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Chapter 8

URBANISATION AND GROUND-DWELLING INVERTEBRATES

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ABSTRACT

Urbanisation is increasing worldwide, as today 45% of the human population around the world lives in cities, increasing to approximately 80% in the industrialised countries. A way to estimate the effects of urbanisation on nature is to study the structure and function of ecological systems along urban-rural gradients. Across these gradients, urban areas are characterised by densely populated, built-up, developed and often highly disturbed city centres and the centres are surrounded by areas of decreasing development and habitation with moderate or light disturbance. Urbanisation effects on the abundance and diversity of arthropods is understudied, even if urbanisation is considered one of the primary causes for declines in arthropod populations. Therefore, studying arthropods in urban environments is an important and timely avenue for research.

To investigate the effects of urbanisation on ground beetles (*Coleoptera: Carabidae*), terrestrial isopods (*Isopoda: Oniscidea*) and on ground dwelling spiders (*Araneae*) samples were taken using pitfall traps along an urban-rural forest gradient representing decreasing human disturbance according to the standard Globenet protocol.

We did not found significant differences either in overall species richness of ground beetles or in overall species richness of isopods along the gradient. Overall spider species richness was significantly higher in the urban area compared to the suburban and rural

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ones. These results did support neither the increased disturbance hypothesis (the overall diversity should decrease under higher levels of disturbance), nor the intermediate disturbance hypothesis (diversity is the highest at intermediate levels of disturbance).

Species richness of the habitat specialist ground beetles significantly increased along the urban-rural gradient. Species richness of the habitat specialist isopods were significantly higher in the suburban and rural areas compared to the urban one. Species richness of the habitat specialist spiders was significantly higher in the rural area than in the suburban and urban ones. These results support the habitat specialist hypothesis, which predicts that the diversity of habitat specialist species (in our case the most adapted forest specialist species for living on the forest floor of the undisturbed sites) should increase from the more disturbed urban area towards the less disturbed rural one.

Concluding, we found a significant effect of urbanisation on the studied arthropod groups. Moreover, our findings showed that overall diversity is not the most appropriate indicator of disturbance. Therefore, species with different habitat affinity should be analysed separately to evaluate the real effect of urbanisation.

INTRODUCTION

The worldwide increasing anthropogenic activities, like farming, forestry and urbanisation cause significant changes to te environments and create patchworks of modified land types that exhibit similar patterns throughout the world. Urbanisation is accelerating, as more than 6 billions humans around the world (45% of the human population) live in cities. In the industrialised countries, approximately 80% of the peoples are city dwellers (United Nations, 2004). Urbanisation involves profound modification in temperature (Hawkins et al., 2004), in deposition of heavy metals (Conti et al., 2004) and other pollutants (Ebert et al., 2004), in the utilizable carbon (Pouyat et al., 2002) and nitrogen levels (Zhu and Carreiro, 2004) and in leaf-litter decomposition rates (McDonnell et al., 1997). In urban habitats the numbers of exotic, invasive and generalist species are also increasing (McDonnell & Pickett, 1990; McDonnell et al., 1997; McIntyre, 2000; Godefroid & Koedam, 2003; Honnay et al., 2003; Moffatt & McLachlan, 2003). Additionally, habitat loss and fragmentation (Miyashita et al., 1998; Gibbs & Stanton, 2001; Suarez & Case, 2002), alteration and modification of natural habitats (McIntyre et al., 2001; Gibb & Hochuli, 2002; Fernandez-Juricic, 2004; Shochat et al., 2004) all contribute to the effects of urbanisation. Urbanisation associated with the above mentioned changes of environmental conditions results in a densely populated, built-up, developed and often highly disturbed urban area (city centre) that is surrounded by areas of decreasing development and habitation with moderate (suburban area) or light disturbance (rural area) level (Dickinson, 1996). The highly affected city centre frequently maintains patches of natural habitats but these are usually more affected, managed, and fragmented than their suburban and rural complements. Such urban-rural gradients representing of diminishing intensities of human influence are characteristic of many cities around the world. Despite the prevalence and acceleration of urbanisation and the fact that urbanisation is considered one of the primary causes for the loss of biodiversity, little is known on whether or not changes caused by urbanisation affect biodiversity in similar ways across the globe (Niemelä et al., 2000).

