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Abstract	Effects of urbanization on rove beetles were studied along a rural-suburban-urban forested gradient characterized by increasing human disturbance in and around Debrecen city (Hungary). Three classical and six novel hypotheses regarding the response of species to urbanization were tested. We found that overall species richness increased significantly with decreasing urbanization (i) as it is predicted by the increasing disturbance hypothesis, and contradicting (ii) the intermediate disturbance hypothesis that predicts the highest species richness in the moderately disturbed suburban area. (iii) The number of forest-associated species was significantly lower in the urban area compared to suburban and rural areas, as predicted by the habitat specialist hypothesis. All of the proposed novel hypotheses are about habitat alteration caused by the urbanization were corroborated. The (iv) richness of hygrophilous species was the highest in the rural area (hygrophilous species hypothesis), while (v) the number of thermophilous species was higher in the urban area (thermophilous species hypothesis). The richness of species directly or indirectly feeding on decaying organic materials ((vi) saprophilous, (vii) phytodetriticol, (viii) myrmecophilous, (ix) mycetophilous species hypotheses) was also highest in the rural area compared to the urban one. We stress that overall species richness is not the most appropriate indicator of the impacts of urbanization and accompanying disturbance on these beetles. Instead, habitat affinity and ecological traits of the species give more information about what habitat properties and environmental variables change drastically during urbanization.
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ORIGINAL PAPER

Rove beetles respond heterogeneously to urbanization

Tibor Magura · Dávid Nagy · Béla Tóthmérész

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Abstract Effects of urbanization on rove beetles were studied along a rural-suburban-urban forested gradient characterized by increasing human disturbance in and around Debrecen city (Hungary). Three classical and six novel hypotheses regarding the response of species to urbanization were tested. We found that overall species richness increased significantly with decreasing urbanization (i) as it is predicted by the increasing disturbance hypothesis, and contradicting (ii) the intermediate disturbance hypothesis that predicts the highest species richness in the moderately disturbed suburban area. (iii) The number of forest-associated species was significantly lower in the urban area compared to suburban and rural areas, as predicted by the habitat specialist hypothesis. All of the proposed novel hypotheses are about habitat alteration caused by the urbanization were corroborated. The (iv) richness of hygrophilous species was the highest in the rural area (hygrophilous species hypothesis), while (v) the number of thermophilous species was higher in the urban area (thermophilous species hypothesis). The richness of species directly or indirectly feeding on decaying organic materials ((vi) saprophilous, (vii) phytodetriticol, (viii) myrmecophilous, (ix) mycetophilous species hypotheses) was also highest in the rural area compared to the urban one. We stress that overall species richness is not the most appropriate indicator of the impacts of urbanization and accompanying disturbance on these beetles. Instead, habitat affinity and ecological traits of the species give more information about what habitat properties and environmental variables change drastically during urbanization.

Keywords Diversity · Disturbance · Forest specialist species · GlobeNet · Habitat affinity · Staphilinids

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Introduction

The process of urbanization includes spatial expansion, population growth in urban settlements and the stretch of the urban life's form. Currently, urbanization and its accompanying environmental impacts are a most important challenge for humanity. Urbanization radically alters native environments and forms new, artificial habitats. Nowadays, 3.5 billion people on Earth are living in cities. Globally, urban populations are projected to increase to 6.4 billion in 2050 (United Nations 2009). Thus, a better understanding of the relationship between the urbanization and ecosystem functioning is important for developing strategies to mitigate unwanted environmental impacts of urbanization for humans.

Urban landscapes typically consist of densely built and highly developed urban core areas surrounded by suburban and rural areas characterized by decreasing intensity of development and increasing naturalness. Rural–urban gradients have this general appearance all over the world, although the exact type of ecosystems involved differs (McDonnell et al. 1997; Niemelä 1999; Niemelä et al. 2000). From rural areas to urban centers the number and the density of human inhabitants increases, along with road density, area covered by artificially created surfaces, and air and soil pollution. Nitrogen (N) deposition, heavy metal content of soil and plants, and decomposition rate are all higher in urban areas than their rural surroundings (Carreiro and Tripler 2005; Simon et al. 2011a, b, 2012a, b, 2013a, b). In addition, ecosystem processes, litter decomposition and soil N dynamics vary significantly along the urban–rural gradient (McDonnell et al. 1997). As habitat is lost to urban development, the habitat that supports the biota becomes increasingly fragmented into more numerous but smaller remnant patches (Collins et al. 2000). In addition to buildings and sealed surfaces, natural habitat for native species is also lost to managed areas (residential, commercial, and other regularly maintained green spaces), ruderal spaces (empty lots, abandoned farmland, and other green space that is cleared but not managed) and remnant patches of native habitats invaded non-native plants (Deutschewitz et al. 2003). As a consequence of fragmentation, connection between the natural habitat patches is often minimal in the urban areas and this appears to reduce species richness (number of species). There are, however, many factors that can affect the rate and consistency of species loss and gain along the gradient, so empirical studies are crucial in measuring urban impacts (McKinney 2008).

