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Biodiversity on urban roundabouts—Hemiptera, management and the species–area relationship

Alvin J. Helden[a,*], Simon R. Leather[b]

[a]*Department of Environmental Resource Management, Faculty of Agriculture, University College Dublin, Belfield, Dublin 4, Ireland*
[b]*Department of Biological Sciences, Imperial College London, Ascot, UK*

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Summary

The biodiversity of insects within urban areas has been relatively little studied. Given the large and ever increasing extent of urban areas, and that the insect species richness there can be high, it is important to know the factors determining that aspect of biodiversity. In this study two of these factors, namely habitat management and area, were considered. Arboreal and grassland Hemiptera, and grassland plants, were sampled on 18 roundabouts and other road enclosed sites in the town of Bracknell. Hemiptera were sampled using suction sampling and tree beating. A significant species–area relationship was found for arboreal Hemiptera, which was strongly related to habitat diversity. For both grassland plants and Hemiptera, grassland management, by mowing, had a significant effect on species richness. Despite the management grassland plants showed a significant species–area relationship. However the effect of management on Hemiptera was great enough to outweigh any area effect. As the size of open spaces is often constrained in urban areas, altering habitat management has a greater potential for enhancing biodiversity. For arboreal Hemiptera choice of trees for planting is of particular importance, while for grassland Hemiptera diversity would be increased with a reduction in the intensity of management, such a reduction in the frequency of mowing.

Zusammenfassung

Die Biodiversität der Insekten auf urbanen Flächen ist relativ wenig untersucht. Angesichts der großen und der immer größer werdenden Ausdehnung urbaner Gebiete und angesichts dessen, dass der Artenreichtum der Insekten dort groß sein kann, ist es wichtig die Faktoren zu kennen, die diesen Aspekt der Biodiversität bestimmen. In dieser Untersuchung wurden zwei dieser Faktoren, nämlich Habitatmanagement und

*Corresponding author. Tel.: +353-1-7167119; fax: +353-1-7161102.
E-mail address: alvin.helden@ucd.ie (A.J. Helden).

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Fläche, betrachtet. Baum- und wiesenbewohnende Hemiptera sowie Wiesenpflanzen wurden in 18 Kreisverkehren und anderen straßenumschlossenen Orten innerhalb der Stadt Bracknell gesammelt. Die Hemiptera wurden mit Saugproben und Klopfproben an den Bäumen gesammelt. Für die baumbewohnenden Hemiptera wurde eine signifikante Art-Areal-Beziehung gefunden, die in enger Beziehung zur Habitatdiversität stand. Sowohl für die Wiesenpflanzen als auch für die Hemiptera hatte das Wiesenmanagement in Form von Mahd einen signifikanten Einfluss auf den Artenreichtum. Trotz des Managements zeigten die Wiesenpflanzen eine signifikante Art-Areal-Beziehung. Die Auswirkungen des Managements auf die Hemiptera waren jedoch groß genug, um den Arealeffekt zu überwiegen. Da die Größe offener Flächen in städtischen Gebieten oft beschränkt ist, hat die Änderung des Habitatmanagements ein größeres Potenzial die Biodiversität zu erhöhen. Für baumbewohnende Hemiptera ist die Auswahl der Bäume für die Bepflanzung von besonderer Wichtigkeit, während für die wiesenbewohnenden Hemiptera die Diversität durch eine Verringerung der Managementintensität erhöht würde, wie z. B. durch die Verringerung der Mahdfrequenz.

Introduction

With the exception of work on synanthropic pest species, the study of insects and other arthropods within urban environments has been a relatively neglected area of study, despite the large and ever increasing size of such areas (McIntyre, 2000; McIntyre, Rango, Fagan, & Faeth, 2001). However those studies that have been published have reported that considerable insect biodiversity exists within towns and cities, including a number of rare and notable species (Chudzicka, 1986; Zapparoli, 1997; McIntyre, 2000; Hostetler & McIntyre, 2001; Jones, 2003). Consequently it is important that consideration is given to the factors, which influence biodiversity within urban areas, particularly as this knowledge has the potential to modify management and planning practices, which would be beneficial to the enhancement of biodiversity.