Recently, an international research project called Globenet (Global Network for Monitoring Landscape Change) was initiated to assess and compare the impact of urbanisation on biodiversity (Niemelä et al., 2000). This project applies the urban-suburban-rural gradient approach (McDonnell et al., 1997; Pickett et al., 2001) using a common, standardised methodology (pitfall trapping) and evaluating the responses of common invertebrates to urbanisation. Up to now, majority of the published papers in the frame of the Globenet project investigated the ground beetles (Alaruikka et al., 2002; Niemelä et al,. 2002; Ishitani et al., 2003; Venn et al., 2003; Magura et al., 2004, 2005, 2006; Gaublomme et al., 2005; Sadler et al., 2006; Elek & Lövei, 2007). Studies analysing other target invertebrates are very limited (for spiders: Alaruikka et al., 2002; for isopods: Hornung et al., 2007; Vilisics et al., 2007). However, without additional studies investigating other reliable indicator taxa along the disturbance gradient, we can not answer whether urbanisation influences epigeic invertebrates in a similar manner across the world.

Urbanisation is usually considered as a form of environmental disturbance (Rebele, 1994). There are several hypotheses to explain the effects of disturbance on biotic communities. The first, and most widely known, is the intermediate disturbance hypothesis (Connell, 1978) which predicts the highest level of diversity at intermediate levels of disturbance. As an alternative, the increasing disturbance hypothesis suggests that species richness monotonously decreases with the increasing level of disturbance (Gray, 1989). As increasing disturbance affects primarily the specialist species, the habitat specialist hypothesis predicts that diversity of habitat specialist species should decrease as the level of disturbance increases (Magura et al., 2004).

The aim of the present study was to investigate the effects of urbanisation on ground beetle, terrestrial isopod and ground dwelling spider assemblages along an urban-rural gradient, and, in particular, to test the following predictions: (1) diversity should be the highest in the moderately disturbed suburban area (intermediate disturbance hypothesis); (2) diversity should decrease from a high value in the lightly disturbed rural area to a low one in the heavily disturbed urban area (increasing disturbance hypothesis); (3) species richness of the habitat specialist species should increase from the more disturbed urban area to the less disturbed rural one (habitat specialist hypothesis).

METHODS

Study Area and Sampling Design

Our study areas were in and around the town of Debrecen (Eastern Hungary), the second largest city of the country (204297 inhabitants in 2005). Three forested sampling areas were selected along an urban-rural gradient within the boundaries of the city, and in the surrounding forest reserve (Nagyerdő Forest Reserve). This represented urban, suburban and rural areas, according to the Globenet project protocol (Niemelä et al., 2000). In all sampling areas old forest stands (>100 yrs) dominated by English oak (*Quercus robur*) were studied. All stands covered an area of at least 6 ha. The characteristic, native forest vegetation of the sampling areas was Convallario-Quercetum association. The criteria for distinguishing sampling areas (urban, suburban, rural) was the ratio of the built-up area to the natural habitats measured by the ArcView GIS program using an aerial photograph. In the urban area the built-up area exceeded 60%, in the suburban area it was approximately 30%, while in the rural area the built-up area was 0%. In the urban area, several paths with asphalt surfaces have been created and the shrub layer was strongly thinned resulting in a park character, while in the suburban area fallen trees were removed.

Distance between the sampling areas was at least 1 km. Four sites (forest stands), in a distance of at least 50 m from each other (in order to achieve independency, see Digweed et al., 1995), were selected within each sampling area. Ground beetles (*Coleoptera: Carabidae*), terrestrial isopods (*Isopoda: Oniscidea*) and ground dwelling spiders (*Araneae*) were collected using pitfall traps, randomly placing ten traps at least 10m apart from each other at each site. This resulted in a total of 120 traps scattered along the urban-rural gradient (3 area × 4 sites × 10 traps). Each pitfall trap was at least 50m from the boundary of the forest stand, in order to avoid edge effects (Molnár et al., 2001). The pitfall traps were unbaited, consisting of plastic cups (diameter 65mm, volume 250ml) containing 75% ethylene glycol as a killing-preserving solution. The traps were covered with bark pieces to protect them from litter and rain (Spence & Niemelä, 1994). Pitfall traps were checked fortnightly from the end of March to the end of November, 2001. The total trapping effort was 4320 trap-weeks (120 traps × 36 weeks). During the analysis, samples of the individual traps were pooled for the whole trapping period.

