Baltic J. Coleopterol. 13(1) 2013
ISSN 1407 - 8619

Role of urban forests as a source of diversity of carabids (Coleoptera: Carabidae) in urbanised areas

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Kosewska A, Nietupski M., Damszel M. 2013. Role of urban forests as a source of diversity of carabids (Coleoptera: Carabidae) in urbanised areas. *Baltic J. Coleopterol., 13(1): 27 - 39.*

We analysed the structure of ground-beetle (Col.: Carabidae) assemblages populating urban forests which differed from one another in the composition of woody plants, soil cover with herbaceous plants, habitat humidity, and extent of stress caused by people. Field tests were carried out in Olsztyn, Northeastern Poland, in 2009. A total of 4,440 individuals, representing 70 species, were captured in pitfall traps. Different ecological groups of carabids were observed depending on the distinguishing features of the analysed urban forests. Redundancy analyses showed that anthropogenic pressure and habitat humidity had significant impact on the formation of carabid assemblages. We observed that the variety of urban forests helped to sustain and improve the species diversity of ground beetles. Owing to their heterogeneity, trees and shrubs in towns provide for the presence of various ecological groups of Carabidae.

Key words: carabid beetles, anthropogenic pressure, urban forests

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INTRODUCTION

Nowadays, most people live in cities or towns, which – according to all estimates – will continue to expand. Urban areas are specific ecosystems characterised by very strong spatial differentiation of microhabitats, which is manifested by a variety of plant cover, type of soil, and exposure to different sources of pollution and interference (McIntyre et al. 2001). Each town creates a set of numerous, mutually interacting factors, of which the anthropogenic influence is extremely important (Żelazna and Błażejewicz-Zawadzińska 2006). Urban residents exert an enormous impact, both directly and indirectly, on their local flora and fauna. Urbanisation is responsible for profound modifications of the natural environment, which may lead to the extinction of many plant and animal species (Marzluff et al. 2001; Elek and Lövei 2007). The current regulations imposed on urban ecological management state that while urban areas are being developed for residential, recreational, or commercial purposes, attention must be paid to the protection of valuable natural plant communities and preservation of biodiversity (Niemelä 1999). For years, studies have been carried out on the effect of urbanisation on biodiversity using ground beetles (Col.: Carabidae) as bioindicators (Niemelä et al. 2000; Magura et al. 2010). Because of their sensitivity to environmental changes, widespread occurrence, and well-known ecology, carabids have long been used as bioindicators of habitat conditions and considered useful in biodiversity studies (McGeoch 1998; Szyszko 2002; Rainio and Niemelä 2003; Skłodowski 2009; Koivula 2011; Skalski et al. 2012).

Urban areas are extremely rich in floral species, frequently much richer than other types of land (Tonteri and Haila 1990). Therefore, urban forests, sometimes even anthropogenic communities of trees and shrubs (e.g. parks and cemeteries) or woodland on the outskirts of towns, play a special role among the plant communities found within town borders. Obviously, they offer home to numerous species of ground beetles (Magura et al. 2010).

The aim of the present study was to analyse the structure of assemblages of carabids dwelling in several urban forests which differed in the composition of woody plants, soil cover with herbaceous plants, presence of shrubs, habitat humidity, and anthropogenic pressure. We aimed at determining which of these factors had the strongest effect on the formation of carabid assemblages.

The following assumptions (research hypotheses) were made for urban forests:

Higher diversity of plants (trees, shrubs and soil cover with herbaceous plants) stimulates the species diversity of carabid beetles.

Higher habitat humidity favours the occurrence of stenotopic species.

The species diversity of carabids decreases with increasing anthropogenic pressure.

Stronger anthropogenic pressure leads to forest carabid species being replaced by eurytopic and open-area species.