A number of anthropogenic activities, such as urbanization, farming and forestry create modified land types that exhibit similar patterns throughout the world (Paillet et al. 2009). To assess the general trends of urbanization on arthropods, there is an urgent need to investigate responses of a range of taxa along the rural–urban gradient. The family of rove beetles (*Coleoptera: Staphylinidae*) is one of the largest families of beetles, with about 32,000 known species (Newton 1990). Rove beetles are distributed worldwide and are found in practically all types of terrestrial ecosystems. About half of rove beetle species are found in litter, and they are among the most common and ecologically important insect components of the soil fauna. Taxonomy, habitat requirements and ecological traits of European rove beetle species are reasonably well known (Boháč 1999). They are fairly easy to collect, and being mobile and relatively short-lived, they adjust rapidly to changes in abiotic and biotic environmental variables and human disturbances. For all of these reasons they have excellent potential as monitoring group (Boháč 1999; Klimaszewski and Langor 2009). In spite of this, staphylinids are used less often than other beetles in indicator studies.

Urbanization is usually considered as a form of environmental disturbance (Rebele 1994). There are several hypotheses to explain the effects of disturbance on biotic communities. Most of these hypotheses make predictions about effects on overall species richness. However, species with different ecological traits respond variously to natural and anthropogenic disturbances (Lövei et al. 2006; Magura et al. 2010a). Therefore, it is important to investigate the groups of species with different ecological traits separately. The aim of the present study was to investigate the effects of urbanization on rove beetles, a beetle taxon that has not yet been studied in the frame of the international Globenet project. In particular, we tested three classical and six novel hypotheses regarding the response of species to urbanization: (i) The increasing disturbance hypothesis claims that species richness monotonously decreases with the increasing levels of disturbance (Gray 1989). (ii) The intermediate disturbance hypothesis predicts that species richness is the highest in the moderately disturbed suburban area (Connell 1978). (iii) The habitat specialist hypothesis predicts that the species richness of forest-associated species decreases with the increasing disturbance (Magura et al. 2004). Our novel hypotheses are related to the habitat alteration caused by the urbanization. Urbanization radically alters the original habitat, the urban forest patches become more open, drier and warmer compared to the suburban and rural ones. Therefore, (iv) the richness of hygrophilous species should be the highest in the rural area (hygrophilous species hypothesis), while (v) the richness of thermophilous species should be the highest in the urban area (thermophilous species hypothesis). In the urban area and somewhat in the suburban area decaying organic material are usually removed during the management of forest patches. Therefore, (vi) the richness of saprophilous species (saprophilous species hypothesis), and (vii) the richness of species living in decaying plant debris (phytodetriticol species hypothesis) should be the highest in the less modified rural area. As ants and fungi prefer habitats with dense dead and decaying organic material, therefore (viii) the richness of myrmecophilous species (myrmecophilous species hypothesis), and (ix) the richness of species preferring the fungi (mycetophilous species hypothesis) also should be the highest in the rural area.

Methods

Study area

The study area was in and around Debrecen city (47°32′N; 21°38′E), the second largest city of Hungary (208,000 inhabitants in 2011), located in the eastern plains area near the country's eastern border (Magura et al. 2004). Three forested areas, representing rural, suburban and urban habitats, were

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selected along an rural–urban gradient running from the adjacent Nagyerdő Forest Reserve into the city. These areas had formerly (a few hundred years ago) been part of a continuous aged (older than 100 years) native *Convallario-Quercetum* forest association. All sampled areas were larger than 6 ha (urban: 6–10 ha, suburban: 6–8 ha, rural: 6–12 ha). Intensity of urbanization was characterized by the ratio of the anthropogenically modified areas (buildings, roads and asphalt covered paths) to natural habitats, as calculated in a GIS (ArcGIS) based on an aerial photograph made in 2009. In the rural area none of the land was covered by built-up surfaces. In contrast, on average 30 % of the suburban area was modified, and >60 % of the surface area in the urban area was built up. In addition, the intensity of the habitat maintenance operations also differed among the three categories of land. In the rural area there were only occasional low-intensity forestry management operations. In habitat management of suburban forest, however, fallen trees and branches were removed, although understory vegetation was largely undisturbed. The urban forest patches were largely park-like; fallen trees and branches were regularly removed, the shrub layer was thinned and highly disturbed, and grass between urban forest patches was frequently mowed and removed. The distance between the sampling areas (rural, suburban and urban) was 1–3 km.