Data Analysis

To test differences in the overall species richness of ground beetles, isopods and spiders and the species richness of habitat specialist species of the three studied invertebrate taxa among the three sampling areas (urban, suburban and rural) and among the 12 sites, nested analyses of variance (ANOVA) were performed using data from the individual traps (sites nested within the sampling areas). Based on the literature, the most adapted forest specialist species for living on the forest floor of the undisturbed sites were regarded as habitat specialist species (Hůrka, 1996; Schmalfuss, 2003; Buchar & Ruzicka, 2002). Normal distribution of the data was achieved by log(x+1) transformation (Sokal & Rohlf, 1995). When ANOVA revealed a significant difference between the means, Tukey test was performed for multiple comparisons among means.

RESULTS

Description of the Assemblages

Overall, 2140 individuals belonging to 50 ground beetle species were collected; in the urban area 477 individuals, belonging to 43 species were captured, 457 specimens of 26 species in the suburban area, and 25 species and 1206 individuals in the rural area. *Pterostichus oblongopunctatus* (Fabricius, 1787) was the most abundant species, which made up 49 % of the total catch.

The total isopod sample consisted of 9115 individuals representing 6 species. 3548 individuals belonging to 6 species were captured in the urban, 5 species and 2720 individuals in the suburban, and 4 species and 2847 individuals in the rural area. The superdominant species was *Armadillidium vulgare* (Latreille, 1804), its abundance made up 72 % of the total.

Altogether 409 spider specimens were trapped, belonging to 20 species. In the urban area 176 individuals belonging to 15 species, while in the suburban area 88 individuals of 8 species, and 145 individuals representing 6 species were captured in the rural area. *Pardosa alacris* (C. L. Koch, 1833) was the most abundant species, which made up 42% of the total catch.

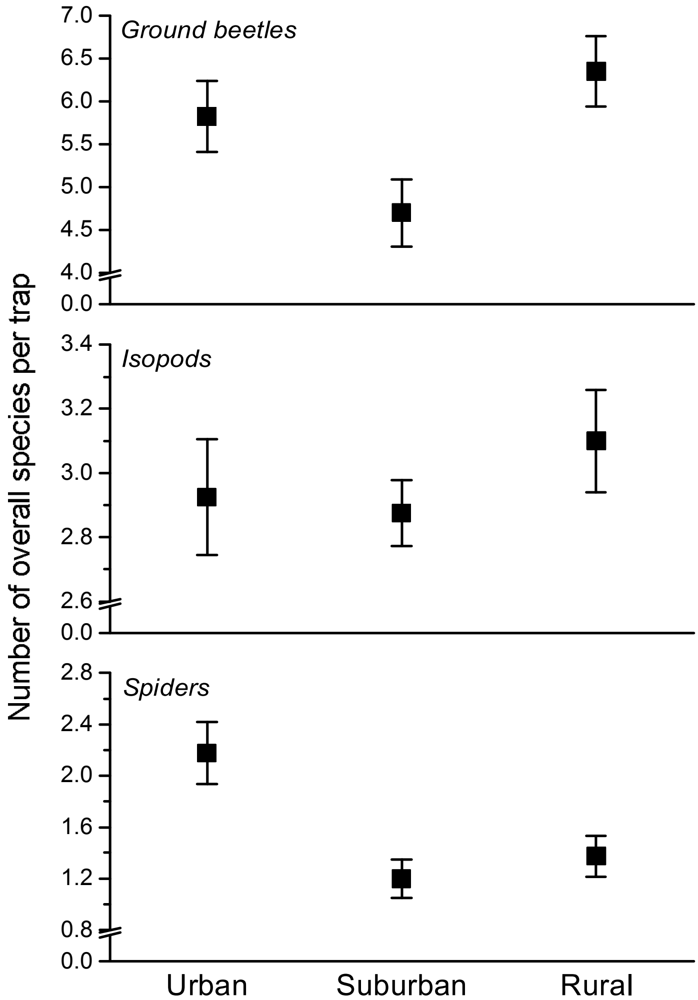

Figure 1. Average values (±SE) of the overall species richness of ground beetles, isopods and spiders along the urban-suburban-rural gradient calculated for the pitfall traps.

