimproved. This shows leafhoppers responding to site vegetation more than to site management history and supports the usefulness of leafhoppers as indicators while suggesting a degree of success for the agri-environmental schemes in rehabilitating grasslands subjected to restoration management.

Conversely, the leafhopper assemblages of some unimproved sites, with vegetation classified as calcicolous grassland, were classified alongside samples from mesotrophic grasslands; at the second division these tend to be grouped with the samples from improved grasslands rather than those from newly-created grassland, but even then there are exceptions. These are potentially more important examples of leafhoppers acting as indicators of habitat quality; assemblages dominated by *Deltocephalus pulicaris* and *Psammotettix confinis* suggest a loss of conservation value. Insects, responding to vegetation structure and management, can respond to changes in habitat quality more quickly than the vegetation, particularly in calcareous grasslands which tend to be rich in long-lived perennials (Mortimer et al. 1998).

The most interesting findings of this study however, are the high levels of between year consistency shown, and the low explanatory power of year of sampling (Table 3), despite the large between-year differences in species abundance Tables 1 and 2. The changes in abundance of species like *Xanthodelphax straminea*, which did not occur at all on any of the studied sites in one year, but were common during the next are not unprecedented; Rombach (1999) observed differences of up to 98% in abundance of species like *Kelisia guttula* between two successional years. In this study, only a few species remained at roughly the same densities over the course of two successional years. On the other hand, there are examples from calcareous grasslands, which show that the composition (species and dominance structure) of the Auchenorrhyncha fauna can be surprisingly stable over several years, despite severe fluctuations of the abundance of single species (Müller 1978).

Clearly, one would expect some differences between years, even if leafhoppers were perfect indicators, due to differences in weather conditions, variation in management, and the likelihood of stochastic differences between groups of sites in different regions. These could range from minor effects like variation in the timing of grazing to extreme cases such as one of the CS sites, which was ploughed for arable between the sample years (and thus not included in the analysis). Other studies have found that the effect of management is not always consistent however, *Kosswigianella exigua* being observed to decrease greatly in numbers after hay cutting in one year but to increase after the same management in the following year (Rombach 1999). In the event, there was an excellent agreement in the primary separation of semi-natural calcareous grasslands from the other sites in both data sets, and good agreement at the second level of classification. The latter, if not as clear-cut as the initial separation, was none the less explicable in terms of site history, vegetation and locality.

Also interesting is the observation that there is a geographical effect on leafhopper communities, which is not merely auto-correlated with the differences in vegetation type (see Table 3). The reasons for this effect require further analysis.

Conclusion

The very high degree of similarity between the classifications for both sets of sites in different years establishes both the potential of the leafhoppers for use as indicators of habitat condition, and the validity of drawing conclusions from multi-site studies carried out in a single year. It remains true that there are difficulties in applying such tools when so little is known about the individual species involved (McCracken and Bignal 1998). One conclusion might be that data for whole assemblages may be more profitable than the use of single indicator species (see also Nickel and Hildebrandt 2003). However, some specialist species can prove very persistent (Hamilton 2004) and further study to identify such species, even if they are not abundant, would be valuable.

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