Sampling design

Two sites, at least 100 m apart, were selected within each of the three sampling areas. Rove beetles were collected using ten unbaited pitfall traps placed randomly at least 10 m apart from each other at each site. This resulted in a total of 60, 10 traps in two replicated forest stand at each stage of the gradient. All traps were at least 50 m from the nearest forest edge, in order to avoid edge effects (Molnár et al. 2001). Pitfall traps were plastic cups (diameter 65 mm) containing about 100 ml of 4 % formaldehyde as a killing-preserving solution. Traps were covered by a square (20 × 20 cm) of fiberboard minimize accumulation of litter and rain. Rove beetles species were collected fortnightly from the end of April to the end of October 2009.

Data analyses

Catches were pooled for the year for analysis. We used nested (sites within sampling areas) GLMs to test differences in the overall rove beetle species richness and the species richness of the rove beetles with different ecological traits among the three areas and among the 6 sites. The response variable (species richness) was a Poisson distribution (with log link function), assuming that the mean and variance of the data were equal. However, because the variance is expected to be larger than the mean overdispersion was also incorporated into the model using quasi-Poisson distribution (Zuur et al. 2009). When the overall GLMs revealed a significant difference between the means, an LSD test was performed for multiple comparisons among means. Ecological traits of rove beetles (forest, hygrophilous, thermophilous, saprophilous, phytodetriticol, mycetophilous, and myrmecophilous species) were obtained from the literature (Irmler and Gürlich 2007; Koch 1989; Stan 2008; Table 1). Composition of rove beetle assemblages along the gradient was compared at trap level using nonmetric multidimensional scaling based on presence-absence data using the Rogers-Tanimoto index of similarity (Legendre and Legendre 1998).

Results

Altogether 3105 individuals belonging to 84 species were trapped during the study (Table 1). This included 1,229 from 60 species in the rural area, 1,204 individuals of 50 species in suburban forest and 672 individuals of 49 species in urban sites. The most numerous species was *Omalium caesum*; 761 individuals were trapped comprising 24.5 % of the total catch and it was the most abundant species in all three sampling areas (Table 1).

The overall species number decreased significantly from the rural sites to the urban ones ($\chi^2 = 75.7$; df = 2, 3; $p < 0.0001$, Fig. 1a). Number of forest-associated species was significantly lower in the urban than in either the suburban or rural areas ($\chi^2 = 37.0$; df = 2, 3; $p < 0.0001$, Fig. 1b). Number of species that appear to respond to environmental conditions based on their lifestyle or habitat use varied significantly along the gradient. For example, number of hygrophilous species decreased significantly from the rural area towards the urban forest ($\chi^2 = 60.0$; df = 2, 3; $p < 0.0001$, Fig. 2a), while number of thermophilous species was significantly higher in the urban area compared to the suburban and rural forests ($\chi^2 = 7.7$; df = 2, 3; $p = 0.0214$, Fig. 2b). Number of species relating directly or indirectly to decaying organic materials also changed significantly along the gradient. Numbers of saprophilous, phytodetriticol species and myrmecophilous species were significantly highest in the rural area ($\chi^2 = 16.47$; df = 2, 3; $p = 0.0003$; $\chi^2 = 45.81$; df = 2, 3; $p < 0.0001$; $\chi^2 = 39.31$; df = 2, 3; $p < 0.0001$, respectively; Fig. 3a-c). The number of mycetophilous species did not differ between rural and suburban areas but was significantly higher than in the urban forest ($\chi^2 = 19.4$; df = 2, 3; $p < 0.0001$, Fig. 3d).