Many factors have been suggested as important in determining the relative species richness of different urban habitats and habitat patches. These include the level of isolation and fragmentation, management practices, disturbance, and habitat type, age, area, diversity and connectivity, as well as the characteristics, such as relative mobility, of different taxonomic groups (Davis & Glick, 1978; Zapparoli, 1997; Denys & Schmidt, 1998; Fernández-Juricic, 2000; McIntyre, 2000; Savard, Clergeau, & Mennechez, 2000; Ganzhorn & Eisenbeiß, 2001; Hostetler & McIntyre, 2001; Rudd, Vala, & Schaefer, 2002; Whitmore, Crouch, & Slotow, 2002; Weller & Ganzhorn, 2004).

In this study the species richness of Hemiptera was investigated in relation to both habitat management and area. Habitat management has long been recognized as having a major effect on grassland Hemiptera communities (Morris, 2000). Both cutting and grazing, have been found to reduce overall abundance and species richness because they reduce vegetation height and structural complexity of the grassland, thus reducing the stratification that is so important in determining species diversity (Andrzejewska, 1965; Waloff & Solomon, 1973; Denno, 1977; Morris, 1979; Morris & Lakhani, 1979; Prestidge, 1982; Sedlacek, Barrett, & Shaw, 1988; Brown, Gibson, & Kathirithamby, 1992; Dennis, Young, & Gordon, 1998; Morris, 2000).

In urban areas grasslands are frequently under relatively intensive management, principally through mowing, which may be repeated at regular intervals throughout the growing season. In contrast, arboreal habitats are much less frequently or catastrophically managed. Management of arboreal habitats is likely to be restricted to tree planting, pruning and felling. In established habitats not undergoing development or other land use changes, felling is relatively uncommon, and pruning, in most cases, does little to alter habitat structure. Tree planting can be quite frequent and as such may be the most important form of arboreal habitat management in the short term. Thus there appears to be a contrast between grassland management with its dramatic alteration to the physical structure of grasslands, and consequent strong influence on Hemiptera populations, and the probably relatively small effect of management on arboreal Hemiptera communities.

Area has been related to biodiversity principally through the species–area relationship. The species–area relationship is a very frequently described pattern in which species richness increases with area (Lomolino, 2001). Such patterns have been found not only on oceanic and other very clearly delimited areas, but also terrestrial habitat patches and even using non isolated quadrats (Denno & Roderick, 1991; Crawley & Harral, 2001). This pattern has been recognized for a long time (Arrhenius, 1921) and much effort has been put to describing species–area relationships mathematically as well as proposing possible mechanisms that may give rise to them (MacArthur & Wilson, 1967; Connor & McCoy, 1979; McGuinness, 1984; Hill, Curran, & Foody, 1994; Lomolino, 2001).

In the work described here the interaction of area and habitat management was studied by looking for species–area relationships in two groups of Hemiptera, arboreal and grassland, as well as grassland plants. Of the very many previous studies of the species–area relationship, very few have been carried out in urban areas. Those that were, have mostly concerned areas such as parks or semi-natural fragments of habitats such as woodland (e.g. Faeth & Kane, 1978; Miyashita, Shinkai, & Chida, 1998; Fernández-Juricic, 2000). However urban areas contain many other open areas, which are potentially important reservoirs of urban biodiversity, including road verges, roundabouts and other road delimited areas. Whitmore et al. (2002) looked at road islands without finding significant species–area relationships. In the work presented here, roundabouts within the town of Bracknell, in south east England, were used to investigate both whether significant species–area relationships can be found in urban areas using relatively small road delimited sites, and whether two groups of Hemiptera exposed to contrasting management intensity showed differences in those species–area relationships.

Materials and methods

Study sites

The study was carried out within Bracknell, which is a town located in southeast England between latitude 51°23′ and 51°26′N, and longitude 0°43′ and 0°47′W. The 18 study sites were a series of 14 roundabouts and four other road enclosed sites. Further details of the names and locations of the sites are given in Table 1.

Site mapping

The area of the study sites (Table 1) was determined by using an aerial photograph of Bracknell, which enabled not only the total area to be assessed but also the area of different sections within each site, such as the area of grassland or pathways.

Each site was divided visually into northwest, northeast, southeast, and southwest sections. Different sections formed a basic framework for the insect and plant sampling procedures and were used in order to take account of possible topographical spatial variation, which can have a considerable effect on insect communities (Morris, 2000).

