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The distribution of grassland Auchenorrhyncha assemblages (Homoptera: Cercopidae, Cicadellidae, Delphacidae) in northern England and Scotland

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Abstract

The distribution of Auchenorrhyncha species assemblages on 174 grassland sites in northern England and Scotland was investigated using ordination and classification techniques. Altitude appeared to be the most important environmental variable influencing assemblage distribution but the effects of altitude on soil type and moisture, and on plant composition, either herbaceous or woody, and structure were likely to have been primary influences. The main differences between sites in the eight habitat groups of the classification were products of these soil and plant variables, with the geographical position of sites in the survey area having less of an effect on site classification. A considerable number of nationally and regionally rare and scarce species were recorded. The results indicate that Auchenorrhyncha could be used in site conservation based on invertebrate species assemblages and rare species distribution but that more information is required to assess both habitat diversity and species rarity. More survey work would also be required to identify appropriate site management procedures for the conservation of Auchenorrhyncha within an overall programme for terrestrial invertebrates.

Introduction

Investigations into the distribution of grassland Auchenorrhyncha range from assessments of large-scale distribution (e.g. Della Giustina & Remane 1999; Grilli & Gorla 1999) through reports on the species of specific sites (Le Quesne & Morris 1971; Hicks & Whitcomb 1996; Peck 1999) to work on the effects of various management practices on species assemblages (Morris 1973, 1975, 1981, 1990). There has been a number of reports of the potential effects of climate change on species distribution in United Kingdom upland sites (Whittaker & Tribe 1996, 1998; Masters *et al.* 1998; Fielding *et al.* 1999).

Novotny (1990) found that Auchenorrhyncha species assemblages were affected by the plant species present and the moisture conditions of the habitat whilst Brown *et al.* (1992) and Hollier *et al.* (1994) reported changes in species assemblages with differences in plant species composition and in vegetation structure. Morris (1992) found fewer species on acid-soil grasslands than on less acid sites whilst Novotny (1994) found more species in ephemeral habitats than on permanent grasslands. On moorland in north-east England the distribution of Auchenorrhyncha species and assemblages were related to the distribution of woody plants, the species richness of grasses and soil acidity (Cherrill & Rushton 1993; Sanderson *et al.* 1995). The species richness of cicadellid species within landscapes was found by Jonsen and Fahring (1997) to be related to the diversity of landcovers with the landscape, the more diverse the landscape the greater the number of species.

Most of the work on the distribution of Auchenorrhyncha species assemblages has been limited to small-scale work with little use of multivariate analyses.

Whilst Cherrill *et al.* (1997) compared classification of species assemblages of Auchenorrhyncha, plant bugs, ground beetles and spiders on a moorland area, there does not appear to have been any classifications of Auchenorrhyncha assemblages covering different land covers over a large area. Work with invertebrate assemblages distributed over large areas has concentrated on ground and water beetles (e.g. Eyre *et al.* 1986, 1993, 2000a; Luff *et al.* 1992; Foster & Eyre 1992). Such work on bugs appears to be limited to aquatic habitats (Eyre & Foster 1989). This paper attempts to classify Auchenorrhyncha assemblages using species lists from 174 sites in northern England and Scotland covering grassland habitats from dunes to moorland. In addition, the influence of a number of environmental factors was investigated and observations on the conservation status of species discussed.

Methods

Sites

Between the years 1993 and 1999 a considerable amount of invertebrate survey work was carried out in northern England and Scotland covering a number of grassland habitat types ranging from coastal dunes to upland moors. Auchenorrhyncha were sampled from 174 sites. Twenty eight sites were located on the north-east England coast and were in a mixture of dune and wet dune slack. There were 35 sites on unmanaged grassland, 34 in northern England and one in Scotland, a number of which were damp or wet, with some shaded to a limited degree by trees and shrubs. There were a total of 42 upland moorland sites, 17 of which were mainly grass moor and 25 were dominated by *Calluna*. Twenty-two of the sites were on post-industrial land, mainly on colliery spoil. The other 47 sites were located on sediments by rivers in five catchments in northern England and Scotland. Twenty-eight sites were in the catchments of the Tyne, Tweed and Nith in lowland regions and 19 by the Carron and Spey in upland Scotland. Most of these sites were open but a number were bounded by trees and shrubs. The distribution of sites in northern England and Scotland is shown in Figure 1.

