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City parks vs. natural areas - is it possible to preserve a natural level of bee richness and abundance in a city park?

Weronika Banaszak-Cibicka [1] · Lucyna Twerd [2] · Monika Fliszkiewicz [1] · Karol Giejdasz [1] · Aleksandra Langowska [1]

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Abstract

Urbanisation is an expansive process and a majority of insects live in human-modified areas. At the same time, a decrease in pollinator species richness and abundance has recently been observed in Europe, which in turn may have serious ecological and economic consequences. This study investigates the abundance, species richness and functional traits of wild bees in urban city parks in comparison to natural areas. The aim of this research was to assess the potential conservation values of urban green areas for bees. The present study demonstrates that a large and diversified city park may be a favourable habitat for bees, comparable to the natural fauna both in terms of the number and abundance of bee species. However, the study also showed that there were differences in the occurrence of species with different functional traits in the city parks investigated and in the natural landscape.

Keywords Hymenoptera · *Apoidea* · Bees · Urban areas · Functional traits

Introduction

Currently, nearly all ecosystems on Earth are directly or indirectly affected by human pressure (Ellis et al. 2010) and a majority of species functions in environments that are subject to strong human pressure. Thus, strongly transformed areas, dominated by man, also play an important role in preserving biodiversity and their significance will increase together with population growth (Hobbs et al. 2009; Kowarik 2011).

Bees are a special group of insects because they are completely dependent on flowers as a source of food. About 85.0% of flowering plants are biotically pollinated and the majority of angiosperm species are pollinated by insects, among which the bees are the most important pollinators in most geographic regions (e.g. Michener 2000; Ollerton et al. 2011). As a major crop pollinator bees play a significant role in food production (e.g. Delaplane and Mayer 2000; Klein et al. 2007). However there is a growing concern about decrease in pollinator species richness and abundance (Biesmeijer et al. 2006; Fitzpatrick et al. 2007; Potts et al. 2010), which may have serious ecological and economic consequences (Corbet et al. 1991; Pywell et al. 2006). Urbanisation processes are listed among the main causes of species extinction and in the United States urbanisation poses risk to the highest number of species out of all other types of human activity (Czech et al. 2000). Simultaneously numerous works show that cities are important habitats for a significant number of bee species (Saure 1996; Matteson et al. 2008; Carré et al. 2009; Banaszak-Cibicka and Żmihorski 2012).

Over the past decade, several studies have assessed bee community richness and/or abundance in urban areas (Eremeeva and Sushchev 2005; McFrederick and LeBuhn 2006; Ahrné et al. 2009; Matteson and Langellotto 2010; Banaszak-Cibicka and Żmihorski 2012; Sirohi et al. 2015). Some were comparing bee richness and abundance between urban and natural landscapes (McKinney 2008; Baldock et al. 2015). However, it is still unclear if urban parks can host bee communities that are comparable to more natural systems. Therefore, as urban areas are constantly expanding, investigation of their impact on bee diversity is an immensely important and topical matter (McKinney 2002; Hall et al. 2017). Efforts at mitigating global

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✉ Weronika Banaszak-Cibicka
banaszak@up.poznan.pl

1 Institute of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71C, 60-625 Poznań, Poland

2 Institute of Environmental Biology, Kazimierz Wielki University, Ossolińskich 12, 85-093 Bydgoszcz, Poland

biodiversity loss have often focused on preserving large, intact natural habitats. However, preserving biodiversity should also be an important goal in the urban environment.

The aim of the present research was to verify whether a large city park with diversified flora might be comparable to natural areas as a place for living and protection of numerous and diverse bee communities. To the best of our knowledge our study is the first one comparing functional traits of bees in natural areas and urban parks.

Materials and methods

Study area

Poznań (52°25′N, 16°58′E) is one of the oldest cities in Poland, with 560,000 inhabitants and the area of 261 km^2. Two biggest and diverse urban parks characterised by different amount of human interference in plant selection and cultivation were chosen within the city. The Citadel Park is situated in the central part of the city and it occupies an area of 97.2 ha (Wronska-Pilarek and Malinski 2008). Deciduous trees and lawn areas dominate in the park. Large groups of shrubs have been planted along the walking paths. In the park, there are also theme gardens: dahlia, rose, summer flower, aquatic plant and perennial gardens. What is important is that there are partly wild areas, where the flora has been developing for half a century now and many processes that take place there are of secondary succession nature. The Citadel Park, together with the adjacent areas, is a complementary element of the cohesive urban green system with a circular-radial layout. It is also a jointer for radial green corridors, so it is indirectly connected with suburban areas (Wilkaniec 2007).

On the other hand botanical garden of Adam Mickiewicz University in Poznań has been a public park and a university research institution. It covers 22 ha, and contains a collection of over 8000 species and varieties of plants from almost every climate zone of vegetation around globe. The display is arranged in separate departments: ornamental plants, geography, ecology and systematic. Planning and managing is much stronger as compared to Citadel Park.

Additionally data from the Wielkopolska National Park (WNP) were used. National parks are the most valuable areas of natural resources and in Poland faunistic surveys were conducted in most of them. WNP is one of the most abundant in Apoidea species as compared to other Polish national parks (Banaszak et al. 2004). This level of faunal identification offers a unique opportunity to compare the bee fauna of Poznań city parks with that of natural areas. WNP is the only National Park and one of the largest green areas located in the nearest vicinity of Poznań with the area of 7584 ha. It is situated at the Warta River, 15 km south of Poznań. There are 18 strict protection areas in the park. They protect different post-glacial landscape forms and the most intact plant communities and animals that live there. The largest area of WNP is covered by forests of different types. There are also meadows in the park. The more detailed information on vegetation is provided in the next section in the characteristics of sampling plots.

Sampling sites and bee sampling

The samples were collected in 2009, in the growing season, from April to September, every 7–10 days (Banaszak et al. 2014) in ten sampling plots in the Citadel Park and ten plots in the Botanical Garden. The investigated parks, despite relatively small surfaces, were very diversified, regarding both plant composition and anthropogenic land transformation. Thus ten sampling plots each were needed to cover diversified habitat types and to collect full set of species with different requirements present in the research area. Habitat types on sampling plots in the Citadel Park ranged from mowed or partly mowed grass and flower meadows surrounded by planted flowering shrubs, through annual plants garden, partly wild areas of warm slopes of fortifications remains, to areas with deciduous trees of old cemetery, fortifications or forest. The Botanical Garden habitat types were mowed grass and flower meadows, rare and endangered species collection, ornamental flower gardens, and dendrological collections which include trees and shrubs occurring in forests of Poland and from different parts of the world. Every plot was described with regard to its covering by trees and mowing frequency. Characteristics of the sampling plots are given in Table 1. The distances between sampling plots ranged 170–880 m in Citadel Park and 170–680 m in Botanical Garden. Although solitary bees have rather small foraging ranges and their communities depends mainly on local landscape structure (Gathmann and Tscharntke 2002), numerical analyses were performed post hoc to confirm that sampling plots were independent units (see *Statistical analysis* below for more details).

