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ORIGINAL ARTICLE

Bark or crown? Spiders (Araneae) and beetles (Coleoptera) on trees in a city centre

Ondřej VANĚK[1], Jan WALTER[2,3,*], Ivana HRADSKÁ[2] and Zdeněk FALTÝNEK FRIC[4]

[1] Gymnázium a Střední odborná škola, Mládežníků 1115, 337 01 Rokycany, Czech Republic; e-mail: ondras.vanek@seznam.cz

[2] Museum of West Bohemia, Department of Zoology, Kopeckého sady 2, 301 00 Plzeň, Czech Republic; e-mails: jwalter@zcm.cz, ihradska@zcm.cz

[3] Faculty of Science, University of South Bohemia, Branišovská 31, 370 05 České Budějovice, Czech Republic

[4] Biology Centre of the Czech Academy of Sciences, Institute of Entomology, Branišovská 31, 370 05 České Budějovice, Czech Republic; e-mail: fric@entu.cas.cz

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Abstract. Rapid urbanisation during the last century caused declines in species diversity. Cities encompass only a limited number of highly fragmented natural habitats and thus trees remain an important key factor for survival of local invertebrates. In 2021, we surveyed spider and beetle assemblages inhabiting trees in Pilsen city (Czech Republic). We selected 18 deciduous trees in the surroundings of the city centre and sampled bark species using corrugated cardboard bands, and crown species using a sweep net. The recorded species were evaluated using their functional traits such as habitat and humidity preferences, body size, and feeding guilds – i.e., the methods of spiders' feeding strategies. Altogether, we recorded 35 spider species/295 individuals, and 43 beetle species/265 individuals. We observed significant differences between the number of species and individuals inhabiting bark and tree crowns. Spiders tended to inhabit bark, while beetles inhabited tree crowns. The trees frequently contained species with different functional traits and with opposite requirements.

INTRODUCTION

Urbanisation has had a crucial impact on the decline of biodiversity due to the loss and fragmentation of natural habitats (McLaughlin & Mineau, 1995), and is increasing globally as people move from rural landscapes to cities. As a result of urbanisation, countless species have become extinct, or their occurrence has become restricted to small isolated habitats, and thus rare in common landscapes (van Swaay & Warren, 1999).

Urban habitats, especially cities, are characterised by extreme habitat conditions such as high temperature, drought stress, water stress, anthropogenic pollution, and reduced vegetation cover (Novák & Konvička, 2006; Horváth et al., 2014; Magura & Lövei, 2021). On the other hand, urban areas host great invertebrate diversity as places where many rare and important species can exist despite extreme conditions (Owen & Owen, 1975; Jones, 2003). Insects respond to the urbanisation gradient differently. For instance, lower species diversity of butterflies and flies has been observed in cities in comparison with neighbouring rural sites, whereas species richness of Hymenoptera was higher in cities (Theodorou et al., 2020). Similarly, assemblages of carabid beetles (Magura et al., 2004) and spiders (Magura et al., 2010; van Keer et al., 2010; Lövei et al., 2019) may prosper well in a city.

Species of "non-flying" or not typically flying invertebrates, due to their limited mobility, are more sensitive to habitat change (Thomas, 2000). They prefer sites where food sources are available in sufficient quantity so that they do not need to waste energy by moving (Gadgil, 1971; Doebeli & Ruxton, 1997). Trees represent suitable sites for invertebrates in urban areas, where high species richness on trees has been repeatedly proven (Machač & Tuf, 2019). Generally, trees represent an important landscape element, providing many benefits such as a cooling effect, oxygen production, improving people's mental health, and they also encourage biodiversity (Raupp et al., 2010). The specific microclimatic conditions, as well as the structures of bark and tree crowns, are key factors affecting their biodiversity (Nikolai, 1986). The affinity to the trees differs partly not only within groups of invertebrates but also at the species level, depending on the species' ecology. Some spiders live on tree trunks throughout the year, some during overwintering only, or, in the case of facultative bark-