The rove beetle assemblages of the rural, suburban and urban areas were clearly separated from each other by the ordination (Fig. 4). Assemblages from rural forests were separated from those of suburban and urban habitats along the first axis. Clearly, composition of the rove beetle

Table 1 Habitat affinity, ecological traits and the trapped number of individuals of the rove beetle species along the urbanization gradient

Species	Habitat affinity and ecological traits	Rural	Suburban	Urban
Abemus chloropterus	For, Hyg	62	115	28
Aleochara erythroptera	Hyg, Myc, Phy	6	1	0
Anotylus rugosus	Hyg, Myc, Phy, Sap	5	1	1
Anthobium atrocephalum	Phy	14	16	11
Astenus immaculatus	Hyg, Phy	1	0	3
Atheta gagatina	Myc, Phy	1	1	9
Atheta sodalis	For, Myc, Phy	0	4	1
Atheta triangulum	Myc, Phy, Sap	4	2	4
Bolitochara bella	Myc	1	0	0
Byraxis curtisii orientalis	Phy	1	2	0
Dropephylla ioptera	For, Hyg, Myc,	0	1	0
Drusilla canaliculata	Phy	1	0	0
Enalodroma hepatica	For	1	0	1
Gabrius osseticus	Hyg, Phy	89	11	5
Geostiba circellaris	Hyg, Myc	3	2	3
Gyrohypnus angustatus	Hyg, Phy	24	58	81
Habrocerus capillaricornis	Myc, Phy	2	3	1
Heterothops dissimilis	Phy	7	1	2
Ilyobates bennetti	Hyg, Phy	13	15	0
Ilyobates nigricollis	For, Hyg, Phy	0	4	1
Lathrobium brunnipes	Hyg, Phy	4	0	0
Lathrobium geminum	Hyg, Phy	14	0	1
Liogluta granigera	Myc, Phy	4	0	0
Liogluta longiuscula	Hyg, Myc, Phy	90	49	20
Mocyta fungi	Hyg, Myc, Phy	6	1	0
Mocyta orbata	Hyg, Myc, Phy	3	1	0
Mycetoporus eppelsheimianus	For, Myc	1	0	2
Mycetoporus erichsonanus	Myc	0	1	0
Mycetoporus forticornis	For, Hyg	0	1	0
Mycetoporus lepidus	Phy	0	4	0
Mycetota laticollis	Phy	0	0	1
Ocalea badia	Hyg, Phy	2	0	0
Ocypus brunnipes	For, Hyg, Myc, Phy	0	2	6
Ocypus mus	For, Myc	7	40	0
Ocypus nitens	For, Hyg	21	43	1
Oligota pusillima	Myc, Phy	0	1	0
Omalium caesum	Hyg, Myc, Phy	257	277	227
Omalium rivulare	Hyg, Myc, Phy, Sap	142	156	90
Ontholestes haroldi	Phy	73	231	50
Othius punctulatus	For, Phy	16	4	0
Oxypoda abdominalis	Myc, Phy	2	8	0
Oxypoda acuminata	Hyg, Myc, Phy	87	13	22
Oxypoda longipes	Phy	0	1	0
Oxypoda opaca	Myc, Phy	5	0	0
Oxypoda vittata	Myr	30	5	1
Paederus balcanicus	Hyg	0	0	1
Pella laticollis	Myr	10	0	0
Pella lugens	Myr	39	4	1

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Table 1 continued

Species	Habitat affinity and ecological traits	Rural	Suburban	Urban
Pella ruficollis	For, Myr	7	0	0
Philonthus carbonarius	Phy	1	0	0
Philonthus intermedius	Phy, Sap	1	0	0
Philonthus laminatus	Myc, Phy, Sap	4	0	0
Philonthus succicola	Myc, Phy	1	0	0
Philonthus tenuicornis	Myc, Phy	0	1	0
Phyllodrepa floralis	Phy	1	0	0
Platydracus fulvipes	For, Hyg	5	14	4
Platystethus cornutus	Hyg	0	1	0
Pselaphus heisei	Phy	0	1	0
Quedius curtipennis	Hyg, Phy	18	4	1
Quedius fuliginosus	Hyg, Phy	2	0	1
Quedius limbatus	For, Hyg, Myc	2	5	0
Quedius longicornis	Hyg	0	0	2
Quedius molochinus	Hyg, Phy	3	0	0
Quedius ochripennis	Phy	0	0	1
Quedius scintillans	Phy	0	1	2
Rugilus rufipes	Hyg, Phy	26	78	24
Sepedophilus marshami	Myc, Phy	2	2	4
Sepedophilus obtusus	Phy, The	0	1	2
Staphylinus erythropterus	For, Hyg	9	0	1
Stenus humilis	Hyg, Phy	2	0	9
Stenus ludyi	For, Hyg, Phy	3	0	2
Stenus ochropus	Hyg, The	0	0	1
Sunius fallax	Phy	0	0	4
Tachinus rufipes	Myc, Sap	10	0	0
Tachyporus formosus	For, Hyg	3	0	0
Tachyporus hypnorum	Hyg, Myc, Phy	0	2	1
Tachyporus nitidulus	Myc, Phy	0	1	0
Tasgius melanarius	Phy	21	5	2
Tasgius morsitans	Phy, The	5	6	16
Tasgius winkleri	Phy	0	0	2
Xantholinus dvoraki	Phy	0	0	1
Xantholinus linearis	Phy	1	0	2
Xantholinus tricolor	For, Phy	53	3	15
Zyras haworthi	Myr, The	1	0	1