In each section a transect line over the grassland area was identified and measured, and these formed the basis for subsequent sampling patterns. On four sites, 4, 5, 7 and 11, two transect lines were measured per section, one for each of the two different management regimes present at these sites.

Land use estimation

In order to enable an assessment of whether the land use surrounding the sites affected Hemiptera species richness and abundance, an estimate was made of the relative area of land under the following categories: buildings, roads and railways, gardens, open space, woodland and open water. Using a 1:25 000 scale map (Ordnance Survey, Explorer series, map number 160), the land use was recorded every 1 mm on the map for 4 cm, equivalent to 1 km, along a north, east, south and west transect from each of the 18 sites. A figure of percentage open area was then calculated as the relative area covered by gardens, open space and woodland around each site. This data was arcsin transformed prior to use in the analysis.

Sampling grassland plant diversity

Grassland plant diversity was assessed by recording the number of species found within a 25 × 25 cm quadrat, placed randomly at five positions on each transect line. As well as the number of species per quadrat the total number of species per site was recorded. The number of individual plants was not recorded.

Recording tree species

At all the sites with the exception of 7 and 11 the location and species was recorded for all trees that were accessible for insect sampling. At sites 7 and 11 there were large blocks of wooded land, and so to enable better comparison with other sites only trees bordering the edge of grassland were recorded.

Table 1. Details of the names, locations, area and grassland management of the sample sites

Site number	Local name	Total area (m^2)	Area of grassland (m^2)	Grassland management regime	
				Cutting frequency (days)	Herbicide[a]
1	Baldocks roundabout	401	401	14	No
2	Running horse roundabout	1962	1581	40	No
3	Eastern road roundabout	1800	1397	7	Yes
4	Meteorological office roundabout	6275	5667	14	No
				40	No
5	Bracknell station roundabout	5198	2277	14	No
				40	No
6	Broad lane roundabout	4132	4132	7	Yes
7	Bill hill	43 574	13 029	14	No
				Not cut	—
8	Bracknell sports centre roundabout	3866	2115	7	Yes
9	Hanworth roundabout	2165	2165	14	No
10	Mill pond roundabout	2050	2050	14	No
11	Mill pond park	63 681	26 109	7	No
				Not cut	—
12	Mill lane slip road	7118	7118	[b]	No
13	Downshire way	4340	2113	Not cut	—
14	Twin bridges roundabout south	3268	2774	14	No
15	Twin bridges roundabout north	2144	1419	40	No
16	The point roundabout	489	356	7	Yes
17	3 M roundabout	5016	3963	14	No
18	Arlington roundabout	1280	931	14	No

[a]Supertox', which contains Mecoprop & 2,4-D.
[b]Cut once/year.

Sampling insects

The aim of this study was not to fully describe Hemiptera community structure, but to investigate inter-site differences in species richness that would enable the investigation of possible species–area relationships, and that would provide insight into the influence of management practices. Given that the nature of the study was essentially comparative it was not considered necessary to take multiple samples over time, although such an extended approach would have indeed provided much additional insight.

Grassland Hemiptera were sampled, between 15th and 17th July 2002, using a Vortis Insect Suction Sampler (Burkard Manufacturing Co Ltd, Rickmansworth, Hertfordshire, UK). A five second sample was taken at ten randomly chosen points on each of transect at each site, and the total catch from a single transect was retained as one overall sample. This gave a total area sampled per transect as 0.20 m^2. In those sites where there was a single grassland management regime, four transects were sampled, but if there were two areas of differing management, four transects were sampled for each area. Data were later randomly corrected to remove the effect of unequal area during the statistical analysis of species–area relationships, such that where there were areas of two different management regimes, two samples were randomly selected from each.

The insects collected were transferred to clear plastic bags and stored at −18 °C. Subsequently the Hemiptera from each overall sample were separated and identified. Due to the small number of species and individuals collected from many of the grassland areas, nymphs were counted and as they could not in most cases be specifically identified, their family or sub-family was recorded. The data for these immature forms was used in analyses of individual-area relationships but not species–area relationships.

Arboreal insect sampling was carried out between 13th and 20th July 2002, by vigorously beating part of the tree for 5 s above a sweep net (45 × 60 cm) and then collecting the adult Hemiptera from the net with a pooter. The insects were subsequently kept in at −18 °C prior to identification.