MATERIAL AND METHODS

Study area

Field tests were carried out within the administrative borders of the town of Olsztyn (UTM - DE 65), Northeastern Poland. Carabidae were captured in three different urban forests. The first site (A) was a woodland located near a housing estate and crisscrossed by footpaths. This site was under the strongest anthropogenic influence. The species composition comprised pine (*Pinus silvestris* L.), which made up about 80 % of all trees, and deciduous trees: common birch (*Betula veruscosa* Ehrh.) and maple (*Acer platanoides* L.). The trees were 70 – 80 years old. Shrubs were abundant and 70 % of the soil was overgrown with grass. This site was characterised by the lowest soil moisture among all analysed urban forests. The second site (B) was about 400 m away from a lake and therefore grew on a rather moist soil substrate. The trees were mainly 90-year-old beech (*Fagus sylvatica* L.) and hornbeam (*Carpinus betulus* L.). Shrubs were scarce and the soil cover with herbaceous plants was incomplete (40 %). The third site (C) consisted of trees growing in the closest proximity (5-10 meters) of a lake. Consequently, the soil-moisture level was highest. This site consisted of 50 – 60-year-old deciduous trees such as poplar (*Populus alba* L.), maple (*Acer platanoides* L.), willow (*Salix cinerea* L.), and aspen (*Populus tremula* L.). The shrub layer was almost as rich as in site A, and the soil cover with herbaceous plants was highest (90 %). With respect to anthropogenic pressure caused by the location and their surroundings (houses, streets, footpaths), the three urban forests rank as follows: A > B > C.

Carabid sampling

In 2009, ground beetles were pitfall-trapped by modified Barber traps, which were 400 ml plastic cups filled with ca. 130 ml ethylene glycol as a preservative medium. Traps were exposed from the end of April to the end of October and emptied every fortnight. Three transects at a distance of at least 100 m were set up in each urban forest. In each transect, 4 traps were placed 10 meters from one another along a straight line. The total number of samples was therefore 468 (36 traps each emptied 13 times).

Data analysis

Collected material was identified to the species using the key by Hůrka (1996) and nomenclature by Aleksandrowicz (2004). Assemblages of ground beetles were classified in ecological groups according to their requirements regarding nutrition, habitat, and humidity, and their type of development (Larsson 1939; Sharova 1974; Thiele 1977; Lindroth 1985, 1986; Aleksandrowicz 2004). The following indices were used for determining the diversity of carabid assemblages: Shannon-Weaver's species diversity (H', log base 2,718), Pielou's species evenness (J'), and Simpson's species richness (D). Differences between the indices' mean values, abundance of individuals, and number of species captured in the urban forests were explored by one-factor analysis of variance (ANOVA).

Ordination methods (e.g. redundancy analysis, RDA) were applied to visualise correlations between a) the number and composition of carabid species inhabiting the three urban forests and b) the following habitat-related variables: Habitat moisture (Humidity), soil cover with herbaceous plants (Soil-cover), presence of shrubs (Shrub), presence of coniferous trees (Coniferous), deciduous trees (Deciduous), and anthropogenic pressure (Anthropopressure). Detrended correspondence analysis (DCA) was performed to assess changes in the ecological classifications of Carabidae within the assemblages populating the three different sites. The results of DCA analyses are presented in the form of diagrams in which the analysed areas as well as the species and ecological groups are arranged relative to the two ordination axes. Statistical significance was determined by the Monte-Carlo test, using original, untransformed data. All statistical calculations and graphs were performed with the software packages Statistica 10 PL and Canoco ver. 4.51 (ter Braak and Šmilauer 1998).