* Corresponding author; e-mail: jwalter@zcm.cz

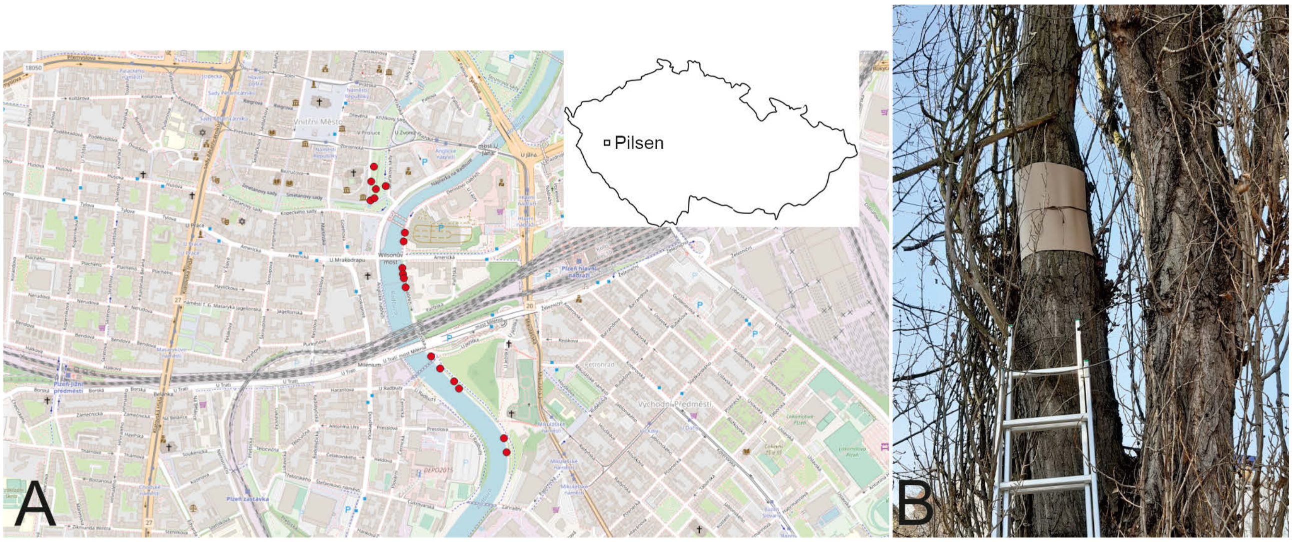

Fig. 1. A map of the study area (A) with marked sites representing the trees in Pilsen city (Czech Republic) where the spiders and beetles were sampled in 2021 using corrugated cardboard bands (B) and a sweep net.

dwelling spiders, in late autumn to early spring (Horváth et al., 2001, 2004; Horváth & Szinetár, 2002). Similarly, many beetle species prefer trees as favourable habitat in urban areas, and not surprisingly, such preferences are connected to their feeding guilds (Hůrka, 2005).

The species inhabiting tree bark or crowns have been poorly studied so far, despite the fact that their sampling is feasible. In this study, we show the importance of the trees in a city as a microhabitat hosting diverse spider and beetle assemblages. We analyse spider and beetle communities through functional traits. We compare species communities living on the bark of tree trunks (hereinafter, "bark") and the communities living on the tree crown using two standard methods – corrugated cardboard traps and sweeping. We investigated the following questions: (1) What are the functional differences in the species communities inhabiting the bark as opposed to the tree crown? (2) How does species richness of the two groups differ between these two microhabitats? and (3) What is the biological potential of trees in a city centre?

