Zoosymposia 12: 051–063 (2018)
http://www.mapress.com/j/zs/

ISSN 1178-9905 (print edition)
ZOOSYMPOSIA
ISSN 1178-9913 (online edition)

http://dx.doi.org/10.11646/zoosymposia.12.1.6
http://zoobank.org/urn:lsid:zoobank.org:pub:00B704AE-241A-49C8-B730-A61D6B1C6818

WHAT CAN WE DO FOR URBAN INSECT BIODIVERSITY? APPLYING LESSONS FROM ECOLOGICAL RESEARCH

ALVIN J. HELDEN[1], GEOFFREY J. MORLEY[2,3], GABRIELLE L. DAVIDSON[2,4] & EDGAR C. TURNER[2,5]

[1]*Applied Ecology Research Group, Department of Life Sciences, Anglia Ruskin University, East Road, Cambridge, CB1 1PT, UK.*
[2]*Institute of Continuing Education, University of Cambridge, Madingley Hall, Madingley, Cambridge, CB23 8AQ, UK.*
[3]*Estates and Facilities, Anglia Ruskin University, East Road, Cambridge, CB1 1PT, UK.*
[4]*School of Biological, Earth and Environmental Sciences, University College Cork, Cork, Ireland.*
[5]*Insect Ecology Group, University Museum of Zoology, Cambridge, Downing Street, Cambridge, CB2 3EJ.*
Corresponding author: Alvin Helden e-mail: alvin.helden@anglia.ac.uk

Abstract

Urban ecosystems are not unique, as the ecological processes and anthropological effects they encapsulate can equally be found in a range of human dominated environments. Applying ecological lessons from both within and outside urban areas is important for insect conservation within our expanding towns and cities. The management of urban grasslands, which in many cases is controlled by private individual and corporate landowners, has the potential to make a large difference to the biodiversity they support. Here we report on an investigation of invertebrate biodiversity within a series of small urban grasslands with contrasting frequency of management by mowing. Seven gardens and five other grassland areas were suction sampled for grassland invertebrates in July 2016. Samples were taken in patches that were regularly cut on a 7-14 day cycle (very short), those cut every six weeks (short) and those than had not been cut since the previous year (long). Invertebrates were mostly identified to order level, with the Hemiptera to species or morphospecies. Invertebrate abundance was significantly inversely related to mowing frequency but overall species richness did not differ between short and very short grasslands. Community structure also was most distinct in the long grasslands. The pattern of abundance varied between different taxonomic groups, with the Hemiptera particularly benefiting from very low levels of management. The value to invertebrates, especially Hemiptera, of reduced grassland management is discussed, with reference to how the owners of gardens and other urban grassy areas can make simple changes to benefit biodiversity on their land.

Introduction

Historically in urban areas, insects and other invertebrates were considered mostly in relation to their pest status (Davis 1976; McIntyre 2000). However in recent years there has been growing interest in their contribution to urban biodiversity (New 2015). Such work is highly pertinent given the continuing growth of urban areas and consequence that the primary source of contact with the natural world for many people is increasingly with those organisms that are able to survive alongside us in our towns and cities (Savard, Clergeau, and Mennechez 2000; Dearborn and Kark 2010). In addition with major declines in many species in rural areas (Krebs *et al.* 1999; Benton 2007), urban areas are becoming relatively more important for the survival of biodiversity (Ryall and Hatherell 2003).

Gardens are a substantial potential resource for biodiversity conservation within urban areas. For example it is thought that approximately 87% of UK households have a garden, and with the mean size estimated to be 190m^2, this land use category covers around 4330 km^2 (approximately 1.8%) of the country's total land area (Davies *et al.* 2009). Gardens are recognized as promoting human well being, and for many people contact

Accepted by Brian Brown: 16 Jan. 2018; published: 26 Mar. 2018

with wildlife is an important contributory factor in this (Dunnett and Qasim 2000; Freeman *et al.* 2012). A consequence of the value that gardeners put on contact with nature, is the large number of households which carry out some sort of wildlife gardening activity (Gaston *et al.* 2007; Goddard, Dougill, and Benton 2013). Although wild bird feeding is rather dominant, there is a range of other wildlife friendly features maintained in gardens, such as compost heaps, ponds, log piles and so called wild or uncultivated areas (Gaston *et al.* 2007; Goddard, Dougill, and Benton 2013). The adoption of wildlife friendly gardening can be increased through education (van Heezik, Dickinson, and Freeman 2012) and has been encouraged by conservation groups (Ryall and Hatherell 2003). However it is also affected by perceptions of public acceptability and social norms, which may for example prevent gardeners from setting aside wild areas that they may fear be unacceptable to their neighbors (Dunnett 2011; van Heezik, Dickinson, and Freeman 2012; Goddard, Dougill, and Benton 2013).

Apart from gardens, urban invertebrate biodiversity has been studied in a range of other habitat types and urban features, including work on roundabouts, urban forest, green roofs and parks (Faeth and Kane 1978; Niemelä *et al.* 2002; Helden and Leather 2005; MacIvor and Lundholm 2011; Helden, Stamp, and Leather 2012). Urban invertebrates have also been used to test ecological concepts including the species area relationship and the effects of habitat isolation (Helden and Leather 2004; Fenoglio *et al.* 2013). Such studies are a reminder that ecological processes are, in most cases, not unique to specific ecosystems and therefore lessons learned in one environment can generally be applied to others.

Grassland invertebrate abundance and species richness are known to be negatively affected by increased grassland management, whether by grazing or cutting (Morris 2000; Helden and Leather 2004; Blake *et al.* 2011). The effects shown in such studies have been demonstrated both at whole field level (Morris 2000; Helden *et al.* 2015) but also at the much smaller scales of small field margins, measured in meters, and grass islets which are only tens of centimeters across (Sheridan *et al.* 2008; Helden *et al.* 2010; Dittrich and Helden 2012; Anderson *et al.* 2013). Therefore it is entirely reasonable to apply the findings of studies in agricultural and other systems to the small-scale urban grasslands than form part of so many of our gardens.

In this study we investigated the effects of one way in which urban gardeners can encourage wildlife, namely by reducing how often they are mowed. We investigated the invertebrate communities of a series of small grassland patches in urban gardens and in a city-center university campus, which differed in the frequency of mowing. We hypothesized that reduced disturbance from mowing would result is greater abundance and taxon richness of invertebrates, and we looked for community compositional changes that may result from differential effects on different taxa. The aim of the study was to provide evidence of the effectiveness of setting aside small areas of grassland in gardens or similar urban settings, in order to increase local biodiversity levels.