Sampling

Pitfall traps (8.5 cm diameter, 10 cm deep), part-filled with ethylene glycol, were used at each site. Nine or ten traps were used at each site in either a line or a 3×3 grid at 1 m intervals, as outlined by Luff (1996), and used in other investigations (e.g. Luff *et al.* 1992; Rushton and Eyre 1992). The traps were set in early May of each year and sampling continued until October. Samples from the nine traps in each month were pooled and taken to the laboratory for sorting. Pitfall traps have been used previously to record Auchenorrhyncha species (Le Quesne & Morris 1971; Payne 1982).

In addition, each site was sampled with either a suction apparatus based on a leaf-blower (Stewart & Wright 1995) or by the use of a sweep net. Sweep nets have been a standard method for the sampling of Auchenorrhyncha (Payne 1982) and each site was sampled for 1 min in July or August when the weather was dry. Nomenclature follows Ossiannilsson (1983).

Analyses

Ordination and classification

In order to investigate the variation in the distribution of the Auchenorrhyncha species assemblages, the data were ordinated using detrended correspondence analysis (DECORANA – Hill 1979a). Presence/absence of species was used in the ordination. Classification was carried out using fuzzy set clustering (Bezdek 1981) based on the ordination. This method gives better clustering than TWINSPAN (Hill 1979b) (see Equihua 1989) with a more parsimonious split of the assemblage continuum. The site scores on the first three axes of the ordination were used for the classifications.

In addition to the ordination by DECORANA, constrained ordination (CANOCO – Ter Braak 1987), using four environmental variables, was also carried out. The altitude of each site (as m OD) was taken from 1 : 50 000 Ordnance Survey maps. The position of each site in northern England and Scotland was estimated as a latitude variable. This was based on how far north, in km, each site was from the 100 km National Grid northing 4 (see Figure1). Thus, the nearest site was 27 km north of this line, the furthest 460 km. In addition, two variables known to affect Auchenorrhyncha species assemblages, the amount of woody plant species and site drainage, were estimated. Sites were given categorical variables if there were no woody plants present (1), if woody plants were present but not dominant (2) or if woody plants dominated (3). The main woody plant in the dataset was *Calluna vulgaris*, found on a number of the upland moorland sites. Other lowland sites were shaded by broadleaved trees and shrubs. Drainage was also categorised on a 1–3 scale with sites which were