MATERIAL AND METHODS

For our study, we selected spider and beetle assemblages which represent established bioindicators of environmental quality (Pearce & Venier, 2006). Both invertebrate groups have strong indicative values (Avgin & Luff, 2010). The study was conducted in Pilsen city (49°44′52″N, 13°22′42″E, Central Europe, Czech Republic): with ca 169,000 inhabitants, it is the fourth most populous city in the Czech Republic. We sampled the species of spiders and beetles in parks around the city centre (Fig. 1A). The immediate surroundings of the trees include manicured lawns (50%), concrete surfaces (40%), and other objects (10%) such as buildings, other trees etc. We selected 18 solitary deciduous trees dominating in the city centre, represented by four ashes (*Fraxinus excelsior* L.), four oaks (*Quercus robur* (Matt.) Liebl.), four planes (*Platanus* sp.), two poplars (*Populus tremula* L.), two small-leaved lindens (*Tilia cordata* Mill.), one elm (*Ulmus glabra* Huds.), and one horse chestnut (*Aesculus hippocastanum* L.).

For sampling of spiders and beetles inhabiting trees, we used two methods. First, we used corrugated cardboard bands (Fig. 1B) for sampling species inhabiting the bark of tree trunks (Isaia et al., 2006). These traps consisted of corrugated cardboard, 50 cm wide and 50 cm long. The cardboard was placed on tree trunks at a height of 3 m, attached with strings. We installed the cardboard bands five times during the year between March and September, in order to cover all the important seasonal periods (spring, late spring, summer, and autumn). The traps were set for a one-week period each time.

Second, we used a sweep net for sampling species inhabiting the tree crowns (Wyss, 1996), with a 3-m-long telescopic handle and net frame diameter of 50 cm. The visits to each tree lasted ≈ 30 min; we swept the trees during the cardboard trap controls. The recorded samples were collected in 70% ethyl alcohol. Spiders and beetles were identified to species level using standard identification keys (Araneae: Heimer & Nentwig, 1991; Nentwig et al., 2022; Coleoptera: Lompe, 2002; Hůrka, 2005; Nedvěd, 2015).

Data analysis

The species were evaluated based on analyses of their functional traits. For spiders and beetles, we classified the species according to their (1) habitat, (2) humidity preferences that describe microhabitat, and (3) body size. The habitat preference categories were open (or semi-open), shaded (or semi-shaded) habitat, and generalist; humidity preferences involved xerophilous, hygrophilous, and eurytopic species (Hůrka, 1996, 2005; Buchar & Růžička, 2002; Kůrka et al., 2015; Nedvěd, 2015). The body size categories were divided according to the mean body length (cf. Alaruikka et al., 2002): spiders – small (< 2.5 mm), medium (2.5–5 mm), and large (> 5 mm); beetles – small (< 7 mm), medium (7–14 mm), and large (> 14 mm). Furthermore, the spiders were classified according to (4) their hunting methods – web builders or active hunters (Cardoso et al., 2011). The beetles were divided based on (5) their adult feeding guilds – carnivorous, phytophagous, and omnivorous species (Hůrka, 1996, 2005; Nedvěd, 2015). Species threatened in the Czech Republic were classified according to national Red Lists (spiders: Řezáč et al., 2015; beetles: Hejda et al., 2017), considering categories CR (critically endangered); EN (endangered); VU (vulnerable); and NT (near threatened).

To assess effects of microhabitat type on species and individual abundance (e.g., Orros et al., 2015; Chakraborty et al., 2020), we used Wilcoxon signed-rank tests (Rey & Neuhäuser, 2011). We analysed the data for each tree separately using paired tests comparing the species data between tree bark and crown. The analyses were performed in Rstudio (R Core Development Team, 2022).

For visualisation of species composition based on trait analysis, we used redundancy analysis (RDA), a multivariate method of linear regression. The square root transformation of the number of species of a given trait category was used as the response variable, whereas the categorical microhabitat type (bark, crown) was used as the explanatory variable. All results of all RDAs were evaluated with 999 Monte Carlo permutation tests in CANOCO 5 (Šmilauer & Lepš, 2014).