One tree of each species present was randomly selected for sampling within each of the four sections of each site. Thus if a tree species was present in all sections four individuals were sampled. In order to reduce the problem of the sampling effect during the analysis of species–area relationships, the data was randomly corrected such that only the numbers of species and individuals from one tree of each tree species per site was used in the analysis.

Wherever it was possible to sample more than one part of a tree, the side of the tree to be sampled was randomly determined.

Sampling

Statistical analysis

Statistical analysis was carried out using the *R* statistical package (version 1.4.0) (Ihaka & Gentleman, 1996). Details of the analyses used are given in the results section. In all cases in which log values were used, one was added to the data prior to the log transformation.

Results

Species recorded

In total 561 individuals of 71 arboreal species, and 579 individuals of 43 grassland species of Hemiptera were recorded (Table 2), with only four species collected during both tree and grassland sampling. A summary of the number of species of trees and grassland plants is given in Table 2.

Species–area relationships: arboreal Hemiptera

There was a significant species–area relationship between the log species richness of arboreal Hemiptera and log area ($F_{1,15} = 11.62$, $p<0.01$, $r^2 = 0.44$) (Fig. 1).

Multiple regression, using log area, the log number of tree species, the log number of sampleable trees and the arcsin percentage open area as explanatory variables, was used to investigate possible reasons for the species–area relationship. The regression was highly significant ($F_{2,14} = 96.95$, $p<0.001$, $r^2 = 0.93$) but log area was not significant itself ($t = 0.94$, d.f.=13). Log number of trees species was significant ($t = 5.20$, $p<0.001$), and therefore the most appropriate model is the regression between log number of arboreal Hemiptera species and log number of tree species, which was highly significant ($F_{1,15} = 131.94$, $p<0.001$, $r^2 = 0.90$) (Fig. 2). As number of tree species determined the number of Hemiptera species

Table 2. The number of species and individuals of Hemiptera recorded overall, and from tree and grassland sampling. Data were randomly corrected to include insects from four grassland transects and from one tree for each tree species, for each study site

Taxon	Species richness or abundance	Site 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
Trees	Species richness	0	2	2	13	12	20	27	12	5	6	28	1	12	2	8	1	6	3	48
	Abundance	0	9	3	76	53	53	248	56	8	28	410	17	102	15	23	5	31	14	1151
Grassland Plants	Species richness	14	25	18	33	35	14	31	22	23	21	40	36	25	30	30	10	27	12	—
	Mean species/quadrat	2.3	4.7	4.5	5.7	7.7	4.0	7.4	5.0	5.2	6.6	7.4	6.3	6.2	5.5	8.0	3.8	6.8	4.1	—
	SD	2.1	2.2	4.4	5.0	2.6	1.6	3.2	1.5	1.5	1.9	2.5	2.6	1.8	2.1	3.0	1.1	2.1	1.1	—
Arboreal Hemiptera	Species richness	0	2	3	10	14	12	28	12	7	10	32	0	12	2	9	0	9	2	71
	Abundance	0	2	7	17	31	84	80	32	37	11	127	0	70	2	28	0	31	2	561
Grassland Hemiptera	Species richness	6	17	1	15	5	3	10	2	4	7	13	14	16	10	2	0	5	4	43
	Abundance	10	91	1	57	10	3	64	5	7	31	46	37	149	51	3	0	8	6	579

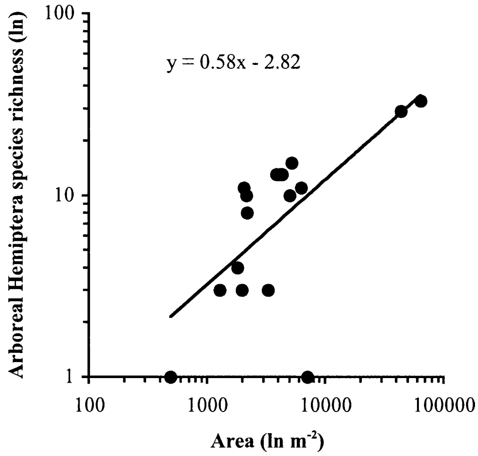

Figure 1. The species–area relationship for arboreal Hemiptera, using log species richness and log area ($r^2 = 0.44$, $a = -2.82 \pm 1.42$ (SE), $b = 0.58 \pm 0.17$).