Two methods were used to collect bees: yellow bowl traps and hand-netting. Three traps were placed in every plot and the captured insects were removed from the traps every 7–10 days. Direct searching along transects, was also conducted at each site. The 200 m long and 1 m wide transect was established as a sampling plot. The surveyor walked at slow speed and collected bees during an observational period of 30 min (Banaszak 1980). Species that could not be identified in the field were kept for identification later. Individuals that could be identified were released. Caught individuals were pinned in the laboratory, sorted and identified to the species level by experienced expert (WBC).

Finally, the data obtained from both city parks were compared with the fauna of one of the largest green areas in the vicinity of Poznań, namely the Wielkopolska National Park. Data collected by Cierzniak (2003a) were used. The methods in his survey were the same as were used in the city parks

Table 1 Characteristics of sampling plots in two types of landscape: urban (Citadel Park; Botanical Garden) and natural (Wielkopolska National Park)

Plot code	% trees	Mowing frequency	Bee species no.	Bee abundance	Details
Citadel Park					
BE	0%	3	47	310	mowed grass surrounded by planted coniferous shrubs
W	40%	1	62	456	partly wild areas of warm slopes of fortifications remains
TA	30%	2	47	395	partly mowed grass and flower meadows surrounded by planted flowering shrubs and trees
GS	10%	2	41	453	mowed grass and flower meadow patches
AP	35%	1	29	154	annual plants garden surrounded by forested area
RG	5%	2	38	388	rose garden surrounded by flower meadow
CM	85%	1	26	129	wooded/forested area
MU	70%	1	23	144	wooded/forested area surrounded by grassy slopes
MG	20%	3	39	302	mowed grass and partly mowed grass surrounded by trees (*Tilia* sp. and *Acer* mainly) and shrubs
FT	95%	1	10	63	wooded/forested area
Botanical Garden					
RS	5%	1	41	281	rare and endangered species collection
OF1	5%	2	27	131	ornamental flower collection surrounded by dendrological collections
GS1	10%	3	52	237	mowed grass with shrubs and trees
OF2	0%	2	51	580	ornamental flower collection and mowed grass surrounded by trees from different areas of the world
DC1	70%	1	28	217	dendrological collections
DC2	75%	1	24	149	dendrological collections
DC3	80%	1	23	61	dendrological collections
GS2	5%	3	52	395	mowed grass with flowering shrubs
GS2	20%	3	45	227	mowed grass with trees
FS	10%	2	45	470	flowering shrubs
Wielkopolska National Park					
N-O-H1	75%	1	23	121	natural oak-hornbeam forest (*Galio silvatici-Carpinetum*)
N-O-H2	80%	1	38	211	natural oak-hornbeam forest (*Galio silvatici-Carpinetum*)
D-O-H1	50%	1	26	342	degenerated oak-hornbeam forest (*Pinus-Quercus-Milium*); *degeneration mainly due to exaggerated dominance of grasses and alien plants*
D-O-H2	90%	1	31	451	degenerated oak-hornbeam forest (*Pinus-Quercus-Milium*); degeneration mainly due to *Pinus silvatica* planting and exaggerated dominance of alien plants, *Rubus* sp. and grasses
BC	0%	1	33	265	bush communities on forest edges
NC	0%	1	31	268	nitrophilous tall herb communities on forest road edges (*Alliario-Chaerophylletum*, *Anthriscetum silvestris*, *Urtico-Aegopodium*)
TC	0%	1	64	566	thermophilous tall herb communities on southern and western forest edges (dominance of *Agrimonio-Vicietumcassubiacae* and *Trifolio-Agrimonietum*)
M	0%	2	69	641	mid-forest mowed meadows with scattered bushes

which makes them comparable. Analogous to urban areas, bees were collected using the same transect method with 200 m long and 1 m wide transect sampling plot (Banaszak 1980); additionally three bowl traps on every research plot were used. In WNP, study plots were located in the natural oak-hornbeam forest (*Galio sylvatici-Carpinetum*), degenerate oak-hornbeam forest, and in nitrophilous tall herb communities, which usually develop in ecotone zones, e.g. forest roadsides or meadow edges. Insects were also collected in mid-forest meadow communities and thermophilic plant complexes, formed at the edge of the forest and meadows, in places with southern and western exposure (Cierzniak 2003a; see also Table 1). Although those data were collected earlier and some authors show possible temporal changes in bee population (summarized in Williams et al. 2001; but see Tepedino and Stanton 1981; Sibly et al. 2007), the fauna of Wielkopolska National Park was proved to be stable and even changes over the last half century seem to be only local (Cierzniak 2003b). This stability may result from high level of naturalness of the Park but also from comprehensive recognition of its bee fauna. What is more, there is evidence that bee fauna in the region (Wielkopolska Kujawy Lowland) have not changed much over the last century (Banaszak 2010).

Not only sampling methods but also sampling effort was comparable among researched areas. In total, 447 samples were collected from Citadel Park, 452 from Botanical Garden and 466 from Wielkopolska National Park.

Species traits data were compiled from primary literature, catalogs, and reference works (Banaszak 1993; Scheuchl 1995; Schmid-Egger and Scheuchl 1997; Banaszak et al. 2001; Pesenko et al. 2002; Pawlikowski and Celary 2003). Trait data for bees included: mean body length (small ≤1.5 cm, large >1.5 cm), nesting place (cavity, soil, hive), social behaviour (solitary, eusocial or cleptoparasite), floral specificity [e.g. oligolectic (single plant species or genus), polylectic (many plant species)], phenology – month of first activity (e.g. April, June, July), occurrence, prevalence, zoogeographical range. As for the latter characteristics, a group of southern bee species was separated. These are bees that inhabit much of the areas surrounding the Mediterranean Sea and the Black Sea and tend to occur in open dry and warm habitats. In Central Europe, these species are observed only in isolated xerothermic localities.

Statistical analysis

To evaluate similarity of samples with respect to species composition among sampling plots within researched areas the percent similarity was calculated and the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) clustering was applied. To compare species richness among areas (WNP, CP, BG) the Sørensen similarity coefficient (Sørensen 1948) was used. For the similarity analysis based on species composition and abundance the Morisita–Horn index (Horn 1966) was used. Calculation of all aforementioned indices was done with the program MVSP 3.22 (Kovach 2002).

To assess the influence of the distances between sampling plots, percentage of trees cover (further in the Results referred as "habitat type") and mowing frequency on bee communities numerical analysis of the collected data was performed using CANOCO v. 4 software (ter ter Braak and Šmilauer 1998). To detect a gradient in total variation of the data, detrended correspondence analysis (DCA) was performed. The gradient was 3.15 standard deviations long, so in further calculations canonical correspondence analysis (CCA) was used (ter ter Braak and Šmilauer 1998). Monte Carlo Permutation Test with 1000 repetitions was conducted to estimate the significance of each variable and the canonical axes.