Methods

STUDY SITES

Invertebrate communities were sampled from a series of small urban grassy patches at three sites in Cambridgeshire and one site in north-west Greater London, in the UK. Eight small grassy patches, with primarily an ornamental function, were located on the Cambridge campus of Anglia Ruskin University (ARU) (0°8'E,52°12'N, UK grid reference (GR) TL460582). The size of the patches varied from 10.4 to 198.7 m^2 (maximum dimensions 2.5 x 5.4 m and 10.5 x 19.2 m, respectively). The other grasslands areas were all within gardens, containing a mixture of more frequently and less frequently mowed areas. There were six gardens, managed by ARU, which belonged to a series of terraced student houses (GR TL460582), close to the main university campus. One garden was located in Sawston, a village approximately 8.75 km south of Cambridge (0°10'E 52°07'N, GR TL490503), and the last site was a garden in Ickenham, a suburb of Greater London (0°26'W 51°33'N, GR TQ076863). The gardens varied in size from 40.8 to 95.0m^2 (maximum dimensions 5.7 x 8.6 m and 6.1 x 17.1 m, respectively). The sample areas were chosen to represent three different levels of grassland management: *very short* grassland that was mowed every seven to 14 days; *short* grassland, mowed on a six week cycle; and *long* grassland that had not been mowed since the previous year's growing season. Each short or long grassland area chosen was close to a sampled, very short grassland area within the same location (i.e. within the same garden or part of the university campus).

SAMPLING

An invertebrate sample and vegetation height measurements were taken within each of 33 sample areas: 15 from very short grassland, 6 from short and 12 from long. The vegetation height was measured at five points within each area with a Filips Folding Plate Pasture Meter manufactured by Jenquip (www.jenquip.co.nz). The invertebrate sampling was carried out using a Vortis suction sampler (Burkard Manufacturing Co Ltd, Rickmansworth, Hertfordshire, UK) (Arnold 1994). A sample consisted of ten 10-second sucks, from ten separate points within the grass patch, representing an area of 0.2 m^2 per sample. The catch was emptied into a portable insect cage (Bugdorm-2120) then individual invertebrates were counted and simultaneously removed from the cage, using a pooter, then released. Invertebrates were all identified to order, with some further level of identification possible for some groups. Hemiptera were identified to species in most cases although for some individuals, genus or morphospecies (e.g. for aphids) was used when the correct species identity was uncertain. Formicidae (ants) and Isopoda (woodlice) were also identified to species, and Coleoptera to morphospecies. Sampling was carried out during dry weather in July 2016, as follows: Cambridge sites (6 & 7 July), Sawston (14 July); and Ickenham (19 July).

STATISTICAL ANALYSIS

All data analysis was carried out using R version 3.3.1 (R Core Team 2016). Separate generalized linear mixed models of vegetation height and invertebrate data were run with the lmer and glmer functions respectively, from the lme4 R package (Bates *et al.* 2015). The vegetation model tested whether there was any difference in vegetation height between the mowing treatments. The response variable was vegetation height, which was log transformed to correct for non-normality of errors, with grassland type as the explanatory variable and site as a random effect, and with Gaussian error structure. There were two initial models for all invertebrate orders combined; one with abundance and the other with taxon richness as the response variable. The models tested whether there were significant differences in abundance and taxon richness between mowing treatments. Taxon richness was measured as recognizable taxonomic units (RTU), due to the mixture of order and genus or species level identifications. The explanatory variable was grassland type, with site as a random variable, and models had a Poisson error structure.

Community composition was compared by ordination, with non-metric multidimensional scaling (NMDS), using the vegan package (Oksanen *et al.* 2016). The NMDS was performed with the metaMDS function, which uses Bray-Curtis dissimilarity. Invertebrates were grouped into six categories for the ordination: Hemiptera (adults), Coleoptera, Formicidae, Araneae, Diptera and parasitic Hymenoptera. The three grassland management types and the invertebrate groups were fitted to the ordination using the envfit function. The significance of fit was assessed with a squared correlation statistic as a goodness of fit test, using 1000 permutations of the data. Taxonomic groups that showed a significant fit (Araneae, Formicidae, Hemiptera (adults) and parasitic Hymenoptera), were subsequently modeled with separate generalized linear mixed models, using the same structure as previously described for overall abundance and RTU.

Species accumulation curves were generated using the specaccum function, also with the vegan package. Curves (±95% confidence intervals) were plotted against the number of samples and against the number of individuals (rarefaction) separately for long grassland and very short grassland. Equivalent curves for short grass were not plotted as there were only six samples.

Results

The model estimate of long grassland vegetation height was 9.0 cm, which was significantly greater than the estimate of 4.3 cm for short ($t = 3.71$ $p = 0.002$) and the estimate of 2.5 cm for very short ($t = 9.12$ $p < 0.001$). Short grassland had significantly higher vegetation than very short ($t = 3.00$ $p = 0.005$).

A total of 2675 invertebrates were sampled. Of these, 633 individuals were identified to species, consisting of three species of Isopoda, one species of Araneae, three each of Coleoptera and Formicidae and 27 of Hemiptera (Appendix 1). The most abundant species was the ant *Lasius niger* (Linnaeus, 1758) (364 individuals) and there were two other common ants, *Lasius flavus* (Fabricius, 1781) (20) and *Myrmica scabrinoidis* Nylander, 1846 (20). The terrestrial isopods, *Armadillidium vulgare* (Latreille, 1804) (31), *Philoscia muscorum* (Scopoli, 1763) (5) and *Porcellio scaber* (Latreille, 1804) (3) were the only other non-hemipterous species identified specifically. Within the Hemiptera itself, the most common species was

Anoscopus serratulae (Cicadellidae) (Fabricius, 1775) (54). However it should be noted that the genus *Javesella* (Delphacidae), which cannot easily by identified to species in the field, was represented by 236 individuals, most of which were nymphs. Other common Hemiptera were, *Balclutha punctata* (Cicadellidae) (Fabricius, 1775) (23), *Arthaldeus pascuellus* (Cicadellidae) (Fallén, 1826) (18).

Long grasslands had significantly higher total invertebrate abundance than either short or very short grasslands ($z = 5.64$ $p < 0.001$ and $z = 13.58$ $p < 0.001$, respectively) (Fig. 1a). There were also significantly more individuals in short grasslands than very short ($z = 3.93$ $p < 0.001$). Model estimates of abundance per $0.2m^2$ were: 97.1, 56.6 and 42.2 for long, short and very short, respectively.