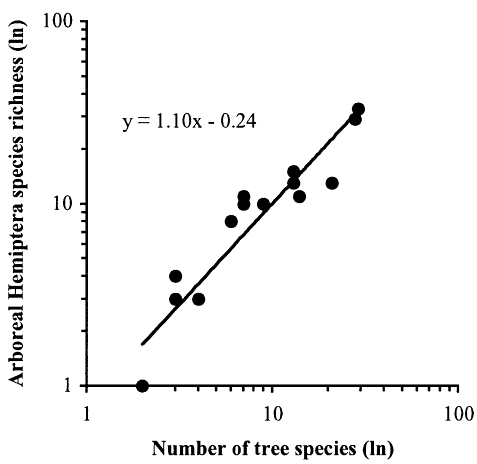

Figure 2. The relationship between log number of Hemiptera species on trees and log number of tree species ($r^2 = 0.90$, $a = -0.24 \pm 0.21$ (SE), $b = 1.10 \pm 0.10$).

rather than area itself, a regression was carried out between log area and log number of tree species, and a significant relationship was found ($F_{1,15} = 15.01$, $p<0.01$, $r^2 = 0.50$, $y = 0.53x - 2.39$, $a = -2.39 \pm 1.14$ (SE), $b = 0.53 \pm 0.14$).

Species–area relationships: grassland Hemiptera

For all grassland analyses the area of grassland on each site was used rather than total area.

There was a significant regression between log number of species and log area ($F_{1,16} = 7.80$, $p<0.05$). However this model was very dependent on the data point for site 16, where no species were recorded. When this data point was removed there was no significant relationship ($F_{1,15} = 3.37$).

Due to the grasslands of the 18 sites having different management regimes, and because there was some ambiguity with regard to the possibility of a species–area relationship, analysis of covariance was used with four categories of management: A, mowed every 7 days; B, mowed every 14 days; C, all or part of the site mowed every 40 days; and D, all or some of the site mowed once or less per year. This confirmed that neither area or log area were significant with regard to species ($t = -0.003$ and $t = -0.18$, respectively, both with d.f.=2). The log number of species of grassland plant, the log of the mean number of plant species

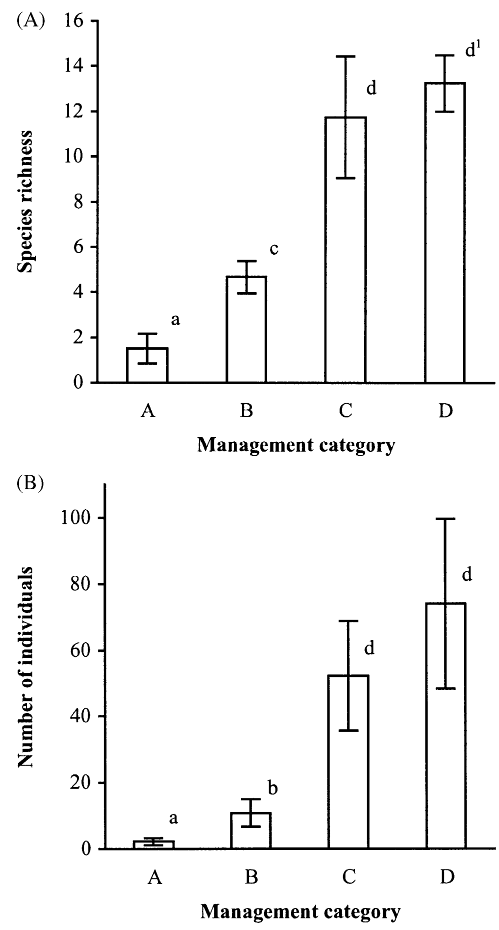

Figure 3. The mean (±SE) (A) species richness and (B) number of grassland Hemiptera individuals, at sites with the four management categories of grassland management (A, mowed every 7 days; B, mowed every 14 days; C, mowed every 40 days; D, mowed once or less per year). Letters above bars indicate significance of analysis of variance contrasts: same letter, not significant; letters differ by one, $p<0.05$; letters differ by two, $p<0.01$; letters differ by three $p<0.001$. ([1]contrast for species richness between categories B and D were significant at the $p<0.01$ level).

per quadrat, and the arcsin percentage open area, were also included in the analyses and were non significant. The only significant factor was found to be mowing regime (analysis of variance, $F_{3,14} = 16.06$, $p<0.001$).