ANOVA with post-hoc Tukey test for unequal group size ($P < 0.05$) was used to compare the structure of Apiformes communities (richness, abundance, diversity) and the occurrence of species with particular functional traits (sociality, nesting behaviour, floral specificity, body length, time of first activity, zoogeographical range, prevalence) in two types of landscape (natural, represented by national park; and urban, represented by city parks). Distributions were measured prior to the analyses. The distribution of values was normal, thus the relationships between bee communities and types of landscape could be analysed with parametric tests. The Brown-Forsythe test was used for testing the homogeneity of variance. The statistical analysis was conducted with the use of the Statistica 9.1 software.

Species richness was assessed using rarefaction curves (Gotelli and Colwell 2001). The computations were performed with the EstimateS software (Colwell 2006). The extrapolated species richness (the number of the observed and unobserved species) was estimated using the Chao2 estimator (Chao 1984).

Results

Similarities among research plots and areas

We found that the similarity in bee species assemblages between plots within three research areas was very differentiated with percent similarity values in the range of 10–73% for Citadel Park, 25–74% for Botanical Garden and 20–61% for Wielkopolska National Park. Similarity between study plots within the research areas was higher when comparing study plots of the similar habitat type (defined with percentage of tree cover, i.e. open habitats, wooded) than when comparing study plots from different habitats types. The bee communities depended on the percentage of tree cover (CCA; *% of explained variation* = 2.77; $P = 0.001$). The distance between the sampling plots did not affect bee communities (CCA; *% of explained variation* = 1.23; $P = 0.230$). (full model: *F-ratio* = 3.13, $P = 0.001$).

Our research also revealed significant similarity of three compared areas, with Sørensen index values in the range of 0.578–0.614 and Morisita–Horn index in the range of 0.729–0.869. Similarity of bee species richness was the greatest between Wielkopolska National Park and Citadel Park (61%) whereas Botanical Garden was the most distinct (BG vs WNP = 57%; BG vs CP = 60%). When it comes to species abundance city parks were more similar to each other (BG vs CP = 86%) than to the National Park, however the similarities between urban parks and National Park were also high (WNP vs BG = 80%; WNP vs CP = 72%) (Fig. 1).

Structure of bee communities

The bee abundance and richness in both city parks was similar (Tukey test; $P = 0.994$ and $P = 0.937$, respectively); total 2799 individuals representing 118 species were collected in the Citadel Park and 2812 individuals (101 species) in Poznań Botanical Garden. This comprises respectively nearly 25 and 21% of the Polish fauna (Banaszak 2000) and almost 46 and 39% of the regional fauna (Banaszak 2010). The Chao2 species richness estimator, corrected for unobserved species in the samples, suggested 152 species for Citadel Park and 131 for Botanical Garden. All of the species collected were native species. The total number of species identified in the city parks was similar to 110 species (Chao2: 145) found in natural areas of WNP (Tukey test; for both comparisons $P \geq 0.943$). The total size of the bee community (2861 individuals) was also similar (Tukey test; for both comparisons $P \geq 0.953$) (Figs. 2 and 3). A detailed bee species list is given in Table 2.

Occurrence of species with particular functional traits

The number of social bee species were significantly higher in the city parks compared to National Park (Tukey test; $P = 0.022$ and $P = 0.048$). The analyses also showed that the abundance of oligolectic bee species were higher in urban landscapes compared to National Park (Tukey test; for both comparisons $P \leq 0.037$). On the other hand, the fauna of cleptoparasitic bees displayed a greater number (Tukey test; $P = 0.048$ and $P = 0.005$) and abundance of species (Tukey test; for both comparisons $P < 0.001$) in natural areas of the National Park.

During the analysis of other functional traits (i.e. body length and time of first activity), significant differences were observed only in the case of (late) spring species and species displaying considerable body weight. The mean abundance of late spring species and the richness of large-sized species was significantly lower in the areas transformed by human activity (city parks) compared to natural landscapes (National Park) (Tukey test; for phenology for both comparisons $P \leq 0.022$; for body size for both comparisons $P \leq 0.019$).

Based on the analyses conducted, both the number and abundance of southern species were significantly higher in the Citadel Park compared to natural landscapes of the National Park (Tukey test; for both comparisons $P \leq 0.012$).

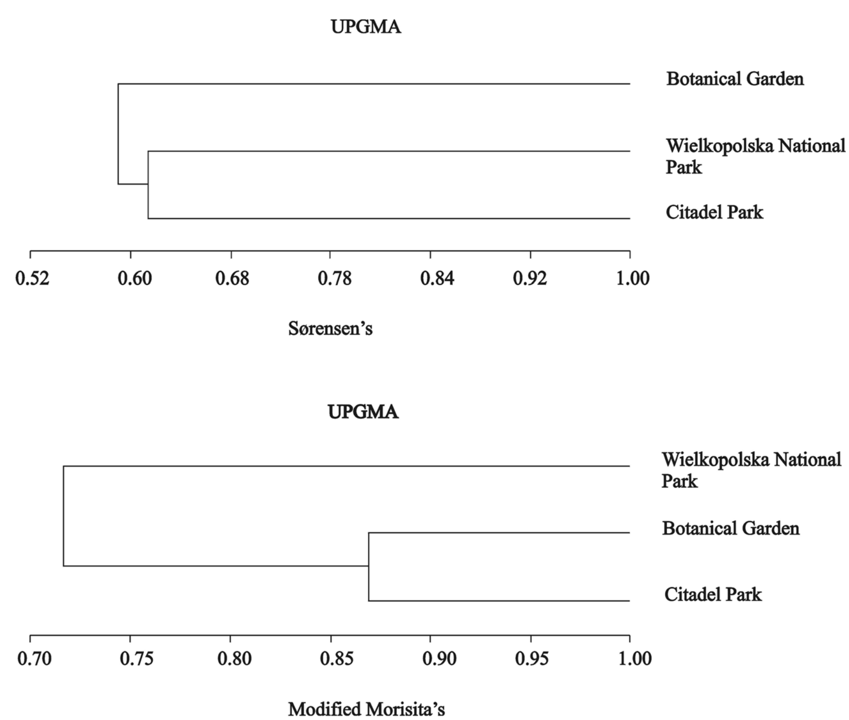

Fig. 1 Similarity of bee species composition (Sørensen index) and abundance of individuals (Morisita-Horn index) between two types of landscape: natural (Wielkopolska National Park - WNP) and urban (Citadel Park – CP; Botanical Garden – BG)

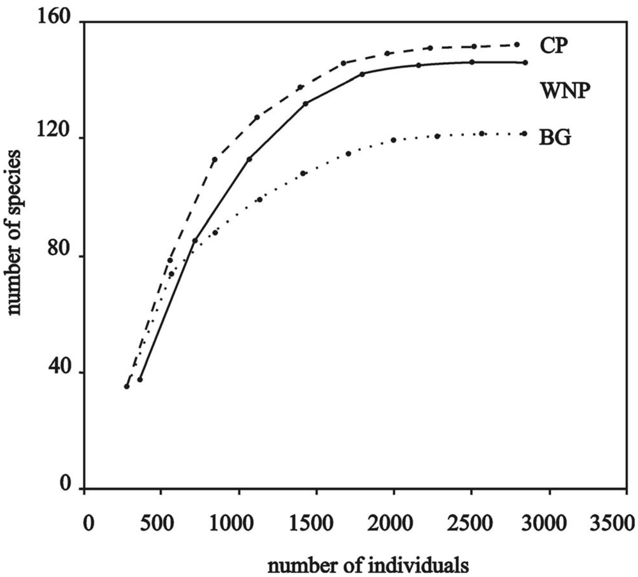

Fig. 2 Individual based rarefaction curves for two types of landscape: natural (Wielkopolska National Park - WNP) and urban (Citadel Park – CP; Botanical Garden – BG)

On the other hand, the number of rare species in Citadel Park and National Park was comparable but it was lower in Botanical Garden (Tukey test; $P \leq 0.007$). Simultaneously the abundance of rare species was lower in urban landscapes as compared to natural areas of the National Park (Tukey test; $P = 0.039$ and $P = 0.001$). All the results of the analyses have been presented in Online Resource 1 and Figs. 4 and 5.