For forest species, *Hyg* hygrophilous species, *The* thermophilous species, *Sap* saprophilous species, *Phy* phytodetriticol species, *Myc* mycetophilous species, *Myr* myrmecophilous species

assemblages of suburban and urban areas was more similar to each other than to the assemblages of the rural area.

Discussion

Overall species richness

Our findings did not support the intermediate disturbance hypothesis, as the overall species richness of the rove beetles was not highest in the moderately disturbed suburban area. The Romanian research examining ground beetles (Tóthmérész et al. 2011) were the only ones of the published Globenet studies that supported the intermediate disturbance hypothesis. The other studies, similarly to our results, disprove this hypothesis (for ground beetles: Alaruikka et al. 2002; Niemelä et al. 2002; Magura et al. 2004, 2005; Gaublomme et al. 2008; for isopods: Magura et al. 2008a; for spiders: Alaruikka et al. 2002; Magura et al. 2010a). Thus, most of the published results contradicted the prediction of the intermediate disturbance hypothesis. Obvious reasons for the failure of the intermediate disturbance hypothesis may be due to the rather problematic quantification of the type, frequency and size

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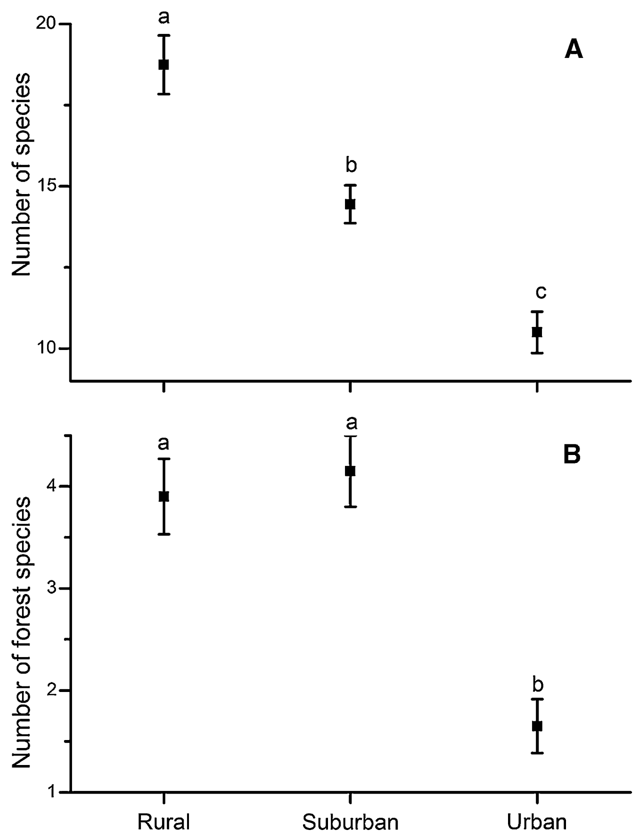

Fig. 1 Average richness of the overall rove beetle species (**a**) and the forest-associated rove beetle species (**b**) (±SE) along the studied urbanization gradient for the pitfall traps. *Different letters* indicate significant differences by LSD test ($p < 0.05$)