We also estimated the species richness of spider and beetle assemblages inhabiting bark and tree crowns using sample-size-based rarefaction curves, allowing for an evaluation of the biological potential of the trees as suitable microhabitats of the target groups. Rarefaction curves were calculated with a parameter q = 0 (for species richness) in Rstudio (R Core Development Team, 2022) using the ggiNEXT function of the iNEXT package (Hsieh et al., 2016).

RESULTS

Spiders

Overall, 35 spider species/295 individuals representing 15 families were identified, from which 22 species/241 individuals of spiders were recorded using cardboard bands, and 22 species/54 individuals using the sweep net technique. The majority of species belonged to the family Theridiidae (9 species), followed by Linyphiidae (4), Araneidae (3), Clubionidae (3), Salticidae (3), Dictynidae (2), Gnaphosidae (2), and Philodromidae (2); other families were represented by a single species: Agelenidae, Anyphaenidae, Dysderidae, Cheiracanthiidae, Mimetidae, Tetragnathidae, and Thomisidae. We also recorded several species belonging to Red List categories EN: *Dipoena torva*; VU: *Micaria subopaca* and *Porrhoclubiona leucaspis*; NT: *Clubiona brevipes* and *Tetragnatha nigrita*.

We found several significant differences between species richness of spiders, as well as between the number of individuals inhabiting the bark and tree crowns (Table 1). Concerning the number of species, we recorded more active hunters, hygrophilous, and large-bodied spider species on the bark than in the crown. We found significant differences in abundances of active hunters, web builders, open and shady habitat species, as well as for hygrophilous and large (> 5 mm) body size species (Table 1). All these species also prevailed on the tree bark. The sample-based rarefaction curves indicated the higher species potential of tree bark habitats (Fig. 2). The visualisation of species composition based on trait analysis using RDA shows that, in general, spiders tend to inhabit tree bark (Fig. 3A).

Table 1. The results of Wilcoxon signed-rank tests comparing the number of species, resp. number of individuals inhabiting tree bark and crowns in the city centre of Pilsen (Czech Republic). The analysis is based on the functional traits of the given group of invertebrates. Statistically significant values are in bold.

	Species richness		Individuals	
	V	p	V	p
SPIDERS				
Hunting method				
hunter	134.5	0.006	140.5	**0.003**
web builder	16	0.827	**127**	**0.002**
Habitat prefferences				
generalist	58.5	0.336	66	0.146
open	47	0.209	**90**	**0.002**
shaded	92.5	0.06	**97**	**0.006**
Humidity affinity				
eurytopic	40	0.209	44	0.337
hygrophilous	**82.5**	**0.009**	**169**	**0.0003**
xerophilous	43.5	0.745	84.5	0.167
Body size				
< 2.5 mm	5	1	11	0.410
2.5–5 mm	54	0.949	73	0.204
> 5 mm	**91**	**0.001**	**153**	**0.0003**
BEETLES				
Feeding guilds				
carnivurous	35	0.158	36.5	0.059
omnivorous	0	0.072	0	0.072
phytophagous	**3**	**0.002**	**9.5**	**0.004**
Habitat prefferences				
generalist	18	0.178	28	0.685
open	**0**	**0.001**	**0**	**0.001**
shaded	28.5	0.023	23	0.119
Humidity affinity				
eurytopic	**18**	**0.003**	**28.5**	**0.014**
hygrophilous	10	0.11	10.5	0.162
xerophilous	8	0.665	13	0.930
Body size				
< 7 mm	**11**	**0.006**	**15.5**	**0.022**
7–14 mm	**0**	**0.002**	**0**	**0.001**
> 14 mm	6	0.149	**5.5**	**0.001**

Beetles

Overall, 43 beetle species/265 individuals representing 19 families were recorded. From them, 15 species/61 individuals of beetles were recorded at tree bark and 32 species/204 individuals at tree crowns. Coccinellidae was the family with the highest species richness (12 species), followed by Chrysomelidae (4), Melyridae (4), Elateridae (3), Cantharidae (2), Carabidae (2), Curculionidae (2), Scirtidae (2), and Tenebrionidae (2); families represented