RESULTS

During field observations carried out in three urban forests in Olsztyn, Northeastern Poland, 4,440 specimens of Carabidae representing 70 species were captured (Tab. 1). The highest number of carabids (2,066) was obtained on site B (old deciduous trees with very poor understorey growth). The highest number of species (56) was captured on site C, where trees grow along a lake shore. The Shannon-Weaver index (H') of species diversity and the interrelated Pielou index (J') of evenness reached the highest values in urban forest A, exposed to the strongest anthropogenic stress. The Simpson index (D), corresponding to species richness, attained the highest value in urban forest B (Tab. 1). When analysing statistical significance of the means, differences between the forests were noticed in the number of individuals and species as well as the diversity indices of carabid assemblages (Fig. 1). Except for the average number of individuals, urban forest B is highly different from the two other sites in all remaining parameters. It may also be distinguished by its structure of species dominance since one species, *Nebria brevicollis* (Fab.), was distinctly more abundant than the other species, making up 87 % of the whole assemblage (Tab. 1). The second most abundant species, *Limodromus assimilis* (Payk.), represented just 7 % of the whole assemblage. Two other species corresponded to more than 1 % of the whole population of carabids while all other species constituted less than 1 % of carabids. In the other urban forests, *Nebria brevicollis* was also a dominant species (A – 39 %, C – 44 %), but the distribution of the other species was more even and there were no large discrepancies in abundance between the dominant and other species of the assemblages.

Redundancy analysis (RDA) (since data were linear at a DCA-gradient length of 2.451) showed the correspondence between carabid-species variability and the analysed habitat-related parameters. The effect of anthropogenic pressure (F = 14.97; p = 0.002) and habitat humidity (F = 12.64; p = 0.004) proved to be significant. The first ordination axis, explaining 93.5 % of the vari-