Patterns of Species Richness

Analysing the trap-level data by nested ANOVA, the overall species richness of ground beetles did not differ significantly across the urban-rural gradient (Table 1 and Figure 1). We did not found statistically significant differences in the overall species richness of isopods among the three sampling area (Table 1 and Figure 1). Overall spider species richness was significantly higher in the urban area compared to the suburban and rural ones (Table 1 and Figure 1). These results did support neither the increased disturbance hypothesis (the overall diversity should decrease under higher levels of disturbance), nor the intermediate disturbance hypothesis (diversity is the highest at intermediate levels of disturbance).

Table 1. Nested ANOVA showing differences in overall number of species and in the number of habitat specialist species along the urban-rural gradient and among the 12 sites

	Source of variation	**df**	**MS**	**F**	**p**	**Tukey test**
Overall number of ground beetle species	Gradient	2	0.1724	1.2089	ns	
	Sites	9	0.1426	4.4600	<0.001	
	Error	108	4.82			
Number of habitat specialist ground beetle species	Gradient	2	1.0670	15.4033	<0.001	U < S < R
	Sites	9	0.0693	3.8278	<0.001	
	Error	108	0.0181			
Overall number of isopod species	Gradient	2	0.0089	0.6306	ns	
	Sites	9	0.0141	0.6205	ns	
	Error	108	0.0228			
Number of habitat specialist isopod species	Gradient	2	0.7982	45.3010	<0.001	U < S = R
	Sites	9	0.0176	2.3333	<0.05	
	Error	108	0.0076			
Overall number of spider species	Gradient	2	0.2195	5.2217	<0.05	U > S = R
	Sites	9	0.0420	0.8317	ns	
	Error	108	0.0505			
Number of habitat specialist spider species	Gradient	2	0.0234	9.3008	<0.01	U = S < R
	Sites	9	0.0025	0.3571	ns	
	Error	108	0.0070			

Results of the Tukey test indicate which area(s) differs significantly (p<0.05) from the others; for example "Urban > Suburban = Rural" indicates that the variable was significantly higher in the urban area than in the suburban and rural areas (these two areas are not different from that point of view).