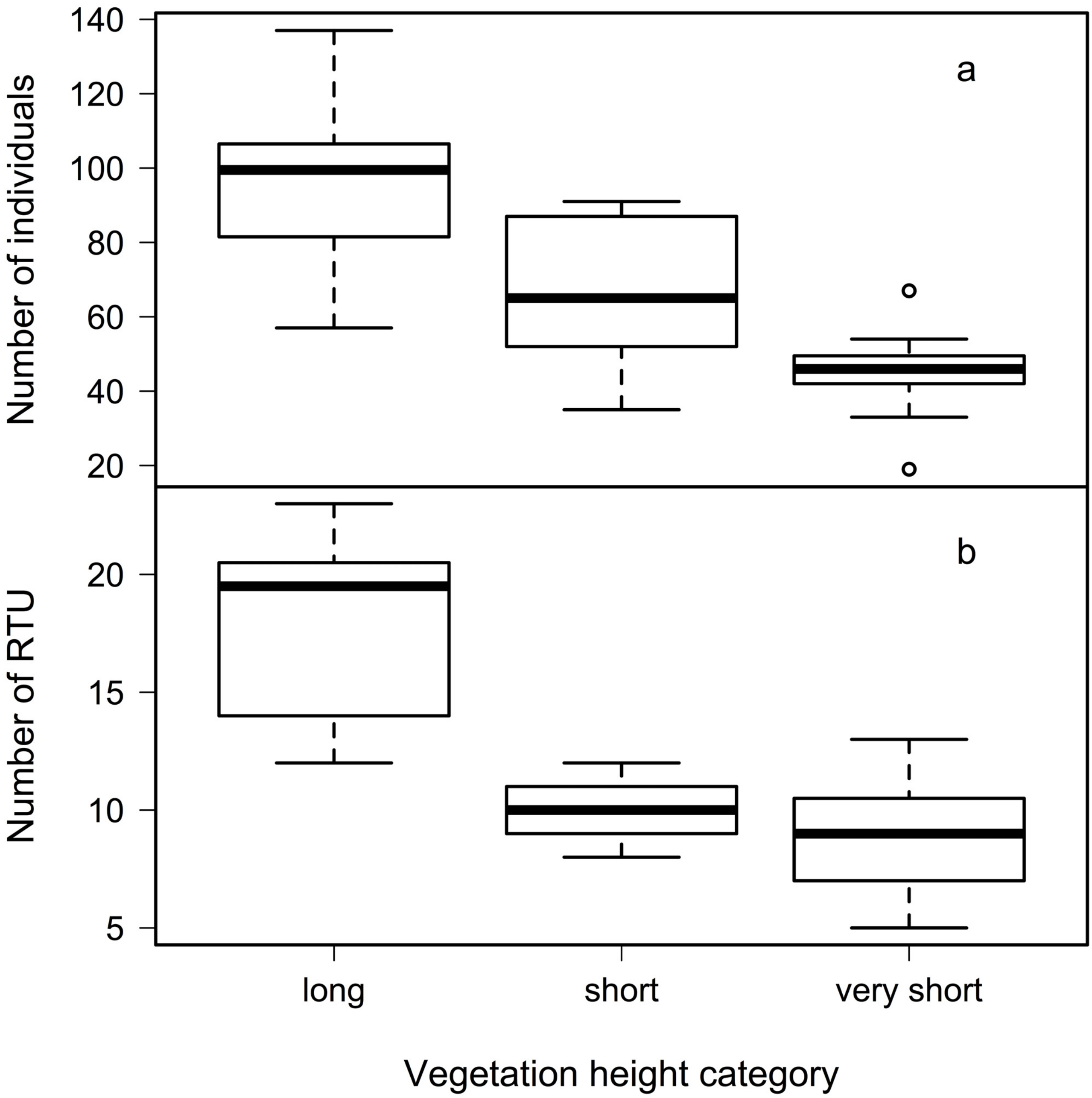

FIGURE 1. Boxplots showing the number of (a) individuals and (b) recognizable taxonomic units (RTU) collected in long, short and very short urban grassland. Dark horizontal lines show the median value, with upper and lower boxes the 25th and 75th percentiles respectively. Dashed lines indicate either 1.5 times the interquartile range or the maximum and minimum values if there are no outliers (small circles).

There were significantly more taxa (RTU) found in long grassland than either short or very short grasslands ($z = 3.99$ $p < 0.001$ and $z = 6.27$ $p < 0.001$, respectively) (Fig. 1b). However unlike for abundance there was no difference between the taxon richness of short and very short grassland ($z = 0.68$ $p = 0.497$). Model estimates of taxon richness were: 17.9, 10.0 and 9.0 for long, short and very short, respectively.