Analysis of variance contrasts (Fig. 3A) were used to compare the mean log number of species found at sites with the four categories of management regime. All comparisons were significant apart from between categories C and D, with the mean number of species being lowest for category A and highest for categories C and D (Fig. 3A).

Four of the sites investigated had a mixture of management regimes, with some areas mowed every 40 days or less frequently, and other areas with more regular management. Log transformed species richness was used in a nested analysis of variance, which showed that there was a significant difference between the management types within roundabouts ($F_{4,8} = 13.69$, $p<0.01$), with more species found in the less frequently mowed areas.

Species–area relationships: grassland plants

Grassland plants showed a significant species–area relationship between log number of species and log area ($F_{1,16} = 20.54$, $p<0.001$, $r^2 = 0.56$) (Fig. 4).

Analysis of covariance performed using log area and the four management categories, was highly significant ($F_{4,13} = 10.36$, $p<0.001$, $r^2 = 0.76$), and showed that both log area and management had significant effects (analysis of variance: area $F_{3,13} = 10.32$, $p<0.001$; management $F_{1,13} = 10.50$, $p<0.01$). Arcsin percentage open area was also included in the analyses but was not significant.

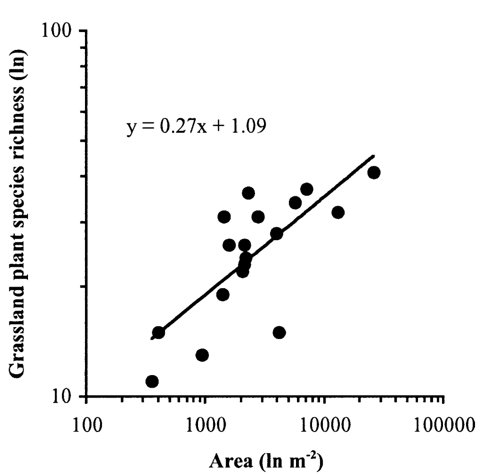

Figure 4. The species–area relationship between log number of grassland plant species and log area (r^2=0.56, a=1.09$\pm$0.47 (SE), b=0.27$\pm$0.06).

Individuals–area relationships: arboreal Hemiptera

There was a significant individuals–area relationship for arboreal Hemiptera, using log abundance and log area ($F_{1,15} = 8.55$, $p<0.05$, $r^2 = 0.36$, $a = -3.90 \pm 2.28$ (SE), $b = 0.80 \pm 0.27$).

Possible explanatory factors for the individuals–area relationship were explored with multiple regression using the log number of tree species, the log number of sampleable trees, log area and arcsin percentage open area. Log area was not significant ($t = 1.14$, d.f.=13). Once log area had been removed from the model both the log number of tree species and log number of trees were significant factors ($t = 6.89$, $p<0.001$ and $t = -2.30$, $p<0.05$, respectively, both with d.f.=14). The overall multiple regression was highly significant ($F_{2,14} = 59.11$, $p<0.001$, $r^2 = 0.89$) and was described by the equation:

$$y = -0.07 + 2.33x - 0.54z,$$

where y is log number of individuals, x is the log number of tree species, and z is equal to the log number of trees.

The relationship between the log number of tree species and log area has already been described. The multiple regression indicated that log number of trees was also a significant factor, and so its relationship with log area was explored, and this was found to be significant ($F_{1,15} = 41.59$, $p<0.001$, $r^2 = 0.74$, $y = 0.92x - 4.15$, $a = -4.15 \pm 1.19$, $b = 0.92 \pm 0.14$). There was also a significant regression between the log number of tree species and log number of trees ($F_{1,15} = 57.20$, $p<0.001$, $r^2 = 0.79$, $y = 0.62x - 0.15$, $a = -0.15 \pm 0.30$, $b = 0.62 \pm 0.08$).

Individuals–area relationships: grassland Hemiptera

There was a significant regression between log area and log number of individuals when all the sites were included ($F_{1,16} = 6.45$, $p<0.05$, $r^2 = 0.29$), but not when site 16 was excluded ($F_{1,15} = 3.00$, ns).