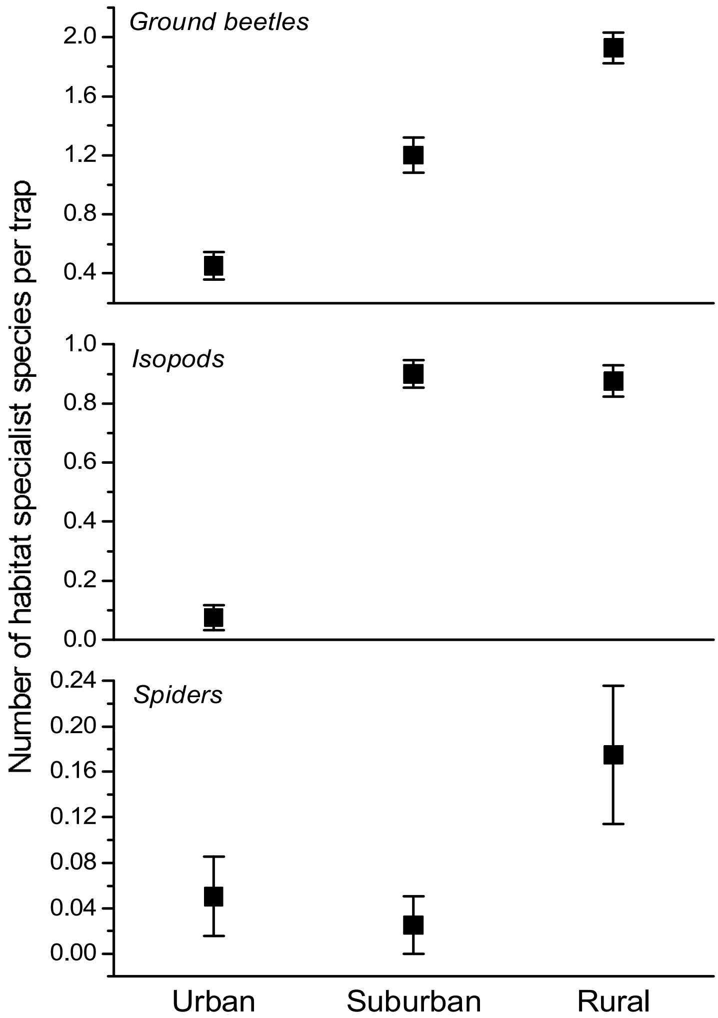

Figure 2. Average values (±SE) of the species richness of habitat specialist ground beetles, isopods and spiders along the urban-suburban-rural gradient calculated for the pitfall traps.

Analysing the habitat specialist species' richness (in our case the most adapted forest specialist species for living on the forest floor of the undisturbed sites) by nested ANOVA gave rather consistent results. Species richness of the habitat specialist ground beetles significantly increased along the urban-rural gradient (Table 1 and Figure 2). Species richness of the habitat specialist isopods were significantly higher in the suburban and rural areas compared to the urban one. Species richness of the habitat specialist spiders was significantly higher in the rural area than in the suburban and urban ones. These results support the habitat specialist hypothesis, which predicts that the diversity of habitat specialist species should increase from the more disturbed urban area towards the less disturbed rural one.

CONCLUSION

Intermediate Disturbance Hypothesis

Our findings did not support the intermediate disturbance hypothesis, as none of the overall species richness of the studied invertebrates was the highest in the moderately disturbed suburban area. Similarly, also all published studies of the Globenet project confute the intermediate disturbance hypothesis (for ground beetles: Alaruikka et al., 2002; Niemelä et al., 2002; Ishitani et al., 2003; Venn et al., 2003; Magura et al., 2004, 2005; Gaublomme et al., 2005; Sadler et al., 2006; Elek & Lövei, 2007; for isopods: Hornung et al., 2007; for spiders: Alaruikka et al., 2002). The explanation of this phenomenon can be that basal species of food webs probably conform to this hypothesis, but top consumers (like ground beetles and spiders) and decomposers (like isopods) do not (Wootton, 1998). Moreover, the impact of disturbances on biodiversity can be complex and the diversity-disturbance curves, deviating from a hump-shaped curve, can be bimodal, with a diversity peak at low disturbance and a second diversity peak at higher intensities (Johst & Huth, 2005). Other obvious reasons for the failure of the intermediate disturbance hypothesis may be due to the rather problematic quantification of the type, frequency and size of the disturbance events along urban-suburban-rural gradients. Therefore it is hard to arrange precisely the study areas along a disturbance continuum. Moreover, the intermediate disturbance hypothesis seems to be more appropriate to describe responses of non-equilibrium systems to the natural disturbance processes (like fires, floods, storms etc.).

Increasing Disturbance Hypothesis

It is generally accepted that the overall diversity should decrease in disturbed habitats (e.g. Gray, 1989). Our results, however, did not support this increasing disturbance hypothesis as the overall species richness of ground beetles and isopods was almost as high in the heavily disturbed urban area as in the lightly disturbed rural one, while the overall species richness of spiders was significantly the highest in the urban area. Some Globenet studies also contradict this hypothesis (for ground beetles: Alaruikka et al., 2002; results from Bulgaria in Niemelä et al., 2002; Magura et al., 2004, 2005; Elek & Lövei, 2007; for isopods: Hornung et al., 2007; for spiders: Alaruikka et al., 2002), whereas others support it (for ground beetles: results from Canada and Finland in Niemelä et al., 2002; Venn et al., 2003; Ishitani et al., 2003; Sadler et al., 2006). One possible reason for these altering responses (measured by the overall species richness) may be that the gradient from urban to rural is a complex system where many factors (temperature, moisture, edaphic conditions, acidity, pollution, decomposition etc.) interact (McDonnell et al., 1997, Niemelä, 1999). These factors are likely to be different in the different countries, which could lead to variation in responses of invertebrates along the urban-rural gradients (Ishitani et al., 2003). Furthermore, in the case of urban and suburban areas fragmentation-like effects also may appear, increasing the edges or edge-like habitats which may modify strongly the species pattern (Lövei et al., 2006). A more obvious reason for these rather inconsistent results is the diverse responses of invertebrates with different habitat affinity to disturbance. Since given groups of species may suffer (e.g.