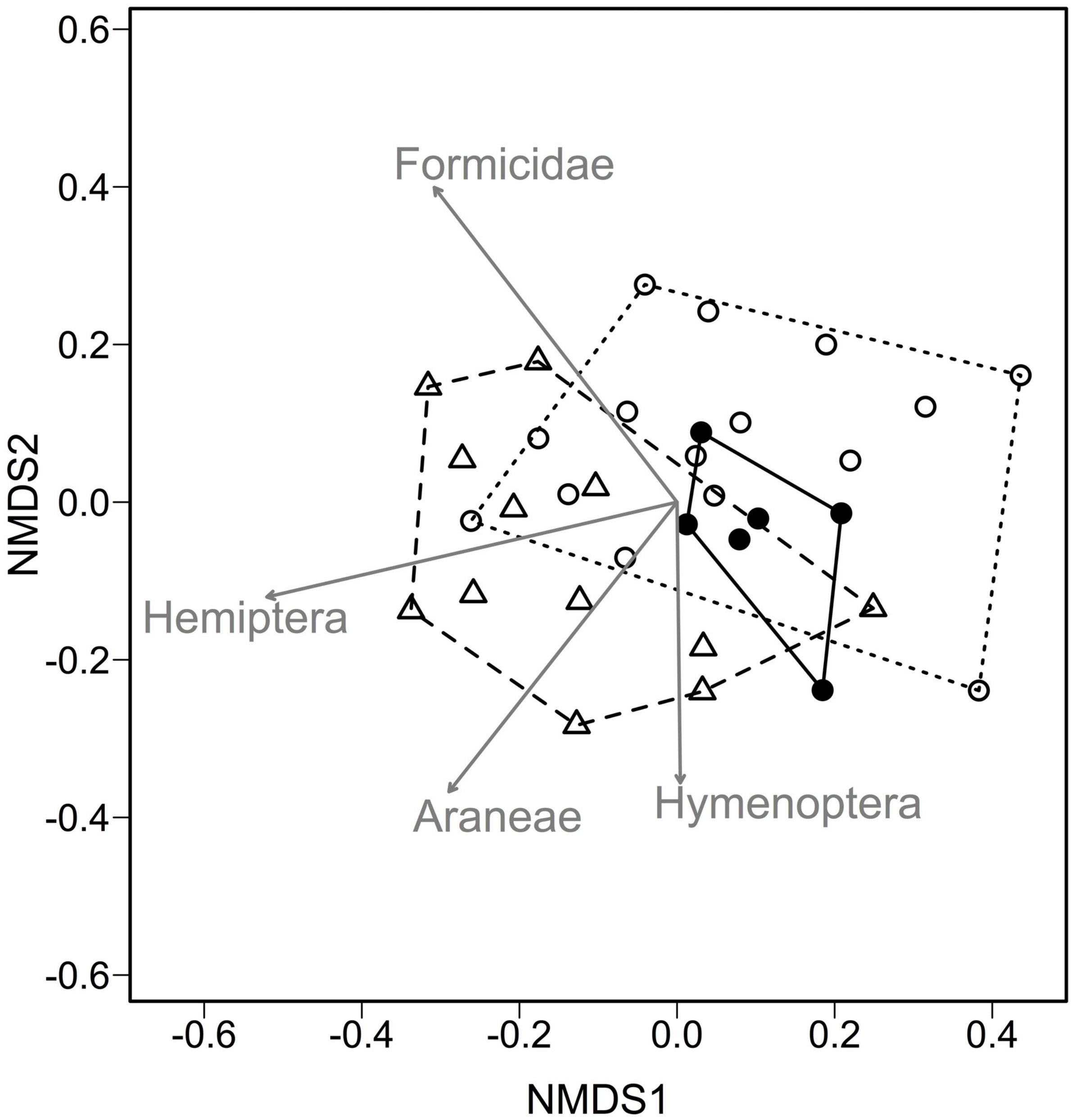

FIGURE 2. Non-metric dimensional scaling (NMDS) ordination plot, showing invertebrate community variation in urban grasslands. Long grassland (open triangles and dashed lines), short grassland (open circles and dotted lines) and very short grassland (filled circles and solid lines). Invertebrate groups fitted to the ordination and indicated in grey arrows were: Formicidae, adult Hemiptera, Araneae and parasitic Hymenoptera.

The NMDS produced an ordination solution with two dimensions and a stress of 0.172, and there was a significant difference in community structure between grassland types ($r^2 = 0.251$ $p = 0.002$) (Fig. 2). Short and very short samples almost completely overlapped within the ordination, while there was a partial separation of long grassland samples. Very short samples showed a much smaller spread within the ordination than either short or long samples. When taxa were fitted to the ordination Coleoptera and Diptera were non significant ($r^2 = 0.05$ $p = 0.472$ and $r^2 = 0.12$ $p = 0.155$, respectively), while there were significant fits for

Araneae ($r^2 = 0.47$ $p < 0.001$), Formicidae ($r^2 = 0.54$ $p < 0.001$), adult Hemiptera ($r^2 = 0.61$ $p < 0.001$) and parasitic Hymenoptera ($r^2 = 0.27$ $p = 0.011$) (Fig. 2). The Araneae, adult Hemiptera and parasitic Hymenoptera all showed fitted vectors aligned towards long grassland, whilst the vector for ants was aligned between short and long grassland samples but away from very short.

Generalized linear mixed modeling indicated no difference in Araneae abundance between long and short grassland ($z = 0.22$ $p = 0.823$) but both sub-habitats had significantly more individuals than very short ($z = 4.46$ $p < 0.001$ and $z = 3.82$ $p < 0.001$, respectively) (Fig. 3a) (Table 1). For Formicidae abundance was higher in long grassland than either short ($z = 2.89$ $p = 0.004$) or very short ($z = 6.10$ $p < 0.001$), with no difference between short and very short ($z = 0.56$ $p = 0.578$) (Fig. 3c) (Table 1). The same pattern was found for adult Hemiptera (long/short $z = 2.20$ $p = 0.028$; log/very short $z = 7.26$ $p < 0.001$; short/very short $z = 0.64$ $p = 0.525$) (Fig. 3b) (Table 1). With parasitic Hymenoptera there were more individuals in long grassland than short ($z = 2.99$ $p = 0.003$) and very short ($z = 8.17$ $p < 0.001$), and also more in short than very short ($z = 2.77$ $p = 0.006$) (Fig. 3d) (Table 1).

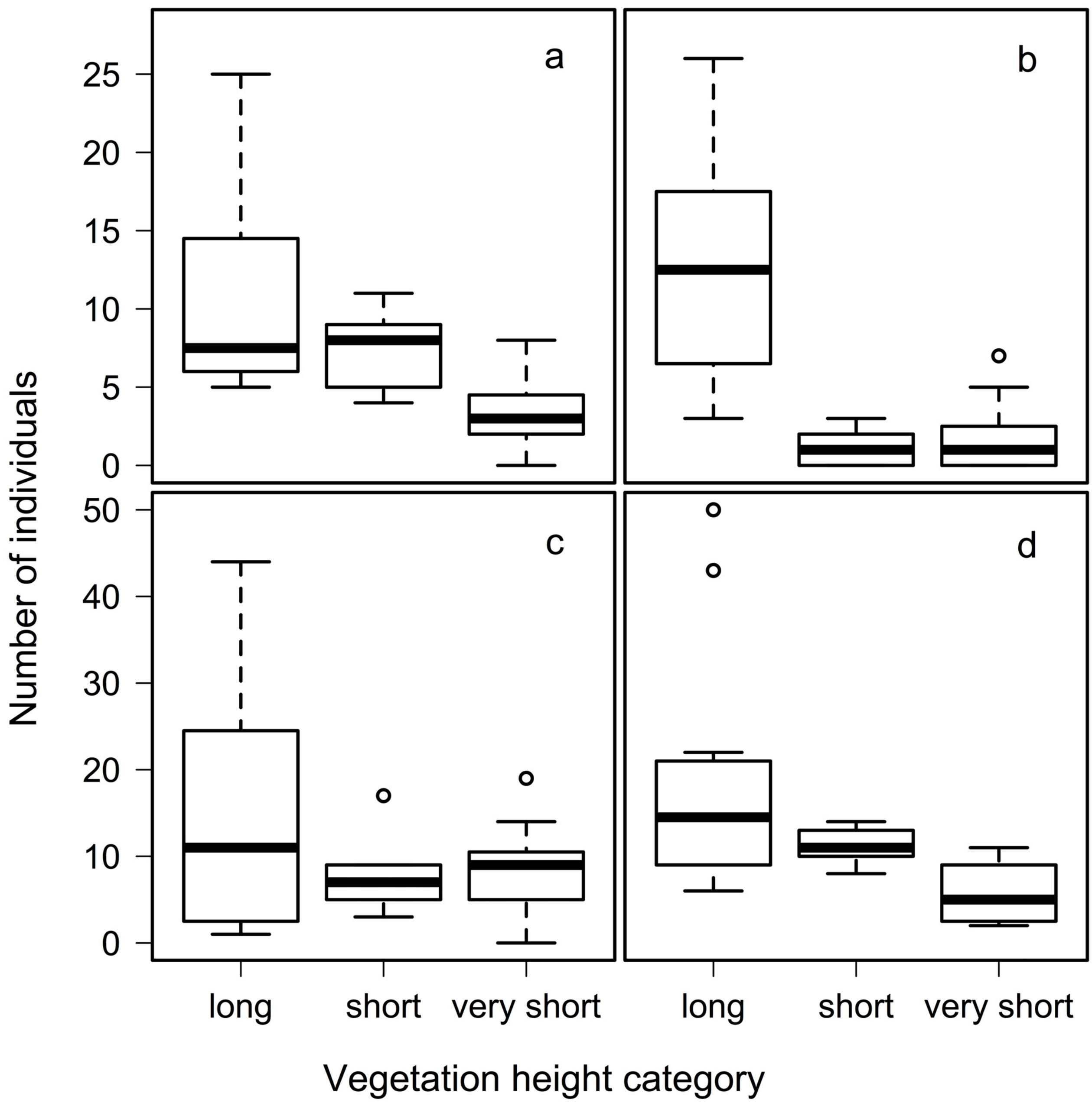

FIGURE 3. Boxplots illustrating the number of (a) Araneae, (b) adult Hemiptera, (c) Formicidae and (d) parasitic Hymenoptera found in long, short and very short urban grassland.