Analyses of covariance were carried out using the four management categories, either log number of plant species or log of the mean number of plant species per quadrat, log area and arcsin percentage open area. Mowing was the only factor found to be significant (analysis of variance, $F_{3,14} = 15.46$, $p<0.001$, $r^2 = 0.78$), and analysis of variance contrasts indicated that the lowest number of individuals were recorded at sites in management category A, with the highest numbers being found at sites of category C and D, between which there was no significant difference (Fig. 3B).

A nested analysis of variance was used to compare management regime within roundabouts, which showed that less frequently managed grassland had greater numbers of individuals ($F_{4,8} = 8.50$, $p < 0.01$).

Discussion

Species–area relationships

The arboreal Hemiptera showed a significant species–area relationship, which was found to be the result of the increasing number of tree species, which was correlated with area. The arboreal Hemiptera show a high degree of host plant specialization, with many monophagous or oligophagous species, and consequently each tree species represents a different habitat with its own particular associated insect species (Southwood & Leston, 1959; Southwood, 1961; Le Quesne, 1965; Le Quesne & Payne, 1981; Hodkinson & White, 1979; Kennedy & Southwood, 1984). The combination of host specificity and host diversity is likely to provide a very strong influence on site specific species richness. Thus the results are consistent with the habitat diversity hypothesis, as an explanation for the significant species–area relationship found (McGuinness, 1984; Hill et al., 1994; Lomolino, 2001). The habitat diversity hypothesis suggests that larger areas contain a larger number of habitats, each of which will support different species, and therefore a greater total species richness.

One further aspect of habitat diversity that may have influenced species richness is tree age and height, as larger trees may support more species than smaller individuals (Lawton, 1983). Consequently sites with more mature trees may support more species of Hemiptera. However given the very large variation in the number of insect species associated with different trees species (Kennedy & Southwood, 1984), and that small trees can still support a large number of species, it is probable that the number of tree species at a site is a much more important factor.

Grassland Hemiptera species richness was found not to be related to area, and the only factor found to significantly affect species richness was the management regime. For the analysis the 18 sites were placed in one of four categories of management according to the frequency of grass cutting: A, every 7 days; B, every 14 days; C, every 40 days; and D, once or less per year. The species richness was greatest in categories C and D, lower for category B, and the lowest for category A. It is possible that the very low number of species found in areas mowed every 7 days may in part be due to the use of a herbicide, which was not used with other mowing regimes, but very few species were still recorded on the one site mowed every 7 days where herbicide was not used. Even if herbicide use did have an influence, it is clear from the comparison of sites mowed every 14 days with those less frequently cut, that management regime has a major impact on the species richness of the grasslands studied.

These findings are consistent with previous work, which has found that grassland management results in a reduction in the species richness and abundance of Hemiptera (Morris, 1979, Morris & Lakhani, 1979, Brown et al., 1992; Dennis et al., 1998; Morris, 2000). The principal reason for the negative effect of cutting on Hemiptera species richness is the reduction in the height and structural complexity of the vegetation. Tall, more structurally complex grasslands have higher species diversity because they provide a greater level of heterogeneity in terms of feeding and oviposition sites, refuges and microclimatic conditions (Andrzejewska, 1965; Waloff & Solomon, 1973; Denno, 1977; Prestidge, 1982).

The frequency of cutting at the 18 sites strongly influenced the grassland structure, with those areas cut every 7 days, and 14 days being maintained in a permanent lawn like state. Areas cut every 40 days were allowed to grow in the intervening periods, during which time grass length became tall, enabling many species to flower before being cut again. Thus, over time, areas cut once or less annually or only every 40 days, had considerable vegetational complexity for at least some part of the study period, which contrasted with the continuous and very low level of complexity of more frequently cut grasslands.

Although the areas cut every 40 days, particularly at site 2, as well as previous studies, have demonstrated that a relatively species rich Hemiptera fauna can be maintained with regular cutting, any level of annual or more frequent management leads to a reduction in Hemiptera abundance and species richness (Morris, 2000). In order to maintain the maximum level of species richness at a given site, cutting should either be limited to cutting once in a year and then not repeated annually, or a system of rotational management should be used, when different areas of a single site have different management regimes, and which has been suggested as the best strategy (Morris, 1979; Morris & Lakhani, 1979; Morris & Plant, 1983; Morris & Rispin, 1987; Morris, 2000).