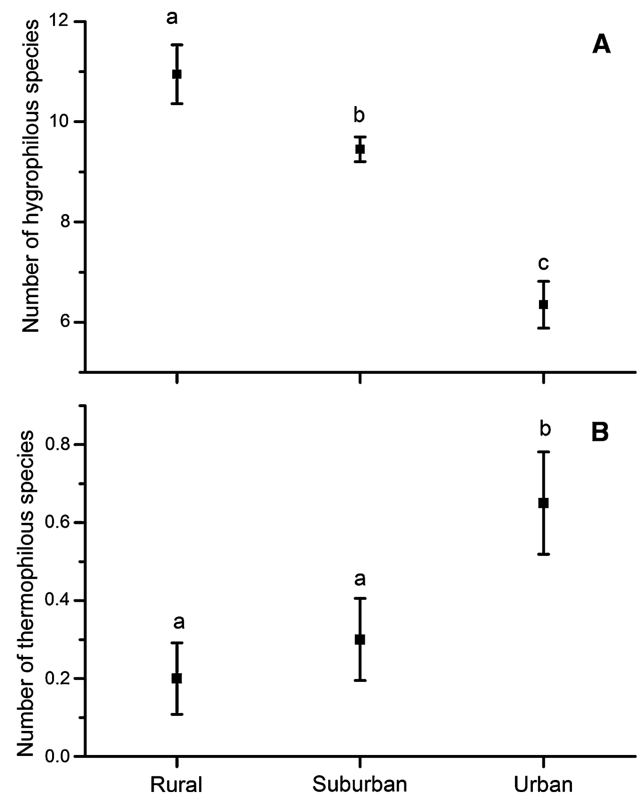

Fig. 2 Average richness of the hygrophilous rove beetle species (**a**) and the thermophilous rove beetle species (**b**) (±SE) along the studied urbanization gradient for the pitfall traps. *Different letters* indicate significant differences by LSD test ($p < 0.05$)

of the disturbance events along the rural-suburban-urban gradients. Therefore, it is hard to arrange precisely the study areas along a disturbance continuum.

The richness of rove beetles increased significantly with decreasing urbanization. This is similar to results with ground beetles for which similar patterns have been reported from Belgium, Canada, Finland, Japan and the United Kingdom (Niemelä et al. 2002; Gaublomme et al. 2008). However, this pattern has not been consistently found. In studies of isopods (Hornung et al. 2007) and ground-dwelling spiders from Hungary (Magura et al. 2010a; Horváth et al. 2012), and ground-beetles from Bulgaria and Denmark (Niemelä et al. 2002; Elek and Lövei 2007) there was no decreasing relationship between urbanization and species diversity. Urbanization generates several forms of disturbance, including loss, alteration, fragmentation and isolation of the original habitats, changes in temperature, moisture, edaphic conditions and air pollution (Niemelä 1999). Moreover, more frequent disturbance seems to homogenize urban forests patches, perhaps eliminating microhabitats favored by some species. Disturbances in urban and suburban areas are continuous, directed and long lasting, leading to decreased diversity (Niemelä et al. 2002).

Clearly, results from studies of overall species richness along the rural–urban gradient are inconsistent. For that reason it is likely that overall species richness itself is not easily interpreted as an indicator of the impacts of urbanization and accompanying disturbance. Some groups of species may decline with habitat loss (e.g., habitat specialists), while other species may increase in number (e.g., opportunistic species) because of the disturbance and habitat alteration caused by urbanization. Thus, impacts on species with different habitat affinity should be analyzed separately to better interpret the effects of urbanization.

Species richness of forest-associated rove beetles

The number of forest associated rove beetle species was significantly lower in the heavily disturbed urban area compared to moderately and minimally disturbed suburban and rural area. In Hungary the abundance of forest specialist terrestrial isopod species also decreased significantly from the rural area toward urban habitats (Magura et al. 2008a). No significant difference in the number of forest specialist spider species was reported across a rural–urban gradient in Finland, while in Hungary the number of forest specialist spiders was significantly highest in the rural area

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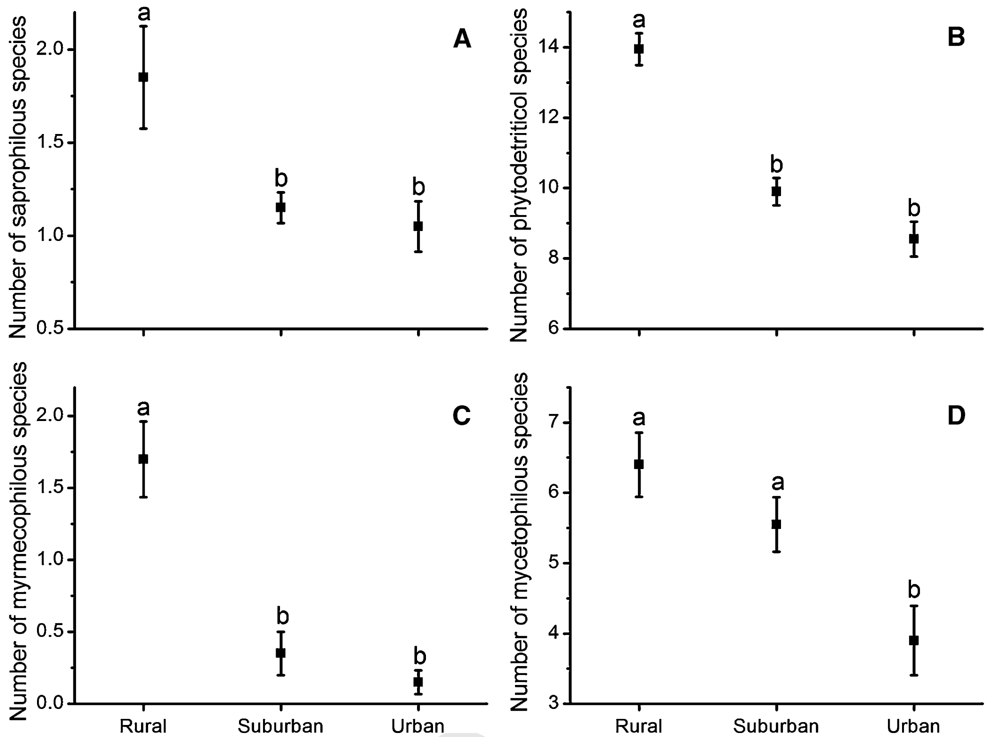