TABLE 1. Generalized linear mixed model estimates of the abundance of different taxa per $0.2m^2$ at the three levels of grassland management.

Taxon	Grassland habitat		
	Long	Short	Very short
Araneae	9.2	9.9	3.6
Coleoptera	6.6	6.4	3.7
Diptera	27.8	17.9	17.1
Formicidae	13.3	6.5	5.8
Hemiptera (adults)	10.3	2.7	1.9
Parasitic Hymenoptera	16.1	7.7	4.5

Species accumulation curves for Hemiptera, when plotted against the number of samples showed a clear difference between grassland type, with many more species found in long grassland than very short grassland (Fig. 4a). Comparison with a generalized linear model showed the same pattern ($z = 5.70$ $p < 0.001$; glmm estimates, 7.0 and 1.8 species per $0.2m^2$ for long and very short, respectively). When species accumulation was plotted against number of individuals (rarefaction) there was a complete overlap between the curves although the number of individuals was very much smaller for very short grassland (Fig. 4b).

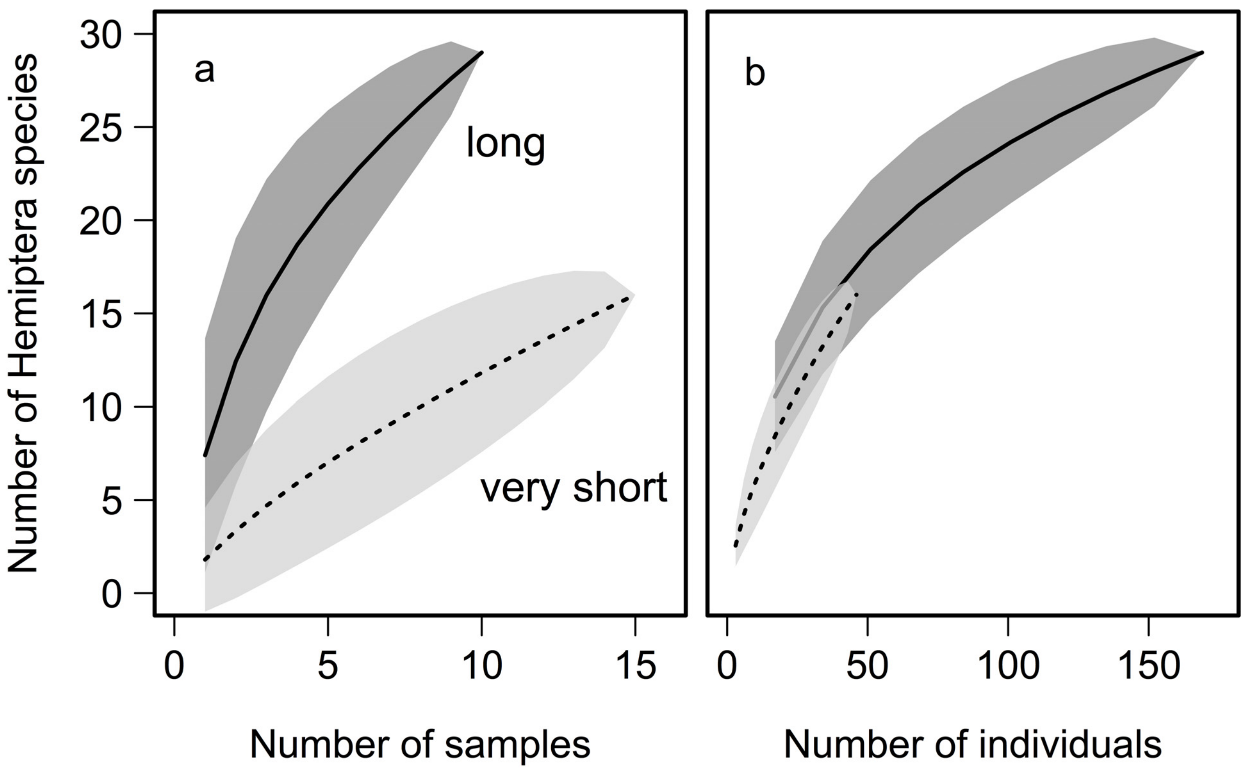

FIGURE 4. Species accumulation curves for long (dark grey and solid lines) and very short grassland (pale grey and dotted lines): a) Number of Hemiptera species plotted against number of samples; b) Number of Hemiptera species plotted against number of individuals.

Discussion

In the grasslands studied, a reduction in management frequency clearly resulted in an overall increase in invertebrate abundance and taxon richness but with the effects varying between taxonomic groups. That simply reducing the number of times a grassland is cut should result in more invertebrates is no surprise, given previous studies that have found similar effects on invertebrate communities in relation to grazing or mowing frequency (Nickel and Hildebrandt 2003; Helden and Leather 2004; Blake *et al.* 2011; Helden *et al.* 2015). As our vegetation height measurements confirmed, less disturbance results in greater plant biomass. This provides more food for herbivores and more shelter, with associated reduction in temperature variation, but also higher niche diversity (Andrzejewska 1965; Morris 2000; Kormann *et al.* 2015).

The differential effects on separate taxa mean that not only do management changes affect abundance and species richness, but it also modifies the invertebrate community structure. Short, regularly mowed grasslands communities showed relatively little variation to each other. In contrast long, less often managed grassland areas were much more varied in community structure and relatively richer in Araneae, Formicidae, Hemiptera and parasitic Hymenoptera. Of these four taxa, the Araneae showed the strongest response to a reduction from a seven or 14 day mowing cycle to six week cycle, indicating that even a small reduction in management is favorable. The Araneae being predatory are likely to benefit from the increase in other invertebrates with a reduction in mowing, as this represents an increase in prey availability. The highly mobile nature of most species would enable them to respond quickly to a reduction in mowing frequency and the increase in vegetation height would provide greater structural complexity and therefore benefits such as more locations to attach their webs (Dennis, Young, and Gordon 1998; Plantureux, Peeters, and McCracken 2005). Even though there were not significantly greater numbers in long grasslands, it is noticeable that the data were somewhat skewed towards larger numbers in long areas and smaller numbers in short. Therefore it is likely that even though not indicated by the statistical analysis, Araneae would gain the most benefit from very infrequent mowing.