Discussion

The present study has demonstrated, that a large and diversified city parks may be a favourable habitat for a diverse and numerous group of bees, comparable to the fauna in natural habitats both in terms of the number of species and their abundance. Many researchers report that natural habitats display greater diversity of pollinators compared to urban areas (McIntyre and Hostetler 2001; Eremeeva and Sushchev 2005; Matteson et al. 2008; Ahrné et al. 2009). At the same time, data provided by other authors show that cities are important habitats for a considerable number of bee species (Saure 1996; Frankie et al. 2005; Banaszak-Cibicka and Żmihorski 2012; Frankie et al. 2013; Baldock et al. 2015; Cariveau and Winfree 2015; Sirohi et al. 2015; Threlfall et al. 2015; Hall et al. 2017; Normandin et al. 2017), and urbanization has a lesser effect on bees than on other insects (Deguines et al. 2012). For instance, urban parks in San Francisco, USA, support higher mean abundances of bumblebees (*Bombus* spp.) than do two parks beyond the city boundary (Goddard et al. 2010).

One of the most important factors affecting natural resources of bees is food supply. Both forage plant richness and the size of the area covered with these plants are equally important (Steffan-Dwenter and Tscharntke 2000; Kearns and Oliveras 2009; Matteson and Langellotto 2010; Matteson et al. 2013). A city provides bees not only with convenient nesting places but also with a great diversity of forage plants, both natural and those artificially introduced (Wojcik and McBride 2012; Hülsmann et al. 2015). These factors, in turn, contribute to the increase of bee species diversity. The present research has demonstrated that species richness and abundance of bees in diversified areas with high concentration of forage plants might be comparable to those in natural environments. Similar correlation has also been observed by other authors (McFrederick and LeBuhn 2006; Sirohi et al. 2015; Baldock et al. 2015; Kaluza et al. 2016).

Thus, the rich diversity of bees in the city parks analysed may be related to wide diversity of micro-environments in the area, including places where human impact is minimal. On the other hand botanical gardens are associated with seed banking, cultivation and exhibition of plants. The way the botanical garden is managed is determined by introduction of large number of plants for cultivation (which belong to many taxa). Various forms of utilization of the area (diversity of microhabitats) within each botanical garden are of great importance. Such an enormous diversity of plants and habitats allows for the occurrence of species with different ecological needs

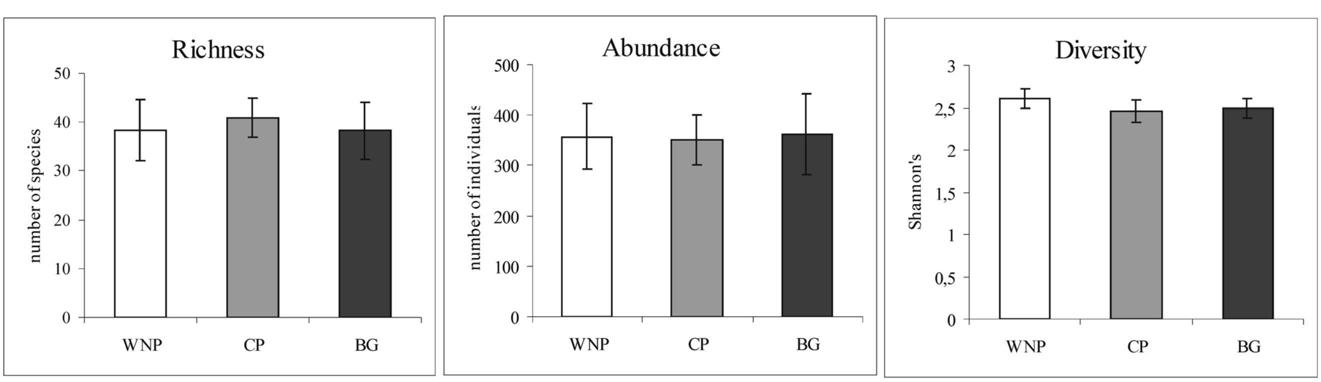

Fig. 3 Mean (±s.e.) species richness, abundance and diversity of bees in two types of landscape: natural (Wielkopolska National Park - WNP) and urban (Citadel Park – CP; Botanical Garden – BG): $^*P < 0.05$; $^{**}P < 0.01$

Table 2 Bee species occurring in Citadel Park, Botanical Garden and Wielkopolska National Park