The lack of a species–area relationship with grassland Hemiptera and the importance of habitat structure, in this case determined by the frequency of cutting, are consistent with the small island effect: a pattern in which significant species–area relationships do not occur for smaller islands due to local stochastic factors being more important than area related factors (Lomolino, 2000, 2001; Lomolino & Weiser, 2001). In contrast, the grassland plants did show a significant species–area relationship, with the analysis indicating that as well as an effect of area, the management regime was important in determining species richness. This contrast in results was despite the fact that the same grassland areas were sampled for both groups, so habitat diversity and management practices were the same, and that in both cases the sampling effect had been controlled for by holding area sampled constant between sites. The results from these two taxa indicate that in each case the balance between localized factors responsible for the small island effect and area related factors may be different. In the grassland Hemiptera the influence of management processes is high and appears to over-ride any processes that may give rise to a species–area relationship. In contrast management seems less important for grassland plants and does not outweigh area related factors, resulting in a significant species–area relationship. Grassland plants may be less affected than Hemiptera by cutting because, at least in the short term, it does not reduce species richness directly, just shortens the height of the vegetation, and also maintains the sward at an earlier stage of successional development, which may help to maintain plant species diversity (Southwood, Brown, & Reader, 1979; Lawton, 1983).

The results from the arboreal Hemiptera indicate a further pattern in which management is very limited but in which habitat diversity, arising from tree species diversity and Hemiptera host plant specificity, is the dominant factor, and which gives rise to a significant species–area relationship.

Individuals–area relationships

The results showed a similar pattern for individuals–area relationships as they did for species–area, with a significant regression for the arboreal Hemiptera but not for grassland Hemiptera, which were only significantly affected by management. Management affects the abundance of grassland insects in the same way as it does species richness (Morris, 1979; Morris & Lakhani, 1979; Brown et al., 1992; Dennis et al., 1998; Morris, 2000).

Analysis of the arboreal fauna individuals–area relationship indicated that both the number of trees as well as the number of species of tree were important. The influence of the number of tree species was probably the result of sampling because as the data from one tree of each species was used in the analysis, the more tree species present the more trees were sampled and therefore the more individuals collected. The significant effect of an increased number of trees may reflect higher population densities being present on sites with more trees. Previous studies however, have found no evidence for a rise in population density with area size for whole faunas (Connor, Courtney, & Yoder, 2000), and as the number of trees could be considered to be equivalent to area and as the numbers of trees and tree species were strongly correlated, it is quite possible that the effect of the number of trees is also a sampling effect.

Conclusions

This study has implications for the conservation and enhancement of urban biodiversity. It has demonstrated that given sympathetic management, small areas of urban grassland can support abundant and species rich Hemiptera communities. The road delimited areas studied are generally of fixed dimension and location, and therefore species richness cannot be enhanced by enlarging their area or increasing connectivity. However they have considerable potential to be altered in terms of their vegetational structure, through various management approaches. For arboreal Hemiptera species richness would be enhanced by planting many different tree species, and by avoiding tree species that are particularly poor for insects, which in many cases are non native (Southwood, 1961; Kennedy & Southwood, 1984). Grassland Hemiptera species richness would benefit from approaches such as a reduction in the frequency of grass cutting and the establishment of a system of rotational management, with different areas being cut a different times and frequencies (Morris, 1979, 1981; Morris & Plant, 1983; Morris & Rispin, 1987).

This study has also shown that it is possible to find significant species–area relationships using small road delimited ecological islands within urban areas. In a previous study, Whitmore et al. (2002)

were not able to find such significant relationships, and it is possible this may have been related to the small island effect, in which local stochastic factors are more important than area related factors in determining species richness. In the study presented here the three groups, sampled from the same sites, demonstrated quite different patterns of species richness relative to area. For the arboreal Hemiptera species richness was strongly related to habitat diversity, which was also correlated with area, thus generating a significant species–area relationship, and there was little evidence for local factors such as management practices. In contrast, for the two grassland taxa there was little indication of any habitat diversity effect, but for both, management was a significant determinant of species richness. In the case of the grassland plants, the effect of management, while significant, did not appear great enough to prevent a significant species area effect. However in the grassland Hemiptera, which are very strongly affected by grassland structure, management appeared to be a great enough influence on species richness to prevent a species–area relationship: an outcome consistent with the small island effect.

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