Although the Formicidae, Hemiptera and parasitic Hymenoptera were all found to be most common in the long grassland, they differed in their relative abundance between the three treatments. The parasitic Hymenoptera followed the abundance pattern of all invertebrates relative to grassland management. This is likely to be related to their role as parasitoids of a wide range of other invertebrates and so their abundance and diversity reflects that of the rest of the invertebrate community; a characteristic that has been suggested as making them good biodiversity indicators (Anderson *et al.* 2011).

The Formicidae and Hemiptera do show a common pattern in abundance in relation to grassland types. However the difference in effect sizes suggest that the Hemiptera are more sensitive to management. Indeed they appeared the most sensitive of all the invertebrate taxa studied, with a 5.4 fold increase in individuals and a 35 fold increase in species density in long grassland, compared to very short. Regularly mowed grasslands such as lawns, ornamental parks and playing fields are likely to support only a very small number of generalist pioneer species, such as the planthopper, *Javesella pellucida* and leafhoppers of the genus *Macrosteles* (Andrzejewska 1979; Nickel 2003; Nickel and Hildebrandt 2003). Other Hemiptera species can be found in urban gardens, and some of these are likely to be transients from more suitable habitat nearby. This together with very low abundance in very short grassland, may explain the overlap in the rarefaction curves when comparing long and very short. However as demonstrated in this study, to support a greater number of species, gardeners are likely to have to leave some grassy parts of their gardens uncut for many months. This is because most Hemiptera species are herbivorous and in contrast to frequently managed grassland, longer vegetation provides more diverse feeding, ovipositional and microclimatic niches, that can support populations of a wider range of species (Andrzejewska 1965; Waloff and Solomon 1973; Denno 1977; Prestidge 1982; Woodcock *et al.* 2009).

The small size of invertebrates enables them to take advantage of a wide diversity of niches, and therefore they are able to respond to structural changes at small scales, such as grassy islets and field margins (Helden *et al.* 2010; Dittrich and Helden 2012; Anderson *et al.* 2013; Helden and Dittrich 2016), as well as the small garden patches considered in this study. Consequently the incorporation of areas of infrequently managed grassland into gardens, can enable householders to readily enhance grassland invertebrate populations, and this very simple methodology can be added to the range of other biodiversity beneficial activities for the garden, such as providing wildlife ponds, pollen and nectar sources, woodpiles and nesting holes for solitary bees (Gaston *et al.* 2007; Goddard, Dougill, and Benton 2013). Using a range of techniques is likely to be very important as each one will benefit different groups of invertebrates to a greater or lesser extent. Obvious examples are that wildlife ponds tend to be most advantageous for aquatic invertebrates, while the benefits of pollen and nectar sources are most likely to be reflected in pollinator numbers, most notably species of Hymenoptera, Diptera and Lepidoptera. Grassland invertebrates such as many leafhoppers (Cicadellidae) and planthoppers (Delphacidae) are much less well know but their presence should be of no less value.

Allowing grasses to grow uncontrolled for long periods might be unwelcome in circumstances when grasslands are being managed to create forb-dominated meadows (Hitchmough, Paraskevopoulou, and Dunnett 2008). It may also not be favored by some people for aesthetic reasons, who may consider it ‘untidy’, or that it is at odds to the social norms (Dunnett 2011; van Heezik, Dickinson, and Freeman 2012; Goddard, Dougill, and Benton 2013). Consequently if such techniques are to be adopted more widely it may require those of us with a particular enthusiasm for wildlife, which surely must include most ecologists, to lead change in our local communities (Goddard, Dougill, and Benton 2013). Whether it becomes widely adopted of course remains to be seen. However as a very simple methodology it can, as we have shown, be very effective in increasing numbers of grassland invertebrates, particularly Hemiptera. Therefore it should be encouraged as one amongst a number of means that householders, like ourselves, can use to encourage biodiversity in their gardens and hence in the wider urban landscape.

Acknowledgements

We thank the following for allowing access and permission to sample in the grassland areas and gardens: Estates and Facilities, Anglia Ruskin University (ARU campus and Collier Road gardens); David and Ruth Helden (Ickenham garden); and Jane Helden (Sawston garden).

Literature cited

Anderson, A., Carnus, T., Helden, A.J., Sheridan, H. & Purvis, G. (2013) The Influence of Conservation Field Margins in Intensively Managed Grazing Land on Communities of Five Arthropod Trophic Groups. *Insect Conservation and Diversity*, 6, 201–211.
https://doi.org/10.1111/j.1752-4598.2012.00203.x

Anderson, A., McCormack, S., Helden, A., Sheridan, H., Kinsella, A. & Purvis, G. (2011) The Potential of Parasitoid Hymenoptera as Bioindicators of Arthropod Diversity in Agricultural Grasslands. *Journal of Applied Ecology*, 48 (2), 382–390.
https://doi.org/10.1111/j.1365-2664.2010.01937.x

Andrzejewska, L. (1965) Stratification and Its Dynamics in Meadow Communities of Auchenorrhyncha (Homoptera). *Ekologia Polska - Seria A*, 13, 685–715.

Andrzejewska, L. (1979) Herbivorous Fauna and Its Role in the Economy of Grassland Ecosystems I. Herbivores in Natural and Managed Meadows. *Polish Ecological Studies*, 5, 5–44.

Arnold, A.J. (1994) Insect Suction Sampling without Nets, Bags or Filters. *Crop Protection*, 13, 73–76.
https://doi.org/10.1016/0261-2194(94)90139-2

Bates, D., Mächler, M., Bolker, B. & Walker, S. (2015) Fitting Linear Mixed-Effects Models Using **lme4**. *Journal of Statistical Software*, 67 (1).
https://doi.org/10.18637/jss.v067.i01

Benton, T.G. (2007) Ecology - Managing Farming’s Footprint on Biodiversity. *Science*, 315 (5810), 341–342.
https://doi.org/10.1126/science.1137650

Blake, R.J., Woodcock, B.A., Ramsay, A.J., Pilgrim, E.S., Brown, V.K., Tallowin, J.R. & Potts, S.G. (2011) Novel Margin Management to Enhance Auchenorrhyncha Biodiversity in Intensive Grasslands. *Agriculture Ecosystems & Environment*, 140 (3–4), 506–513.
https://doi.org/10.1016/j.agee.2011.02.003

Davies, Z.G., Fuller, R.A., Loram, A., Irvine, K.N., Sims, V. & Gaston, K.J. (2009) A National Scale Inventory of Resource Provision for Biodiversity within Domestic Gardens. *Biological Conservation*, 142 (4), 761–771.
https://doi.org/10.1016/j.biocon.2008.12.016