Species	Abundance			Sociality	Pollen specificity	Nest substrate	Bee size	Southern species	Rare species
	CP	BG	WNP						
Colletidae									
Colletes cunicularius (Linnaeus, 1761)	3	–	15	S	P	S	S		
Colletes daviesanus (Fourcroy, 1785)	4	10	–	S	O	S	S		
Colletes fodiens (Fourcroy, 1785)	–	1	1	S	O	S	S		
Colletes similis Schenck, 1853	–	3	1	S	O	S	S		
Hylaeus angustatus (Schenck, 1859)	1	1	1	S	P	C	S		
Hylaeus bisinuatus Foerster, 1871	3	–	–	S	P	C	S		+
Hylaeus brevicornis Nylander, 1852	–	–	2	S	P	C	S		
Hylaeus cardioscapus Cockerell, 1924	1	–	–	S	x	C	S		+
Hylaeus communis Nylander, 1852	1	1	21	S	P	C	S		
Hylaeus confusus Nylander, 1852	1	–	1	S	P	C	S		
Hylaeus gibbus Saunders, 1850	–	4	1	S	P	C	S		
Hylaeus gracilicornis (Morawitz, 1867)	–	–	1	S	P	C	S		
Hylaeus gredleri Förster, 1871	1	–	–	S	x	C	S		+
Hylaeus hyalinatus Smith, 1842	5	14	–	S	P	C	S		
Hylaeus nigritus (Fabricius, 1798)	–	5	–	S	x	C	S		
Hylaeus styriacus Forster, 1871	–	–	3	S	x	C	S	+	+
Andrenidae									
Andrena albofasciata Thomson, 1870	–	1	–	S	P	S	S		
Andrena alfkenella Perkins, 1914	3	–	3	S	P	S	S		
Andrena apicata (Smith, 1847)	26	–	–	S	P	S	S		
Andrena barbilabris (Kirby, 1802)	–	2	4	S	P	S	S		
Andrena bicolor fabricius, 1775	–	12	–	S	P	S	S		
Andrena bimaculata (Kirby 1802)	–	3	–	S	P	S	S		
Andrena chrysosceles (Kirby, 1802)	1	–	3	S	P	S	S		
Andrena cineraria (Linnaeus, 1758)	–	–	5	S	P	S	S		
Andrena clarkella (Kirby, 1802)	–	–	2	S	P	S	S		
Andrena combinata (Christ, 1791)	–	1	8	S	P	S	S		
Andrena congruens Schmiedeknecht, 1883	–	1	–	S	P	S	S	+	
Andrena denticulata (Kirby, 1802)	–	4	–	S	P	S	S		
Andrena dorsata (Kirby 1802)	1	14	1	S	P	S	S		
Andrena flavipes Panzer, 1799	13	31	13	S	P	S	S	+	
Andrena florea Fabricius, 1793	1	2	–	S	O	S	S	+	+
Andrena fucata Smith, 1847	1	–	51	S	P	S	S		
Andrena fulva (Müller, 1766)	5	64	95	S	P	S	S		
Andrena fulvago (Christ, 1791)	6	–	–	S	P	S	S		
Andrena gelriae van der Vecht, 1927	1	–	1	S	P	S	S	+	
Andrena gravida Imhoff, 1899	8	7	19	S	P	S	S		
Andrena haemorrhoa (Fabricius, 1781)	20		2-30	237	S	P	S	S	
Andrena helvola (Linnaeus, 1758)	2	60	20	S	P	S	S		
Andrena jacobi Perkins, 1921	–	3	20	S	P	S	S		
Andrena labiata (Fabricius, 1775)	3	–	2	S	P	S	S		
Andrena lapponica Zetterstedt, 1838	–	–	26	S	P	S	S		
Andrena minutula (Kirby, 1802)	27	7	10	S	P	S	S		
Andrena minutuloides Perkins, 1914	6	7	9	S	P	S	S		

Table 2 (continued)

Species	Abundance			Sociality	Pollen specificity	Nest substrate	Bee size	Southern species	Rare species
	CP	BG	WNP						
Andrena mitis Schmiedeknecht, 1838	–	1	–	S	P	S	S		
Andrena nigroaenea (Kirby, 1802)	–	1	3	S	P	S	S		
Andrena nitida (Müller, 1776)	8	116	14	S	P	S	S		
Andrena nitidiuscula Schenck, 1853	6	–	–	S	P	S	S	+	
Andrena ovatula (Kirby, 1802)	3	–	–	S	O	S	S		
Andrena pilipes Fabricius, 1781	–	1	–	S	P	S	S		
Andrena praecox (Scopoli, 1763)	2	4	7	S	P	S	S		
Andrena proxima (Kirby, 1802)	1	–	–	S	P	S	S		
Andrena subopaca (Nylander, 1848)	46	26	147	S	P	S	S		
Andrena tibialis (Kirby, 1802)	–	6	–	S	P	S	S		
Andrena vaga Panzer, 1799			5- 23	425	9	S	O	S	S
Andrena varians (Rossi, 1792)	4	–	–	S	P	S	S		
Andrena ventralis Imhoff, 1832	4	90	1	S	P	S	S		
Andrena wilkella (Kirby, 1802)	11	2	13	S	O	S	S		
Panurgus calcaratus (Scopoli, 1763)	3	2	3	S	O	S	S		
Halictidae									
Evylaeus aeratus (Kirby, 1802)	–	–	3	x	P	S	S		+
Evylaeus albipes (Fabricius, 1781)	18	18	1	E	P	S	S		
Evylaeus brevicornis (Schenck, 1863)	–	1	–	E	P	S	S		
Evylaeus calceatus (Scopoli, 1763)	25	69	36	E	P	S	S		
Evylaeus fratellus (Perez, 1903)	–	–	12	S	P	S	S		+
Evylaeus fulvicornis (Kirby, 1802)	1	–	1	E	P	S	S		
Evylaeus laticeps (Schenck, 1868)	111	37	1	E	P	S	S		
Evylaeus leucopus (Kirby, 1802)	–	–	12	x	P	S	S		
Evylaeus linearis (Schenck, 1869)	1	–	–	E	P	S	S	+	
Evylaeus lucidulus (Schenck, 1861)	8	–	–	S	P	S	S		+
Evylaeus morio (Fabricius, 1793)			2- 40	40	–	E	P	S	S
Evylaeus minutissimus (Kirby, 1802)	1	–	–	S	x	S	S		+
Evylaeus nitidulus (Fabricius, 1804)	3	–	–	E	P	S	S		
Evylaeus parvulus (Schenck, 1853)	2	2	82	S	P	S	S		
Evylaeus pauxillus (Schenck, 1853)			3- 08	53	25	E	P	S	S
+									
Evylaeus glabriusculus (Morawitz, 1872)	1	–	–	E	x	S	S		+
Evylaeus punctatissimus (Schenck, 1853)	1	–	10	x	O	S	S		+
Evylaeus rufitarsis (Zetterstedt, 1838)	–	–	23	S	P	S	S		+
Evylaeus semilucens (Alfken, 1914)?	1	–	–	S	x	S	S		+
Evylaeus sexstrigatus (Schenck, 1868)	2	25	9	S	P	S	S		
Evylaeus tarsatus (Schenck, 1868)	–	–	4	S	x	S	S	+	+
Evylaeus villosulus (Kirby, 1802)	1	3	21	S	P	S	S		
Halictus quadricinctus (Fabricius, 1776)	1	1	1	S	P	S	S		
Halictus rubicundus (Christ, 1791)	3	2	x	E	P	S	S		
Halictus sexcinctus (Fabricius, 1775)	1	6	2	S	P	S	S		
Lasioglossum laevigatum (Kirby, 1802)	–	–	2	S	P	S	S		+

Table 2 (continued)