Fig. 3 Average richness of the saprophilous rove beetle species (**a**), the phytodetriticol rove beetle species (**b**), the myrmecophilous rove beetle species (**c**), and the mycetophilous rove beetle species (**d**) (±SE) along the studied urbanization gradient for the pitfall traps. *Different letters* indicate significant differences by LSD test ($p < 0.05$)

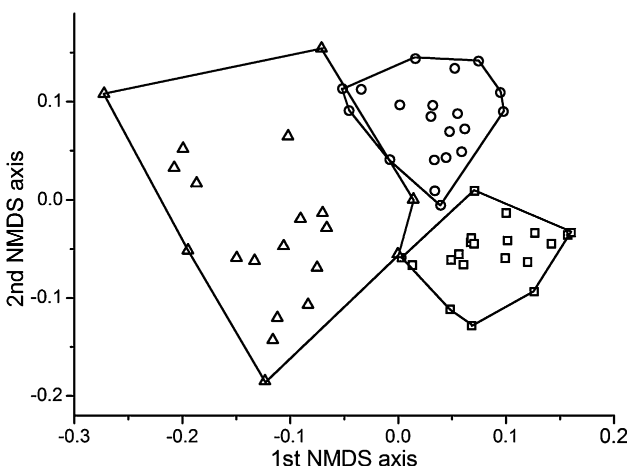

Fig. 4 Ordination (nonmetric multidimensional scaling using the Rogers-Tanimoto index of similarity) of the rove beetle assemblages along the studied rural–urban gradient (*unfilled triangles*: rural traps, *unfilled circles*: suburban traps, and *unfilled squares*: urban traps)

(Magura et al. 2010a). In general it appears that habitat modification associated with urbanization exerts a strong effect upon forest specialist species even in residual forest patches (Niemelä and Kotze 2009; Magura et al. 2010b).

Forest specialist species require a particular kind of environmental heterogeneity associated with provision of favorable microclimate, dead and decaying trees, and significant cover of leaf litter, shrubs and herbs, as in an undisturbed forest habitat (Desender et al. 1999). Urbanization appears to eliminate favorable microsites for forest specialist species and thus contributes to the decline of specialist species' richness in the assemblage. Others have demonstrated that rove beetles are especially sensitive to modification of forested habitat (Boháč 1999; Pohl et al. 2007, 2008; Klimaszewski and Langor 2009), and the proportion of forest specialist staphylinid species decreased, as in the present study, with increasing urbanization in Berlin (Deichsel 2006).

Richness of species indicating habitat alteration

Urbanization drastically modifies the original habitats (McKinney 2008), and in our study the nature of some of these changes was underscored by responses of sensitive species. For example, number of hygrophilous species was highest in the rural area, while the number of thermophilous species was highest in the urban area. The number of the species associated with decaying organic materials (saprophilous species, phytodetriticol species, myrmecophilous species and mycetophilous species) was also highest in the rural area and reached its lowest value in urban habitats. It seems that the fauna responded to increasing dryness and a general reduction in forest floor organic matter on the urban end of the gradient.