Davis, B.N.K. (1976) Wildlife, Urbanization and Industry. *Biological Conservation*, 10, 249–291.
https://doi.org/10.1016/0006-3207(76)90002-1

Dearborn, D.C. & Kark, S. (2010) Motivations for Conserving Urban Biodiversity. *Conservation Biology*, 24 (2), 432–440.
https://doi.org/10.1111/j.1523-1739.2009.01328.x

Dennis, P., Young, M.R. & Gordon, I.J. (1998) Distribution and Abundance of Small Insects and Arachnids in Relation to Structural Heterogeneity of Grazed, Indigenous Grasslands. *Ecological Entomology*, 23, 253–64.
https://doi.org/10.1046/j.1365-2311.1998.00135.x

Denno, R.F. (1977) Comparison of the Assemblages of Sap-Feeding Insects (Homoptera-Hemiptera) Inhabiting Two

Structurally Different Salt Marsh Grasses in the Genus Spartina. *Environmental Entomology*, 6, 359–372. https://doi.org/10.1093/ee/6.3.359

Dittrich, A.D.K. & Helden, A.J. (2012) Experimental Sward Islets: The Effect of Dung and Fertilisation on Hemiptera & Araneae. *Insect Conservation and Diversity*, 5, 46–56. https://doi.org/10.1111/j.1752-4598.2011.00133.x

Dunnett, N. (2011) Urban Meadows: An Ecological Discussion. *Aspects of Applied Biology*, 108, 11–17.

Dunnett, N. & Qasim, M. (2000) Perceived Benefits to Human Well-Being of Urban Gardens. *HortTechnology*, 10: 40–45.

Faeth, S.H. & Kane, T.C. (1978) Urban Biogeography. City Parks as Islands for Diptera and Coleoptera. *Oecologia*, 32, 127–33. https://doi.org/10.1007/BF00344697

Fenoglio, M.S., Videla, M., Salvo, A. & Valladares, G. (2013) Beneficial Insects in Urban Environments: Parasitism Rates Increase in Large and Less Isolated Plant Patches via Enhanced Parasitoid Species Richness. *Biological Conservation*, 164, 82–89. https://doi.org/10.1016/j.biocon.2013.05.002

Freeman, C., Dickinson, K.J.M., Porter, S. & van Heezik, Y. (2012) 'My Garden Is an Expression of Me': Exploring Householders' Relationships with Their Gardens. *Journal of Environmental Psychology*, 32 (2), 135–143. https://doi.org/10.1016/j.jenvp.2012.01.005

Gaston, K.J., Fuller, R.A., Loram, A., MacDonald, C., Power, S. & Dempsey, N. (2007) Urban Domestic Gardens (XI): Variation in Urban Wildlife Gardening in the United Kingdom. *Biodiversity and Conservation*, 16 (11), 3227–3238. https://doi.org/10.1007/s10531-007-9174-6

Goddard, M.A., Dougill, A.J. & Benton, T.G. (2013) Why Garden for Wildlife? Social and Ecological Drivers, Motivations and Barriers for Biodiversity Management in Residential Landscapes. *Ecological Economics*, 86 (February), 258–273. https://doi.org/10.1016/j.ecolecon.2012.07.016

Heezik, Y.M. van, Dickinson, K.J.M. & Freeman, C. (2012) Closing the Gap: Communicating to Change Gardening Practices in Support of Native Biodiversity in Urban Private Gardens. *Ecology and Society*, 17 (1). https://doi.org/10.5751/ES-04712-170134

Helden, A.J., Anderson, A., Sheridan, H. & Purvis, G. (2010) The Role of Grassland Sward Islets in the Distribution of Arthropods in Cattle Pastures. *Insect Conservation and Diversity*, 3, 291–301. https://doi.org/10.1111/j.1752-4598.2010.00106.x

Helden, A.J. & Dittrich, A.D.K. (2016) Hemiptera Community and Species Responses to Grassland Sward Islets. *Entomologica Austriaca*, 23, 19–28.

Helden, A.J. & Leather, S.R. (2004) Biodiversity on Urban Roundabouts - Hemiptera, Management and the Species-Area Relationship. *Basic and Applied Ecology*, 5 (4), 367–77. https://doi.org/10.1016/j.baae.2004.06.004

Helden, A.J. & Leather, S.R. (2005) The Hemiptera of Bracknell as an Example of Biodiversity within an Urban Environment. *British Journal of Entomology and Natural History*, 18, 233–52.

Helden, A.J., Mckenzie, R., Cobbold, G., Grice, P.V., Anderson, G.Q.A. & MacDonald, M.A. (2015) Field-Based Grassland Management for Cirl Buntings (*Emberiza Cirlus* L.) and Its Effect on Plant- and Leafhoppers (Hemiptera: Auchenorrhyncha). *Insect Conservation and Diversity*, 8 (3), 272–281. https://doi.org/10.1111/icad.12106

Helden, A.J., Stamp, G.C. & Leather, S.R. (2012) Urban Biodiversity: Comparison of Insect Assemblages on Native and Non-Native Trees. *Urban Ecosystems*, 15, 611–624. https://doi.org/10.1007/s11252-012-0231-x

Hitchmough, J., Paraskevopoulou, A. & Dunnett, N. (2008) Influence of Grass Suppression and Sowing Rate on the Establishment and Persistence of Forb Dominated Urban Meadows. *Urban Ecosystems*, 11 (1), 33–44. https://doi.org/10.1007/s11252-007-0041-8

Kormann, U., Rösch, R., Batáry, P., Tscharntke, T., Orci, K.M., Samu, F. & Scherber, C. (2015) Local and Landscape Management Drive Trait-Mediated Biodiversity of Nine Taxa on Small Grassland Fragments. Edited by Ingolf Kühn. *Diversity and Distributions*, 21 (10), 1204–1217. https://doi.org/10.1111/ddi.12324

Krebs, J.R., Wilson, J.D., Bradbury, R.B. & Siriwardena, G.M. (1999) The Second Silent Spring? *Nature*, 400, 611–612. https://doi.org/10.1038/23127

MacIvor, J.S. & Lundholm, J. (2011) Insect Species Composition and Diversity on Intensive Green Roofs and Adjacent Level-Ground Habitats. *Urban Ecosystems*, 14 (2), 225–241. https://doi.org/10.1007/s11252-010-0149-0

McIntyre, N.E. (2000) Ecology of Urban Arthropods: A Review and a Call to Action. *Annals of the Entomological Society of*

America, 93, 825–835.
https://doi.org/10.1603/0013-8746(2000)093[0825:EOUAAR]2.0.CO;2

Morris, M.G. (2000) The Effects of Structure and Its Dynamics on the Ecology and Conservation of Arthropods in British Grasslands. *Biological Conservation*, 95, 129–142.
https://doi.org/10.1016/S0006-3207(00)00028-8

New, T.R. (2015) *Insect Conservation and Urban Environments*. Springer International Publishing.
https://doi.org/10.1007/978-3-319-21224-1

Nickel, H. (2003) *The Leafhoppers and Planthoppers of Germany (Hemiptera, Auchenorrhyncha): Patterns and Strategies in a Highly Diverse Group of Phytophagous Insects*. Sofia-Moscow, Pensoft.