Species	Abundance			Sociality	Pollen specificity	Nest substrate	Bee size	Southern species	Rare species
	CP	BG	WNP						
Lasioglossum lativentre (Schenck, 1853)	–	–	3	S	P	S	S	+	
Lasioglossum leucozonium (Schrank, 1781)	2	–	3	S	P	S	S		
Lasioglossum majus (Nylander, 1852)	1	–	–	S	P	S	S	+	+
Lasioglossum quadrinotatum (Kirby, 1802)	–	–	1	S	P	S	S		
Lasioglossum sexnotatum (Kirby, 1802)	8	3	3	S	P	S	S		
Lasioglossum subfasciatum (Imhoff, 1832)	1	–	8	S	P	S	S		
Lasioglossum zonulum (Smith, 1848)	–	1	x	S	P	S	S		
Seladonia confusa (Smith, 1853)	9	2	4	E	P	S	S		
Seladonia leucahenea (Ebmer, 1972)	–	–	1	E	P	S	S		+
Seladonia subaurata (Rossi, 1792)	4	23	–	E	P	S	S		
Seladonia tumulorum (Linnaeus, 1758)	26	21	46	E	P	S	S		
Sphecodes albilabris (Fabricius, 1793)	2	1	2	CP	[P]	[S]	S		
Sphecodes crassus Thompson, 1870	2	–	–	CP	[P]	[S]	S		
Sphecodes ephippius (Linnaeus, 1767)	2	6	13	CP	[P]	[S]	S		
Sphecodes ferruginatus Hagens, 1882	1	–	–	CP	[P]	[S]	S	+	+
Sphecodes gibbus (Linnaeus, 1758)	–	1	–	CP	[P]	[S]	S		+
Sphecodes hyalinatus Hagens, 1882	–	–	2	CP	[P]	[S]	S		
Sphecodes pellucidus Smith, 1845	–	1	1	CP	[P]	[S]	S		
Sphecodes punctipes Thomson, 1870	–	2	7	CP	[P]	[S]	S		
Melittidae									
Dasypoda hirtipes (Harris, 1780)	23	11	84	S	O	S	S		
Macropis fulvipes (Fabricius, 1804)	–	–	3	S	O	S	S		
Melitta leporina (Panzer, 1799)	18	–	1	S	O	S	S		
Melitta tricincta Kirby, 1802	–	–	1	S	O	S	S		
Megachilidae									
Anthidiellum strigatum (Panzer, 1805)	1	–	8	S	O	C	S		
Anthidium manicatum (Fabricius, 1775)	1	4	–	S	P	C	S		
Anthidium oblongatum (Illiger, 1806)	–	1	–	S	O	C	S		+
Anthocopa spinulosa (Kirby, 1802)	1	–	–	S	O	C	S	+	+
Chelostoma campanularum (Kirby, 1802)	–	2	–	S	O	C	S		
Chelostoma florisomne (Linnaeus 1758)	2	1	12	S	O	C	S		
Chelostoma rapunculi (Lepeletier, 1841)	–	1	–	S	O	C	S		
Coelioxys elongata Lepeletier, 1841	1	1	–	CP	[P]	[S]	S		
Coelioxys inermis (Kirby, 1802)	1	–	–	CP	[P]	[S]	S		
Coelioxys quadridentata (Linnaeus, 1758)	–	1	5	CP	[P]	[S]	S		
Coelioxys rufocaudata Smith, 1854	–	1	–	CP	[P]	[S]	S		
Heriades crenulatus Nylander, 1856	–	–	3	S	O	C	S	+	+
Heriades truncorum (Linnaeus, 1758)	–	9	1	S	O	C	S		
Hoplitis adunca (Panzer, 1798)	2	–	–	S	O	C	S		
Hoplitis leucomelana (Kirby, 1802)	7	1	–	S	P	C	S		
Megachile alpicola Alfken, 1924	–	–	3	S	P	S, C	S		
Megachile centuncularis (Linnaeus, 1758)	2	–	1	S	P	S, C	S		
Megachile circumcincta (Kirby, 1802)	2	12	1	S	O	S	S		
Megachile leachella Curtis, 1828	6	2	–	S	P	S	S		
Megachile ligniseca (Kirby, 1802)	1	6	8	S	P	S	S		
Megachile versicolor Smith, 1844	2	–	2	S	P	C	S		

Table 2 (continued)

Species	Abundance			Sociality	Pollen specificity	Nest substrate	Bee size	Southern species	Rare species
	CP	BG	WNP						
Megachile willughbiella (Kirby, 1802)	2	11	1	S	P	C	S		
Osmia aurulenta (Panzer, 1799)	29	4	–	S	P	C	S	+	
Osmia bicolor (Schrank, 1781)	26	–	–	S	P	C	S	+	+
Osmia coerulescens (Linnaeus, 1758)	1	1	–	S	P	C	S		
Osmia fulviventris (Panzer, 1798)	1	2	–	S	O	C	S		
Osmia mustelina Gerstaecker, 1869	2	2	–	S	O	C	S	+	+
Osmia rufa (Linnaeus, 1758)	6	20	5	S	P	C	S		
Chalicodoma ericetorum (Lepeletier, 1841)	–	7	–	S	P	S	S		
Proanthidium oblongatum Latreille, 1809	1	–	1	S	P	C	S	+	+
Stelis ornatula (Klug, 1807)	1	–	–	CP	[P]	[C]	S		+
Stelis punctulatissima (Kirby, 1802)	–	1	–	CP	[P]	[C]	S		+
Apidae									
Anthophora bimaculata (Panzer, 1798)	–	–	2	S	P	S	S		
Anthophora furcata (Panzer, 1798)	1	–	–	S	O	S	S		
Anthophora plumipes (Pallas, 1772)	48	57	7	S	P	S	S		
Anthophora pubescens (Fabricius, 1781)	–	1	–	S	P	S	S		
Anthophora quadrimaculata (Panzer, 1806)	–	19	–	S	P	S	S		
Apis mellifera Linnaeus, 1758			5-66	727	630	E	P	H	L
Bombus bohemicus (Seidl, 1837)	–	–	43	CP	[P]	[H]	L		
Bombus cryptarum Fabricius, 1775	–	–	9	E	P	H	S		
Bombus hortorum (Linnaeus, 1761)	3	10	3	E	P	H	L		
Bombus hypnorum (Linnaeus, 1758)	6	12	10	E	P	H	L		
Bombus jonellus (Kirby,1802)	2	–	–	E	P	H	S		+
Bombus lapidarius (Linnaeus, 1758)	43	40	47	E	P	H	L		
Bombus lucorum (Linnaeus, 1761)	36	30	209	E	P	H	L		
Bombus pascuorum (Scopoli, 1763)			2-44	215	359	E	P	H	S
Bombus pratorum (Linnaeus,1761)	5	–	108	E	P	H	S		
Bombus ruderarius (Müller, 1776)	14	3	2	E	P	H	L		
Bombus rupestris (Fabricius, 1793)	1	–	11	CP	[P]	[H]	S		
Bombus sylvarum (Linnaeus, 1761)	4	4	–	E	P	H	S		
Bombus terrestris (Linnaeus, 1758)			1-02	97	35	E	P	H	L
Bombus vestalis (Geoffroy in Fourcroy, 1785)	–	–	1	CP	[P]	[H]	L		
Ceratina cyanea (Kirby, 1802)	1	3	4	S	P	C	S		
Epeolus variegatus (Linnaeus, 1758)	1	–	–	CP	[P]	[S]	S		
Eucera longicornis (Linnaeus, 1758)	1	–	–	S	O	S	S		
Melecta luctuosa (Scopoli, 1770)	2	–	–	CP	[P]	[S]	S	+	
Melecta punctata (Fabricius, 1775)	–	1	–	CP	[P]	[S]	S		
Nomada atroscutellaris Strand, 1921	8	–	–	CP	[P]	[S]	S		+
Nomada bifasciata Olivier, 1811	3	–	3	CP	[P]	[S]	S		
Nomada conjugens Herrich-Schaffer, 1839	1	–	–	CP	[P]	[S]	S		+
Nomada emarginata Morawitz, 1877	1	–	–	CP	[P]	[S]	S		+