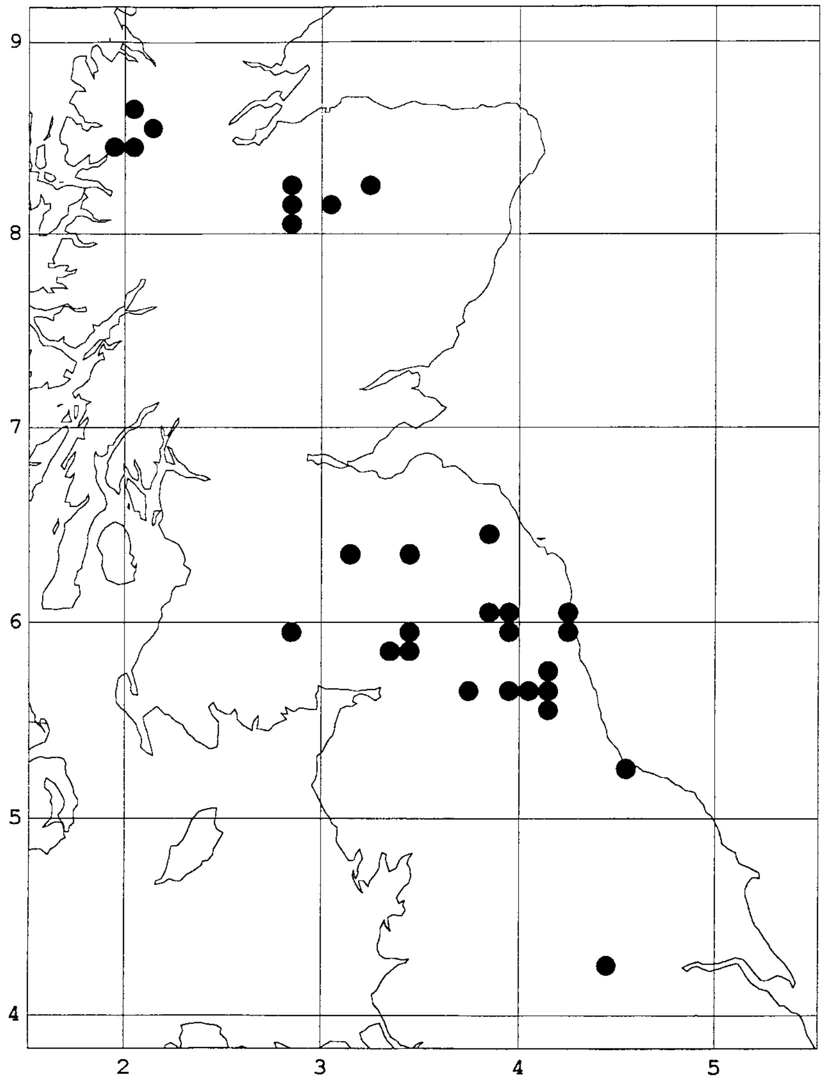

Figure 1. Map showing the distribution of the 10 km national grid squares in northern England and Scotland containing sites in the survey, together with the 100 km National Grid squares and the eastings and the northings.

dry and well-drained all year given 1, sites which were wet in winter but dried in summer 2 and sites which were wet all year 3.

Rarity

Kirby (1992) produced a review outlining the national rarity and scarcity statuses of Hemiptera species, including Auchenorrhyncha, in the United Kingdom. A number of species found in the present survey in northern England and Scotland were nationally rare or scarce and one was new to the United Kingdom. In addition, the information on Auchenorrhyncha species distribution given in Ball (1997) indicates that a number of species were rare in northern England and Scotland. The distribution of these nationally scarce and regionally rare species within the classifications of habitats was assessed.

Results

Ordination

The major variation along axis 1 of the ordination (eigenvalue 0.403) within the dataset was from coastal dune and post-industrial spoil sites at the origin to upland grass moorland sites at the other end. There were obvious differences along axis 1 associated with altitude but there were also large differences in soil moisture on sites. Axis 2 (eigenvalue 0.337) also showed altitudinal variation with *Calluna*-dominated moorland sites near the origin. Sediments by large lowland rivers were at the opposite end of axis 2. The dominant variation along axis 2 appeared to be caused by differences between woody and grassy sites. The sites near the origin of axis 3 (eigenvalue 0.269) were a mixture of dry, open areas found on spoil, dunes and river sediments. At the other end of axis 3 were unmanaged grassland sites which were all near or were shaded by trees and shrubs. The variation along this axis appeared to be a product of site moisture and differences in plant species composition.

Classification

The classification of the 174 sites produced eight groups. The frequency of occurrence of species in each group is shown in Table 1. The groups were:

Group 1 31 sites located on a mixture of post-industrial and dune areas. All the sites were in the south of the survey area, in lowland areas, and all were open, well-drained sand or spoil with sparse, ruderal vegetation and a considerable amount of bare ground. There was a high incidence of *Eupelix cuspidata, Aphrodes makarovi, Neophilaenus lineatus* and the most in any group of *Muirodelphax aubei, Psammotettix frigidus, Megophthalmus scanicus* and *Aphrodes albifrons.*

Group 2 21 sites comprising a mixture similar to that of group 1 with spoil and dune sites with some inland sand and river sediments. These were well-drained, open sites but had denser vegetation than the sites in group 1, although there was some bare ground. Most of these sites were in the lowland south of the survey area but there was one upland and one northern Scottish site. These sites had the most *Euscelis incisus, Agallia brachyptera, Agallia venosus* and *Criomorphus albomarginatus* with a high incidence of *Aphrodes makarovi*.