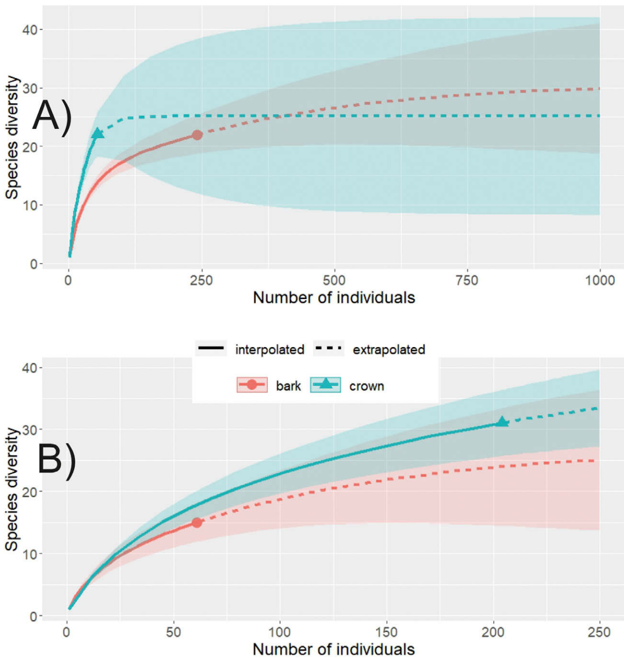

Fig. 2. The sample-based rarefaction curves of the spider (A) and beetle (B) species collected on tree bark (red) and in tree crowns (blue) in Pilsen city centre for species richness with 95% confidence intervals (shaded areas). Interpolation (solid line) and extrapolation (dotted line) are presented.

by a single species were Anthicidae, Apionidae, Brentidae, Cerambycidae, Dermestidae, Latriidae, Nitidulidae, Ptinidae, Scraptiidae, and Throscidae. Three species of Red List categories were recorded, namely VU: *Adrastus limbatus* and *Cryptocephalus populi*; NT: *Clitostethus arcuatus*.

The significant differences between the number of species inhabiting bark and tree crowns were found for phytophagous, open habitat, eurytopic, and small and medium body sized species (Table 1). All species prevailed on the tree crowns. Differences between the number of individuals of species inhabiting and type of microhabitat were significant for phytophagous, open habitat, eurytopic, and small (< 7 mm), medium (7–14 mm), and large (> 14 mm) body size species (Table 1); again, all of them prevailed at tree crowns except large body size species, which prevailed on tree bark. Sample-based rarefaction curves indicated the higher species potential of tree crown habitats (Fig. 2). Contrary to the spider traits, the analysis of beetle species traits shows the tendency of beetles to inhabit tree crowns, with the exception of large body size species (Fig. 3B). Lists of recorded spider and beetle species are presented in Table S1.