Nickel, H. & Hildebrandt, J. (2003) Auchenorrhyncha Communities as Indicators of Disturbance in Grasslands (Insecta, Hemiptera)—a Case Study from the Elbe Flood Plains (Northern Germany). *Agriculture, Ecosystems & Environment*, 98 (1–3), 183–99.
https://doi.org/10.1016/S0167-8809(03)00080-X

Niemelä, J., Kotze, D.J., Venn, S., Penev, L., Stoyanov, I., Spence, J., Hartley, D. & Montes de Oca, E. (2002) Carabid Beetle Assemblages (Coleoptera, Carabidae) across Urban-Rural Gradients: An International Comparison. *Landscape Ecology*, 17, 387–401.
https://doi.org/10.1023/A:1021270121630

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpon, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E. & Wagner, H. (2016) Vegan: Community Ecology Package. R Package Version 2.4-0.

Plantureux, S., Peeters, A. & McCracken, D.I. (2005) Biodiversity in Intensive Grasslands: Effect of Management, Improvement and Challenges. *Agronomy Research*, 3, 153–164.

Prestidge, R.A. (1982) The Influence of Nitrogenous Fertilizer on the Grassland Auchenorrhyncha (Homoptera). *Journal of Applied Ecology*, 19, 735–749.
https://doi.org/10.2307/2403278

R Core Team (2016) *R: A Language and Environment for Statistical Computing.* Vienna, Austria. R Foundation for Statistical Computing. Available from: http://www.R-project.org/

Ryall, C. & Hatherell, P. (2003) A Survey of Strategies Adopted by UK Wildlife Trusts in the Promotion of Gardening for Wildlife. *The Environmentalist*, 23, 81–87.
https://doi.org/10.1023/A:1022995610486

Savard, J-P.L., Clergeau, P. & Mennechez, G. (2000) Biodiversity Concepts and Urban Ecosystems. *Landscape and Urban Planning*, 48, 131–142.
https://doi.org/10.1016/S0169-2046(00)00037-2

Sheridan, H., Finn, J.A., Culleton, N. & O'Donovan, G. (2008) Plant and Invertebrate Diversity in Grassland Field Margins. *Agriculture Ecosystems & Environment*, 123 (1–3), 225–232.
https://doi.org/10.1016/j.agee.2007.07.001

Waloff, N. & Solomon, M.G. (1973) Leafhoppers (Auchenorrhyncha: Homoptera) of Acidic Grassland. *Journal of Applied Ecology*, 10, 189–212.
https://doi.org/10.2307/2404725

Woodcock, B.A., Potts, S.G., Tscheulin, T., Pilgrim, E., Ramsey, A.J., Harrison-Cripps, J., Brown, V.K. & Tallowin, J.R. (2009) Responses of Invertebrate Trophic Level, Feeding Guild and Body Size to the Management of Improved Grassland Field Margins. *Journal of Applied Ecology*, 46 (4), 920–929.
https://doi.org/10.1111/j.1365-2664.2009.01675.x

APPENDIX 1. The abundance of different species identified in long, short and very short urban grasslands.

Order & family	Species	Number of individuals in different grassland types			
		Long	Short	Very short	Total
Isopoda: Armadillidiidae					
	Armadillidium vulgare (Latreille, 1804)	8	22	1	31
Isopoda: Philosciidae					
	Philoscia muscorum (Scopoli, 1763)	3	2	0	5
Isopoda: Porcellionidae					
	Porcellio scaber (Latreille, 1804)	2	1	0	3
Araneae: Pisauridae					
	Pisaura mirabilis (Clerck, 1757)	1	0	0	1
Hemiptera: Aphididae					
	Sitobion avenae (Fabricius, 1775)	0	0	1	1
Hemiptera: Delphacidae					
	Criomorphus albomarginatus Curtis, 1833	0	1	0	1
	Dicranotropis hamata (Boheman, 1847)	0	1	0	1
	Javesella dubia (Kirschbaum, 1868)	1	0	0	1
	Javesella pellucida (Fabricius, 1794)	4	0	0	4
	Kosswigianella exigua (Boheman, 1847)	4	1	0	5
	Scottianella dalei (Scott, 1870)	3	0	0	3
Hemiptera: Cicadellidae					
	Anoscopus serratulae (Fabricius, 1775)	22	28	4	54
	Aphrodes bicincta (Schrank, 1776) sensu Tishechkin (1998)	13	0	0	13
	Arthaldeus pascuellus (Fallén, 1826)	10	7	1	18
	Balclutha punctata (Fabricius, 1775)	22	0	1	23
	Deltocephalus pulicaris (Fallén, 1806)	3	0	2	5
	Dikraneura variata Hardy, 1850	7	0	1	8
	Eupteryx decemnotata Rey, 1891	1	0	0	1
	Eupteryx notata, Curtis, 1837	1	0	0	1
	Euscelis incisus (Kirschbaum, 1858)	3	1	1	5
	Graphocraerus ventralis (Fallén, 1806)	0	1	0	1
	Megophthalmus scanicus (Fallén, 1806)	3	3	1	7
	Mocydia crocea (Herrich-Schaeffer, 1837)	3	4	0	7
	Streptanus sordidus (Zetterstedt, 1828)	2	1	0	3
	Zyginidia scutellaris (Herrich-Schäffer, 1838)	10	2	2	14
Hemiptera: Lygaeidae					
	Drymus sylvaticus (Fabricius, 1775)	1	0	0	1
	Megalonotus chiragra (Fabricius, 1794)	0	1	0	1
Hemiptera: Nabidae					
	Himacerus apterus (Fabricius, 1798)	1	3	0	4

...Continued on next page

APPENDIX 1. (Continued)

Order & family	Species	Number of individuals in different grassland types			
		Long	Short	Very short	Total
Hemiptera: Miridae					
	Chlamydatus saltitans (Fallén, 1807)	0	0	1	1
	Stenodema laevigata (Linnaeus, 1758)	1	0	0	1
Hemiptera: Pentatomidae					
	Podops inuncta (Fabricius, 1775)	0	1	0	1
Coleoptera: Coccinellidae					
	Harmonia axyridis (Pallas, 1773)	0	1	0	1
	Propylea quattuordecimpunctata (Linnaeus, 1758)	1	0	0	1
	Psyllobora vigintiduopunctata (Linnaeus, 1758)	0	1	0	1
Hymenoptera: Formicidae					
	Lasius flavus (Fabricius, 1781)	11	6	3	20
	Lasius niger (Linnaeus, 1758)	156	94	114	364
	Myrmica scabrinoidis Nylander, 1846	4	11	5	20