Group 3 26 sites, a mixture of damp coastal sites, unmanaged grasslands, damp spoil and sediments. These had denser, mainly grassy, vegetation with little bare ground and were on damper soils than sites in groups 1 and 2. Most were again located in the lowland, southern part of the survey area but with three sites in northern Scotland. There was again a high incidence of *Aphrodes makarovi*, with *Macustus griscecens, Aphrodes albifrons* and *Philaenus spumarius* usually present and the most *Aphrodes flavostriatus*.

Group 4 19 sites, again a mixture of unmanaged grassland, coastal and riverside sites. All were damp or wet, had dense grass and some had *Carex*. Most were in northern England with one in northern Scotland and 10 of the sites were in upland areas. *Aphrodes makarovi* was again abundant with a high incidence of *Aphrodes albifrons, Philaenus spumarius* and *Streptanus sordidus* and the most *Arthraldeus pascuellus, Streptanus aemulans* and *Cicadella viridis.*

Group 5 26 mainly upland sites with *Calluna*, with four sites by rivers. Most were located in southern Scotland, with one in northern England and three in northern Scotland. There was a high incidence of *Macustus grisescens, Aphrodes bifasciatus* and *Philaenus spumarius*. This was the only group with *Ulopa reticulata* at most sites and the least *Aphrodes makarovi.*

Group 6 21 sites, most upland grass moor with some riversides in upland catchments. Three sites were in northern England, 11 in southern Scotland and seven in northern Scotland. This group had the *Psammotettix nodosus, Conomelus anceps, Deltocephalus pulicaris, Muellerianella fairmairei* and *Jassargus distinguendus.*

Group 7 13 mainly riverside sites, with one on grassland. These sites were damp with adjacent broadleaved trees. Four were in northern Scotland, six in southern Scotland and three in northern England. This group had the fewest species. *Aphrodes makarovi* and *Philaenus spumarius* had the highest incidence with *Evacanthus interruptus* the only other species occurring in more than half the sites in the group. The presence of *Oncopsis flavicollis* and *Aphrophora alni* indicated that sites were near or shaded by broadleaved trees.

Group 8 17 unmanaged grassland sites in the upland areas but not on moorland. These sites were damp with dense grass. Two sites were in southern Scotland, three in northern Scotland and 12 in northern England. There was a high incidence of lowland grass species (e.g. *Aphrodes makarovi, Arthraldeus pascuellus*) and upland species such as *Jassargus distinguendus, Muellerianella fairmairei and Conomelus anceps*.

Constrained ordination

The distribution of group centroids, with the standard deviations, are shown as crosses on the constrained ordination biplot (Figure 2), with the environmental variables shown as arrows. All four environmental

Table 1. The frequency of occurrence (%) of Auchenorrhyncha species in the eight groups derived from the classification (minimum 20% in one group). Species order is as the first axis of the ordination.