Table 2 (continued)

Species	Abundance			Sociality	Pollen specificity	Nest substrate	Bee size	Southern species	Rare species
	CP	BG	WNP						
Nomada flavoguttata (Kirby, 1802)	1	2	17	CP	[P]	[S]	S		
Nomada fucata Panzer, 1798	1	2	–	CP	[P]	[S]	S		
Nomada fulvicornis Fabricius, 1793	–	–	8	CP	[P]	[S]	S		
Nomada goodeniana (Kirby, 1802)	5	–	5	CP	[P]	[S]	S		
Nomada lathburiana (Kirby, 1802)	1	–	–	CP	[P]	[S]	S		
Nomada marhamella (Kirby, 1802)	–	–	25	CP	[P]	[S]	S		
Nomada moeschleri Alfken, 1913	–	–	23	CP	[P]	[S]	S		
Nomada ochrostoma Zetterstedt, 1838	13	1	2	CP	[P]	[S]	S		
Nomada ruficornis (Linnaeus, 1758)	–	–	6	CP	[P]	[S]	S		
Nomada sheppardana (Kirby, 1802)	–	1	–	CP	[P]	[S]	S		
Nomada signata Jurine, 1807	4	1	31	CP	[P]	[S]	S		+
Nomada panzeri Lepeletier, 1841	–	1	–	CP	[P]	[S]	S		
Nomada leucophthalma (Kirby, 1802)	–	–	9	CP	[P]	[S]	S		

Abundance - total number of specimens collected across all sites in CP- Citadel Park, BG - Botanical Garden, WNP - Wielkopolska National Park. Sociality classification as either E—eusocial, CP—cleptoparasitic, S—solitary. Pollen specificity classification as either polylectic (collecting pollen from multiple plant families) or oligolectic (collecting pollen from a single plant family or genus); [P] indicates parasitic species that do not collect pollen. Nest substrate classification of the nest substrate of each nonparasitic species as C—cavity, H—hive, S—soil; letters in brackets ([]) indicate the nest substrate of the host of a parasitic species; x - indicate attribute is unknown. Bee size classification as S—small ≤1.5 cm, L—large >1.5 cm. The list of species was arranged in systematic order

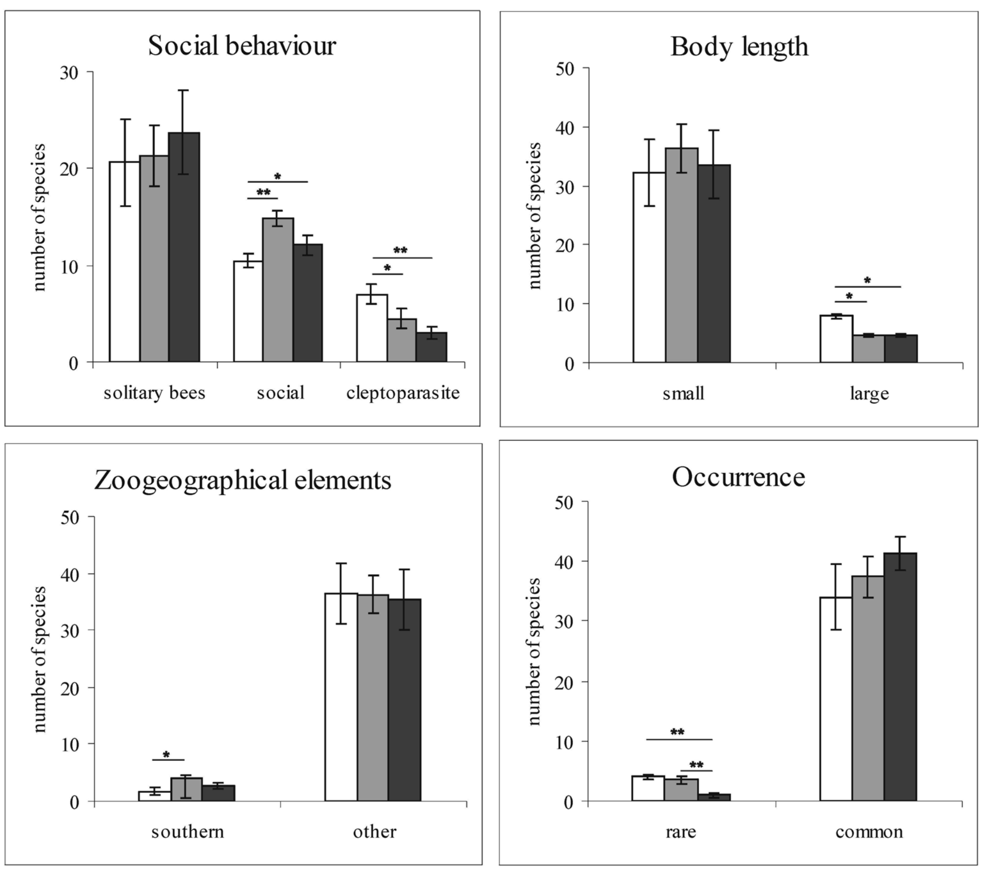

Fig. 4 Mean (±s.e.) number of bee species displaying different functional traits in two types of landscape: natural (Wielkopolska National Park - white) and urban (Citadel Park – light gray; Botanical Garden – dark grey): $*P < 0.05$; $**P < 0.01$