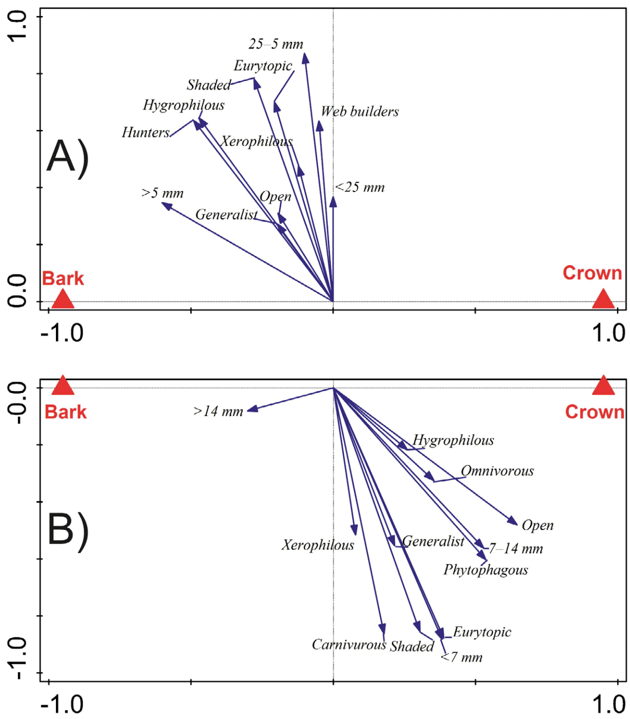

Fig. 3. The results of redundancy analyses (RDA) comparing the number of species inhabiting tree bark and crowns for spider (A) and beetle (B) assemblages. The analysis is based on the functional trait data of the given group of invertebrates. Ordination plot RDA: A – eigenvalues of axes 1–4: 0.1047, 0.3916, 0.1900, 0.1113, pseudo-F = 4.0, p = 0.008; B – eigenvalues of axes 1–4: 0.1566, 0.5285, 0.1281, 0.0526, pseudo-F = 6.3, p = 0.005.

DISCUSSION

Although the trees in the city centre are exposed to extreme conditions, they may represent an important habitat with a suitable microclimate for invertebrates. Altogether, we recorded 73 beetle and spider species and 560 individuals in the city centre in Pilsen (Czech Republic). The spider and beetle assemblages were relatively poor in comparison with other studies targeting invertebrates inhabiting urban areas (e.g., Prelik et al., 2009; Blick, 2010). However, these studies used different methods of sampling, such as eclectors (Blick, 2010) and pitfall traps (Prelik et al., 2009), and rarely sampled the invertebrate fauna directly inhabiting the trees (e.g., Horváth, 2001, 2004; Machač & Tuf, 2019).

Spiders

Few studies have confirmed the important role of urban habitats for spider assemblages (Alaruikka et al., 2002). Our study confirmed the occurrence of several spider species which are nationally rare in the Czech Republic. For instance, the spider *Philodromus buxi*, a typical tree species, was known in the Czech Republic only from the capital city of Prague, where it was discovered in 2019 (Růžička et al., 2019). Other recorded Red Listed species *Dipoena torva*, *Micaria subopaca*, *Porrhoclubiona leucaspis*, and *Clubiona brevipes* (Řezáč et al., 2015) are also known to be associated with trees (Kubcová & Buchar, 2005; Stańska et al., 2010). Some species which preferably inhabit bark are: *Nuctenea umbratica*, *Clubiona brevipes*, *C. pallidula*, *Porrhoclubiona leucaspis*, *Micaria subopaca*, *Moebelia penicillata*, *Philodromus buxi*, *Salticus zebraneus* and *Theridion mystaceum*; and some recorded species preferably inhabit crowns: *Anyphaena accentuata*, *Nigma walckenaeri*, *Ballus chalybeius*, *Anelosimus vittatus*, *Dipoena melanogaster*, *Platnickina tincta* and *Theridion pinastri* (Buchar & Růžička, 2002).

The numbers of spider species inhabiting the tree bark and tree crowns were identical, but with a strong difference in abundance. Our results, based on species richness and number of individuals, revealed that more actively hunting, hygrophilous, and large body size spiders tend to prefer tree bark (Fig. 3). Moreover, the differences between tree bark and crowns based on the number of individuals were found for web builders, open, and shaded habitat species; these species tend to inhabit tree bark (Table 1). The affinity of spiders to bark is relatively well known (Buchar & Růžička, 2002), and our analyses based on the sample-based rarefaction curves also indicated the higher species potential of bark as a habitat for spiders (Fig. 2). Bark represents a suitable microhabitat with specific microclimatic conditions (Machač & Tuf, 2019), which might represent the main factor influencing spider presence on the trees. The climatic stability of the bark is the crucial condition across several spider traits, allowing co-existence of species with different habitat preferences, thus producing more diverse spider assemblages (Nikolai, 1986). This was also supported by the fact that the family Theridiidae presented the richest species family in our study: these species build their webs on bark or under bark. The higher humidity of the bark favoured hygrophilous species and large body size species which probably used bark as a shelter, which is in accordance with similar studies (Isaia et al., 2006).