Species	Group							
	1	2	3	4	5	6	7	8
Magamelodes quadrimaculatus	23	—	—	—	—	—	—	—
Doratura stylata	48	24	—	—	—	—	—	—
Muirodelphax aubei	45	—	4	—	—	—	—	—
Eupelix cuspidata	68	43	8	—	4	—	—	—
Aphrodes histrionicus	—	24	—	5	—	—	—	—
Euscelis incisus	45	52	15	—	—	—	—	—
Agallia brachyptera	26	57	23	—	—	—	8	—
Psammotettix frigidus	55	24	12	—	15	5	—	—
Agallia venosus	61	71	31	—	—	10	—	6
Psammotettix confinis	32	—	—	—	—	19	—	6
Megophthalmus scanicus	71	57	50	42	23	5	—	29
Speudotettix subfusculus	—	29	8	—	—	—	—	—
Criomorphus albomarginatus	6	43	23	5	4	10	—	6
Psammotettix nodosus	35	—	4	—	23	43	—	18
Conosanus obsoletus	55	—	27	47	—	29	15	59
Macustus grisescens	55	48	62	47	77	43	8	29
Aphrodes bifasciatus	65	29	35	26	88	52	—	35
Aphrodes makarovi	81	86	96	89	27	43	69	94
Aphrodes albifrons	77	57	62	74	54	57	8	47
Adarrus ocellaris	16	33	12	16	15	19	—	24
Neophilaenus lineatus	81	38	54	58	54	52	31	59
Philaenus spumarius	61	71	73	79	69	48	69	35
Aphrodes flavostriatus	3	33	62	53	—	10	23	24
Evacanthus interruptus	—	19	50	26	—	—	54	—
Arthaldeus pascuellus	10	10	19	68	4	14	31	71
Oncopsis flavicollis	—	10	4	5	—	—	23	—
Ulopa reticulata	—	—	—	—	65	5	—	—
Javesella discolor	—	14	15	11	35	24	31	6
Streptanus aemulans	3	5	46	58	—	14	38	53
Diplocolenus abdominalis	6	5	8	—	—	33	8	59
Streptanus sordidus	6	5	31	84	15	33	31	59
Aphrophora alni	—	—	15	11	—	—	31	—
Cicadula quadrinotata	—	5	12	16	50	24	—	12
Dikraeura variata	6	5	4	16	30	33	—	47
Conomelus anceps	3	—	12	58	19	62	8	53
Streptanus marginatus	3	—	4	—	38	24	—	6
Javesella forcipata	—	—	4	26	—	5	—	12
Mocuellus metrius	—	—	—	5	—	—	31	—
Cicadella viridis	—	—	—	58	12	29	8	35
Eupteryx aurata	—	—	—	—	—	—	31	—
Delphacodes venosus	—	—	—	26	—	—	—	12
Deltocephalus pulicarius	—	—	4	16	8	52	8	47
Muellerianella fairmairei	—	—	8	32	27	57	—	53
Jassargus distinguendus	—	—	—	11	15	71	8	71
Javesella obscurella	—	—	—	11	—	—	23	6
Jassargus sursumflexus	—	—	—	—	31	33	—	—
Balclutha punctata	—	—	—	—	—	10	31	—

variables were related to the positive axis 1, to varying degrees. The variable with most effect was altitude, with drainage and latitude having similar influence; the amount of woody plants was the least important variable. Latitude was the only variable showing a relationship to axis 2, along the positive half, with altitude, drainage and woody plants having little influence along the negative axis.

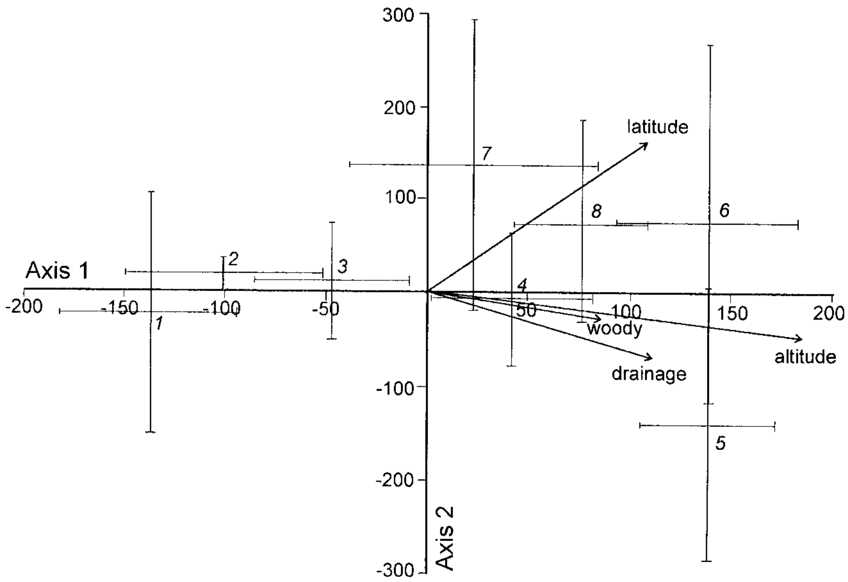

Figure 2. Constrained ordination biplot showing the distribution of the eight group centroids and standard deviations as crosses along axes 1 and 2 with the effects of altitude, drainage, latitude and amount of woody plants variables indicated by arrows.