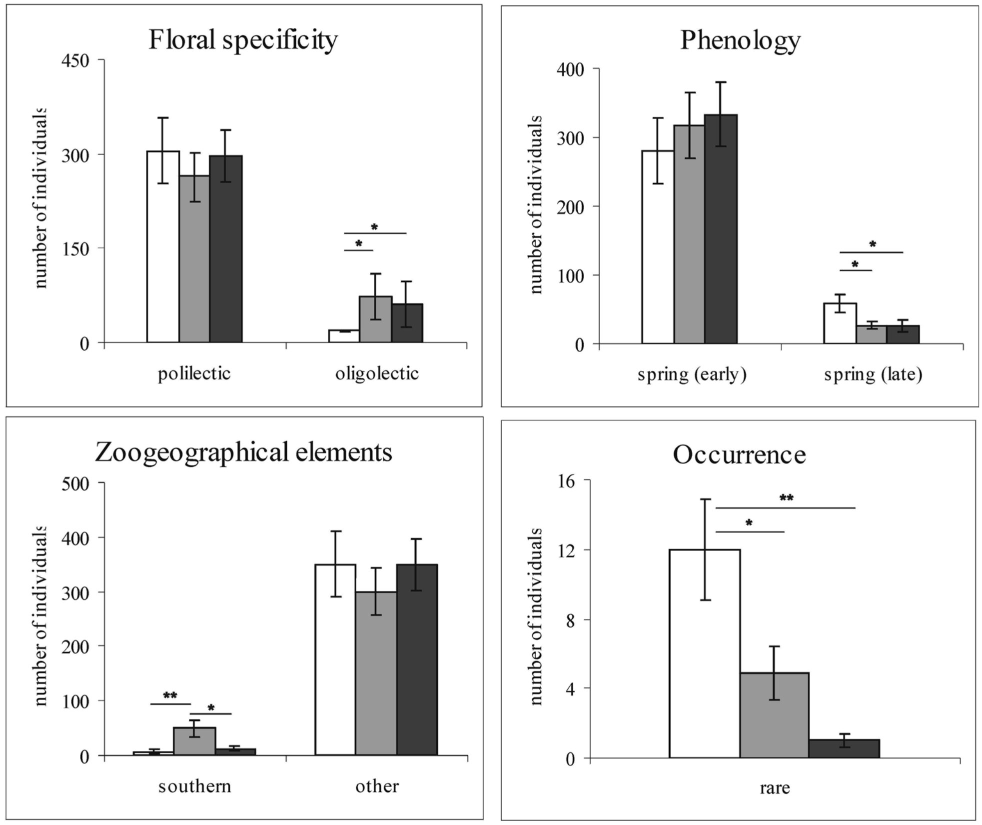

Fig. 5 Mean (±s.e.) abundance of bee species displaying different functional traits in two types of landscape: natural (Wielkopolska National Park - white) and urban (Citadel Park – light gray; Botanical Garden – dark grey): $^*P < 0.05$; $^{**}P < 0.01$

(Savard et al. 2000). At the same time, the relatively large area of the Citadel Park and direct vicinity of the Warta River are conducive to migration and inflow of taxa to the Park from other areas (Banaszak-Cibicka et al. 2016). Environments in the urban landscape, which display richness of plant species or community structure comparable to that encountered in natural settings, might support bee occurrence also in other parts of the city (Garbuzov and Ratnieks 2014).

The increase in species richness, in the context of moderate human pressure, is related to the intermediate disturbance hypothesis (Blair and Launer 1997; Roxburgh et al. 2004). According to the hypothesis, intermediate level of disturbances caused by human impact is conducive to species diversity (McKinney 2008). Zerbe et al. (2003) suggest that land mosaics and intermediate level of human activity maximise species diversity by means of environmental heterogeneity increase. Reviews of urban ecology studies indicate that spatial diversity of urban settings is conducive to plant and animal diversity (Niemelä 1999; Porter et al. 2001). This correlation has also been observed in the case of bees in New Jersey (Winfree et al. 2007). The present research seems to corroborate this correlation.

It is true that in the course of this study no differences were observed in terms of bee richness and abundance in the two city parks investigated and in natural areas. However, there were differences in the occurrence of species with various functional traits.

Social bees in the urban environment presented greater species richness. Those bees display considerable ecological and ethological plasticity and a high degree of tolerance to transformations of the environment. Therefore, in the context of urbanisation, they have a greater capacity for adaptation to new, often unfavourable conditions, compared to solitary animals (Chapman and Bourke 2001).

At the same time, a lower number and abundance of parasitic species were observed in the city parks compared to the protected natural areas. Persistence of a population of species that form a community may be assessed by means of a percentage share of parasitic species in that community. Lack of parasites or their low share in the community may indicate poor persistence of the host species population. It might also stem from the fact that the host species population has been present in a given area for a short time or that it displays considerable abundance fluctuations. Increased frequency of ecological disturbances such as plant removal or deforestation etc. might cause large fluctuations in abundance or temporary extinction of the host population (Cierzniak 2003a). A similarly low number of parasitic species was observed during the studies in the gardens of New York (Matteson et al. 2008) and in Berkeley (Frankie et al. 2005) as well as in the communities of the cultural landscape in Poland (Cierzniak 2003a). On the other hand higher number and abundance of cleptoparasitic species in natural areas indicate high quality of this environments which are able to sustain stable populations of host species.

Also large-sized bee species and late spring species displayed respectively lower richness and abundance in the urban parks compared to natural areas. Such correlation has also been observed in beetles and spiders (Miyashita et al. 1998; Weller and Ganzhorn 2004). Large size is a correlate of extinction risk in many groups, including some bee communities (Flynn et al. 2009; Hinners et al. 2012). Lower abundance of late spring species might, in turn, be related to the fact that a considerable part of lawns in the city park is regularly mowed. Frequent lawn mowing in the flowering time of plants that constitute a food source for bees has a greater influence on late spring species than on early spring species. Early spring bee species feed on tree pollen to a great extent, and trees comprise the most stable food source in a city. Smaller amount of food available later translates into lower bee abundance.

On the other hand, southern bee species in the city park displayed greater diversity and abundance compared to natural areas. Urban environment presents higher temperatures compared to suburban areas. Thus, it is a convenient habitat for southern fauna (Banaszak-Cibicka 2014). This pattern is especially visible in Citadel Park which is probably because of the specific climate conditions of this area. The remains of brick walls of old fortifications and warm sloped clay hillsides provide the favourable conditions for nesting of thermophilic bee species. The low number of southern species in WNP, on the other hand, is related to the scarcity of xerothermic environments in its area, like dry and hot meadows, banks of valleys and sandy slopes with southern or western exposure. Moreover, these environments are continuously becoming overgrown (Banaszak et al. 2003).

We did not observe any significant differences in the number of rare species in Citadel Park and natural areas but the richness of rare species in WNP was higher than in Botanical Garden. Moreover, the abundance of rare species was significantly lower in both urban habitats. The Citadel Park is large and diversified. What is more, there are areas similar to natural ones. Hence, it may provide favourable habitat conditions not only for common species but also for rarer ones. Nevertheless, natural reserve turned out to be better place to harbour greater abundance of rare species.

National parks are legally protected, intact or almost intact areas, which means that the influence of human activity on their flora and fauna is very limited. However, such areas have not been designed for the purposes of a specific group of animals which live there, and thus their characteristics might not always be beneficial for bees. At the same time, large city parks may be a convenient habitat for a very diverse and numerous group of bees. Moreover, such parks may be specially adapted in order to increase their attractiveness to pollinators, which is their undoubted advantage. Due to the fact that urbanisation is an expanding process and larger and larger areas are becoming parts of cities, the role of urban greenery as a habitat for the local fauna will be increasing. Therefore, in order to protect these immensely beneficial insects it is important to improve the quality of urban green areas, which provide a habitat for bees (McIntyre and Hostetler 2001; McFrederick and LeBuhn 2006; Smith et al. 2006; Matteson et al. 2008). It is vital to preserve diverse urban green areas and improve the way they connect with larger green areas directly adjacent to suburban areas (Snep et al. 2006; Banaszak-Cibicka et al. 2016). Moreover, it would also be necessary to limit the frequency of lawn mowing in the flowering time of plants that comprise an important source of food for bees in cities, as well as to plant additional shrubs, which could complement or replace the mowed herbaceous plants. Apart from their recreational value, adequately designed and properly used green areas in large urban agglomerations may be a perfect place for living and protection of this exceptionally significant group of pollinators.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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