Beetles

Beetle species preferred the tree crowns over the tree bark and the total number of individuals was also higher for tree crowns. Some recorded beetle species are nationally rare (Hejda et al., 2017), namely Red Listed *Clitostethus arcuatus*, *Adrastus limbatus*, and *Cryptocephalus populi*. These species are associated with tree trunks, as are carabid beetles *Dromius quadrimaculatus* and *Ocys quinquestriatus* (Hůrka, 1996).

Analyses of traits showed that the number of species and individuals were significantly higher for phytophagous, open habitat, eurytopic, small (< 7 mm), and medium body size species (7–14 mm); these species prevailed in tree crowns. In general, the species' preference for crowns is evident (Fig. 3). Beetles inhabited different habitats than spiders, with the exception of large body size species, which prevailed on bark, similarly to the large body size spiders (Table 1). Not surprisingly, we recorded a higher proportion of phytophagous species (24 species; almost 60%) feeding on leaves. The sample-based rarefaction curves estimated a higher increase of species richness in tree crowns than on bark (Fig. 2).

We sampled a high proportion of beetles from the Coccinellidae family, represented by 12 species (28%), which is in accordance, for instance, with a similar study: Skuhrovec et al. (2021) recorded 13 species of coccinellids from the city centre in Prague (Czech Republic) during 2016–2019. This family may be positively affected by temperate microclimatic conditions and smaller differences between day and night temperatures (Skuhrovec et al., 2021), as well as by the higher concentration of aphids on trees, their common prey (Nedvěd, 2015). Our study indicates that carnivorous species marginally significantly tended to inhabit tree crowns.

In general, the high concentration of invertebrates on trees in an urban area may result from the small number of potential areas of urban green space, surrounded by dominant built-up areas. These small and isolated green sites often represent the only possible habitats in an urban area for many species (Konvička & Kadlec, 2011). Habitat changes in the past caused the decline of species richness and some species were restricted to sites with extreme habitat conditions, similarly to post-mining or burn sites (e.g. Tropek et al., 2010; Walter et al., 2021, 2022). Some urban habitats are referred to as secondary refuges for invertebrates (Schmitz, 1996). These sites are commonly inhabited by species with different functional traits, often with opposite requirements such as open vs. shaded habitats, or xerophilous and hygrophilous, which we also confirmed in the case of trees in urban habitats in the city centre. Here, the trees are inhabited not only by eurytopic species, but also species specialised to these habitats with different sets of traits (Hůrka, 1996; Buchar & Růžička, 2002), because trees provide a wide spectrum of various and even contrasting microclimatic conditions (Nikolai, 1986).

Similarly, some vertebrates are sensitive to environmental changes and may respond to urbanisation effects differently. It has been confirmed that trees in urban parks have an impact on the bionomy of birds, supporting birds with foraging, breeding, and nesting (Chaiyarat et al., 2019). Insectivorous birds could especially prosper in the city (Kang et al., 2015). Habitat connectivity is the main characteristic which may increase insect abundance; on the contrary, habitat fragmentation decreases insect abundance (Gonzalez et al., 1998). The occurrence of insectivorous birds in the city is connected with the rich insect assemblages (Kang et al., 2015). Conversely, insectivorous bats react to high density housing negatively, and they prefer the older, less dense outskirts of cities (Gaisler et al., 1998).

The relationships between different species or groups on the trees in the city are more complex than is obvious. General conclusions are still lacking due to the insufficient number of relevant studies. Our results indicate that trees represent an important habitat for spider and beetle species with diverse specialisation. Moreover, the trees frequently host species with different functional traits and with opposite requirements. Further studies are needed to understand the species diversity of the urban area.

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Online supplementary file:
S1 (http://www.eje.cz/2023/008/S01.xlsx). Table S1. Lists of recorded spider and beetle species.