The distribution of the sites in the eight habitat groups was highly related to axis 1. The lowland sites in groups 1, 2 and 3 were located along the negative axis 1, with the sites in groups 5 and 6, containing the most upland sites, at the extreme of the positive axis 1. Groups 4, 7 and 8, with mixtures of lowland and upland sites, were situated around or near the origin of axis 1. The lowland sites in group 1 were mainly situated along the negative axis 2, with sites in groups 6 and 7, containing a number from the north of Scotland, were furthest along the positive axis 2.

Rarity

The distribution of the nationally scarce and regionally rare species (Kirby 1992; Ball 1997), and one species new to the United Kingdom, within the eight habitat groups of the classification is shown in Table 2. The lowland sites in groups 1, 2 and 3 had most records of these rare and scarce species, with a considerable number recorded from dune and post-industrial spoil sites in northern England. The most frequently recorded species from these sites were *Psammotettix frigidus*, a Nationally Scarce A species and *Agallia brachyptera*, a Nationally Scarce B species. The important records from the upland sites in groups 6 and 8 were for *Elymana koshevnikovi*, a species not previously recorded in the United Kingdom.

Discussion

It was obvious from both ordinations that altitude appeared to be the most important variable affecting the distribution of species assemblages. However, the constrained ordination showed that the other three environmental variables had a similar effect on assemblage distribution as altitude, but to a lesser degree. Site drainage and amount of woody plants were especially related to altitude, with the wettest sites and those with most woody plants, in this case *Calluna vulgaris*, found on upland moorland. The latitude variable was less associated with altitude but the presence of a number of northern Scottish sites in groups 5 and 6 of the classification, with few in groups 1, 2 and 3, indicated that site geographical position had some limited effect on species assemblage distribution.

As with other research on the distribution of Auchenorrhyncha, the results of the ordination and the composition of groups in the classification indicated that the variation within the dataset was mainly a product of site plant composition and structure, allied to differences in soil type and site drainage. Cherrill and Rushton (1993) and Sanderson *et al.* (1995) found that Auchenorrhyncha species assemblages on a northern English moor were related to soil pH and moisture and the relative cover of woody and herbaceous plants. These factors were obviously important in affecting the distribution of upland sites in northern England

Table 2. The number of records of nationally rare and scarce and regionally rare Auchenorrhyncha species (New, New to the United Kingdom; Na, Nationally Scarce A, Nb, Nationally Scarce B; Rr, Regionally rare) in each of the groups of the classification.

Species	Group							
	1	2	3	4	5	6	7	8
Agallia brachyptera Nb	8	12	6	—	—	—	1	—
Allygus modestus Rr	1	—	—	—	—	—	—	—
Cercopis vulnerata Rr	1	3	1	—	—	—	—	—
Cixius cambricus Nb	—	—	—	1	—	—	—	1
Dicranotropis divergens Nb	—	—	—	—	—	1	—	—
Ebarrius cognatus Nb	—	—	—	—	1	—	—	—
Elymana koshevnikovi New	—	—	—	—	—	3	—	3
Eurysa lineata Rr	1	—	—	—	—	—	—	—
Evacanthus acuminatus Rr	—	3	2	—	—	—	1	—
Graphocraerus ventralis Rr	—	—	1	1	—	—	—	—
Macropsis infuscata Rr		—	2	—	—	—	—	—
Macrosteles sordidipennis Nb	—	—	—	—	—	1	—	1
Mocuellus metrius Rr	—	—	—	1	—	—	4	—
Mocydia crocea Rr	1	—	1	1	—	—	—	—
Mocydiopsis parvicauda Rr	5	—	—	—	—	—	—	—
Oncopsis carpini Rr	—	—	—	1	—	—	2	—
Paluda adumbrata Rr	4	1	—	—	—	—	—	—
Psammotettix frigidus Na	17	4	3	—	4	1	—	—
Stenocranus minutus Rr	—	3	2	—	—	—	1	—
Total number of records	38	26	18	5	5	6	9	5