The urban forest studied here is considerably fragmented by paved footpaths, increasing edge habitat within the forest patches. This fragmentation together with cutting of the shrub layer, allows sunlight to penetrate more deeply, making urban forest patches drier and warmer (McDonnell et al. 1997). These features of urban patches support survival and/or immigration of open-habitat species that do best under

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lighter, warmer and drier conditions. Similar findings have been published for terrestrial isopods (Magura et al. 2008a), ants (Vepsäläinen et al. 2008), ground dwelling spiders (Magura et al. 2010a), ground beetles (Magura et al. 2004, 2008b; Tóthmérész et al. 2011), and weevils (Germann et al. 2008), suggesting that this situation applies quite generally to invertebrates in urban forest patches.

In both urban and suburban areas dead and decaying organic materials are commonly removed from forest patches as part of the management regime. Intensity of this sort of habitat management will be generally highest in urban areas, and in our study, it certainly decreased through suburban to rural areas. Decaying wood material provides favorable microclimate, shelter against predators, and sites suitable for feeding, aestivation, hibernation, overwintering, egg and larval development and thus, the number of the saprophilous rove beetle species decreased along the rural–urban gradient. Similarly to our finding, Vepsäläinen et al. (2008) reported that in urban environments ant species dependent on dead wood were very rare. Similar trend was reported for spiders as forest species requiring presence of dead and decaying wood materials were more species rich in the rural sites characterized by higher amounts of decaying woods (Magura et al. 2010a).

Intensity of urbanization is a function of disturbance and the structural simplification of remaining habitat by management practices that remove not only the dead woody and herbaceous material, but the living trees, shrubs and herbs. These practices decrease the habitat quality of remaining habitats (McKinney 2008). In the present study, reductions in coarse woody material and litter doubtlessly were associated with decreasing of the richness of species using decaying plant debris ad habitat (phytodetriticol species). Reductions in plant debris are also harmful for rove beetle larvae. As they are soil bound and less mobile than adults (Boháč 1999), disturbance of the litter and soil are important in determining their survival and thus adult population size. Together with similar findings for terrestrial isopods and millipedes (Riedel et al. 2009) and ants (Savitha et al. 2008) our results suggest that dense decaying plant debris and litter promote the establishment and maintenance of species rich assemblages.

Myrmecophilous staphylinids are specialized predators that eat ants or saprophages living on waste in or near ant nests (Boháč 1999). Lessard and Buddle (2005) and Vepsäläinen et al. (2008) reported decreased ant species richness in urban areas relative to surrounding rural areas, and that the decline varied directly with the degree of the urbanization. Vepsäläinen et al. (2008) also reported that ant species dependent on dead wood were rare or absent in urban areas that they studied. Therefore, significant impoverishment of the myrmecophilous rove beetle species in the urban forest patches was expected. The occurrence of aggressive, dominant and competitively dominant non-native species in urban areas could negatively affect not only the other ant species, but also the other ground-dwelling arthropods (Lessard and Buddle 2005).

Mycetophilous rove beetles live in or near fungi (Boháč 1999). Fungi are sensitive to environmental changes, specialized in substrate requirements, and depend on decomposing organic plant material as their living substrate (Rayner and Boddy 1988). Thus, urbanization is associated with decreases in abundance and species richness in urban areas (McDonnell et al. 1997). In consequence of the impoverishment of fungi at the urban forest patches, our hypothesis assumed significant decrease of the mycetophilous rove beetle species along the rural–urban gradient. Earlier results also showed that urbanization negatively affected both the fungivous microinvertebrates (nematods, microarthropods) and the fungi. Moreover, the larvae of the rove beetles are more sensitive to air pollution (Boháč 1999), so damage of the larvae could negatively affect the abundance and species richness of imagoes.

Conclusions

Our results show that urbanization had a strong effect on rove beetles, with their overall species richness decreasing significantly with urbanization. Thus, this group, although not frequently used as such, are reliable indicators of urbanization. Species composition of rove beetle assemblages changed remarkably along the studied rural-suburban-urban gradient, something that likely reflects disproportionate effects on species associated with organic matter and the degree of openness in forest habitats. We conclude that overall species richness is not a sufficient indicator of urbanization and its accompanying disturbance because it does not include an understanding of these disproportionate effects. Therefore, species with different habitat affinity should be analyzed separately to evaluate the real effects of urbanization. In this way we showed, that in accordance with the habitat specialist hypothesis, the number of forest-associated rove beetle species was significantly lower in the heavily disturbed and altered urban area compared to the suburban and rural area. Beside the habitat affinity of the species, the ecological traits of the species are also important. Namely, species with different ecological traits may also response variously to the urbanization and the accompanying processes. Thus, ecological traits of the species should be considered to detect accurately those environmental variables that changed drastically during the urbanization.

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