habitat specialists), while other groups may benefit (e.g. generalists and/or invaders) from the disturbance and habitat alteration caused by urbanisation. For that reason, it is likely that the overall diversity is not the most appropriate indicator for disturbance. Therefore, species with different habitat affinity should be analysed separately to evaluate the real effect of urbanisation, otherwise the basic ecological rules may disguise.

Habitat Specialist Hypothesis

In accordance with the habitat specialist hypothesis, species richness of the habitat specialist invertebrates (expressed as the richness of the most adapted forest specialist species for living on the forest floor of the undisturbed sites) increased linearly (in case of ground beetles), asymptotically (as regards isopods) or exponentially (in case of spiders) along the urban-rural gradient. Earlier studies also demonstrated that urbanisation caused a pronounced change in the assemblages with the strongest effect upon the habitat specialist species (for ground beetles: Magura et al., 2004, 2005; Sadler et al., 2006; Elek & Lövei, 2007). Habitat specialist species (forest specialist species here) require microsites with a particular kind of environmental heterogeneity, such as favourable microclimate, presence of dead and decaying trees, significant cover of leaf litter, shrubs and herbs, together forming an undisturbed forest habitat (Desender et al., 1999; Hornung et al., 2007; Oxbrough et al., 2005). Habitat alteration caused by urbanisation appears to eliminate favourable microsites for specialist species and contributes to the decline of specialist species' richness in the assemblage. Along the studied gradient, disturbance was the highest in the urban area (paved paths, thinned shrub layer), it was moderate in the suburban area (fallen trees removed), and lowest in the rural area. This decreasing disturbance was also expressed by the increased species richness of specialists.

In conclusion, overall species richness as a sole indicator of the impacts of urbanisation on invertebrate assemblages is not an entirely suitable parameter. Species richness of habitat specialists should be considered to detect accurately the diversity pattern along the urbanisation gradient.

Implications for Management of Urban Forests

Forested urban habitat patches can retain species from the original forest fauna but the richness of the stenotopic specialist species will decrease as human disturbance increases. Nevertheless, urban green areas, including forest patches, have a vital recreational importance and contribute to the quality of urban life and thus should be conserved. Current urban habitat management accompanying by extensive alteration of habitat structure, however, could be one of the leading causes of loss of several specialist species (Davis, 1978; Samways, 2005). Therefore, there is a growing need for appropriate management strategies which simultaneously consider recreational, economic and conservation criteria (Gilbert, 1989). We propose that widespread modification of habitats (e.g. by strong thinning and removing decaying wood material) should be avoided. These alterations are associated with unfavourable changes in the microclimatic, abiotic and biotic conditions of the area. They cause shortage of shelter sites for e.g. survival, hiding and reproduction. All these changes have a direct, harmful effect on the composition of native invertebrate assemblages. Habitat alteration caused by urbanisation also has indirect effects on specialist species. The fragmentation of the original forest into small, isolated patches causes also a loss of sensitive specialist species through a reduction in the habitat area, an increase in remnant isolation and a decrease in habitat connectivity (Didham et al., 1996). The population size of specialist species in isolated patches could decrease because the patches are too small to maintain viable populations and there is too little dispersal between the patches. Small populations of specialist species in isolated patches are at greater risk of local extinction and genetic isolation. Therefore, habitat management minimising modification of habitat structure and trying to mimic natural processes could serve both the demands of city-dwellers and the maintenance of biodiversity.

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