and Scotland. The effect of woody plants was less on lowland sites and soil type and moisture, and plant composition and structure appeared to be the most important factors. Morris (1990, 1992) and Novotny (1994) found that plant composition, especially the types of grasses present, were important determinants of Auchenorrhyncha assemblage composition whilst Brown *et al.* (1992) and Hollier *et al.* (1994) found that vegetation structure was also an important variable. As with the observations on upland sites, Novotny (1990) found that site moisture also had a profound effect on the Auchenorhyncha of lowland grassland sites.

The soil and vegetation variables affecting the distribution of Auchenorrhyncha species assemblages also affect the distribution of other invertebrate groups. Soil moisture is usually the most important variable affecting the distribution of ground beetle species assemblages (e.g. Luff *et al.* 1989, 1992; Eyre 1994) but vegetation structure and management can also influence distribution (Rushton *et al.* 1989, 1990; Eyre *et al.* 1990). The distribution of spider assemblages is primarily affected by vegetation structure (Rushton & Eyre 1992; Downie *et al.* 1995, 1996). Cherrill et al. (1997) found that variation in these soil and plant variables had differing influences on the distribution of Auchenorrhyncha, plant bug, ground beetle and spider assemblages on a moorland in northern England.

Whilst the environmental factors influencing the distribution of a number of invertebrate species assemblages are similar, the effects vary and the number of habitat types on a given area tend to differ. Eyre (1998) reported that there were five ground beetle, four plant bug and three rove beetle and spider assemblages on the same area of moorland in southern Scotland whilst there were only seven spider assemblages in a classification of grassland sites in north-east England where ten ground beetle assemblages were identified (Luff *et al.* 1992; Rushton & Eyre 1992). It is apparent that there is a requirement when considering the conservation of invertebrate habitats to understand that the number of habitat types is not the same for all invertebrate groups and that site management will affect assemblages to varying degrees. Grassland management has a profound effect on the distribution of Auchenorrhyncha assemblages (Morris 1981, 1992) but the influence on other invertebrate groups is unlikely to be the same.

The number of records of nationally and regionally rare and scarce species, including a species not previously found in the UK, indicates that the basic knowledge of Auchenorrhyncha species distribution is inadequate. This survey work carried out in northern England and Scotland was not designed to find rare species and the results indicate that the rarity and scarcity statuses (Kirby 1992; Ball 1997) of some species are inaccurate. This problem has been highlighted a number of times with beetles in the UK (e.g. Eyre 1998; Eyre *et al.* 1998, 2000b), which has consequences since invertebrate conservation, especially Biodiversity Action Plans (Department of Environment 1995; UK Biodiversity Group 1999), are based on this inadequate baseline distribution knowledge. The identification of invertebrate habitats based on invertebrate survey work (e.g. Foster & Eyre 1992; Rushton & Eyre 1992; Eyre *et al.* 2000a) may provide a better basis for invertebrate conservation than concentrating on a list of rare species, some of which are neither rare nor declining (Eyre *et al.* 2000b).

This paper indicates that an approach based on survey work incorporating the recording of Auchenorrhyncha, along with other groups such as ground beetles and spiders, could be utilised to identify sites for conservation based on invertebrates. However, the input of Auchenorrhyncha into the conservation process is going to be severely limited because coverage of habitat types is still inadequate and because there is an insufficient knowledge of species distribution, and therefore of species rarity. Considerably more survey work covering all relevant habitat types will also be required to identify which site management procedures are applicable for the maintenance of both Auchenorrhyncha habitat diversity and of rare species, in the context of conservation programmes incorporating other invertebrate assemblages and species.

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