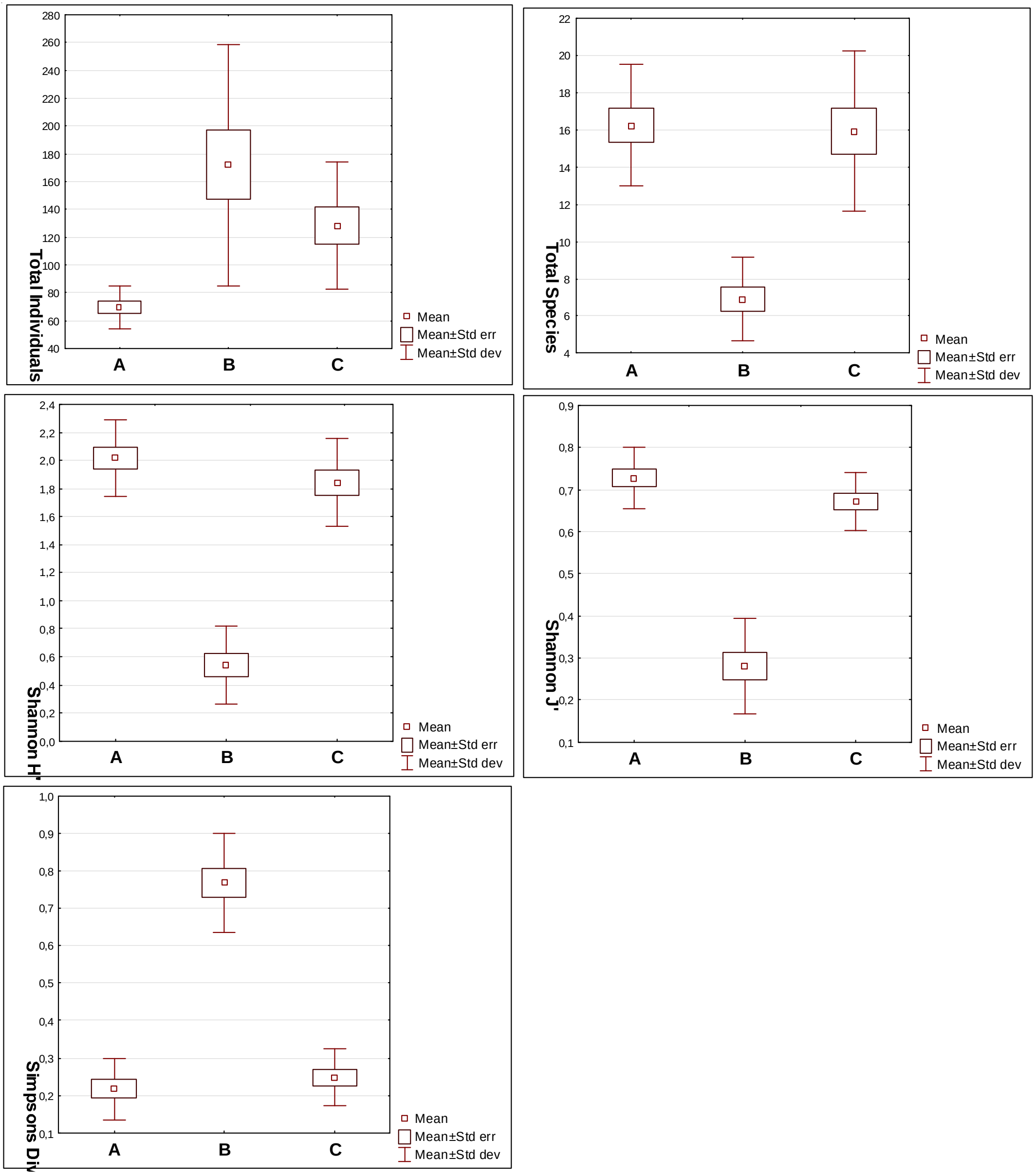

Fig. 1. Means of numbers of individuals and species as well as diversity indices of Carabidae populating three urban forests (A, B, and C). Significance is indicated at p<0,05.
A - woodland located near a housing estate with the strongest anthropogenic influence; B - site about 400 m away from the lake; C - trees growing next to the lake.

ability of the analysed assemblage (Tab. 2), closely corresponded to the occurrence of the most abundant species in the assemlage, i.e. *Nebria brevicollis* and *Limodromus assimilis* (Fig. 2). The second ordinanation axis, accounting for 6.2 % of the variability, was positively correlated with habitat humidity and soil cover with herbaceous plants while being inversely correlated with anthropogenic pressure. Higher soil moisture was correlated with the occurrence of species characterised by strong hygropreference such as *Pterostichus anthracinus* (Ill.), *Patrobus atrorufus* (Str.), *Clivina collaris* (Her.), or *Loricera pilicornis* (Fab.). Moreover, presence of a large group of carabid species was correlated with coniferous trees and a rich layer of shrubs (Fig. 2).

Carabid species inhabiting urban forests represent different ecological groups. Eurytopic species are abundant, but there are also open-area- and forest-related species demonstrating different hygrophilic and trophic preferences. The DCA diagram (Fig. 3) sheds light on the presence of different ecological groups in the analysed tree assemblages, both in terms of their individual count and species composition. The two major ordinanation axes, accounting for 62 % of the species variability (Tab. 3), were positively correlated with urban forests A and C. Xerophilic species including small zoophages and hemizoophages were typical for site A, which was composed of patches of mixed forest with the dominance of pine and a rich layer of shrubs. This finding is confirmed by the data set given in Table 4, where the contribution of particular ecological groups to the structure of the whole assemblage is

Table 1. Species composition and dominance [%] of Carabidae in the analysed urban forests

Species	Abbreviation	Site		
		A	B	C
		%	%	%
Agonum sexpunctatum (Linnaeus,1758)	Ag_sexp	0.12	0	0
Agonum viduum Sturm,1824	Ag_ vid	0	0	0.19
Amara aenea (Degeer,1774)	A_aene	0.36	0	0
Amara bifrons (Gyllenhal,1810)	A_bifr	3.96	0	0.58
Amara brunnea (Gyllenhal,1810)	A_brun	2.28	0	0.13
Amara communis (Panzer,1797)	A_com	4.56	0	0.32
Amara consularis (Duftschmid,1812)	A_cons	0	0	0.06
Amara convexior Stephens,1828	A_conv	16.81	0	0.45
Amara eyrinota (Panzer,1797)	A_eyri	0.24	0	0
Amara familiaris (Duftschmid,1812)	A_fami	0.48	0.05	0
Amara fulva (Degeer,1774)	A_fulv	0.12	0	0
Amara ingenua (Duftschmid,1812)	A_ing	0	0	0.06
Amara littorea Thomson,1857	A_litt	0	0	0.13
Amara municipalis (Duftschmid,1812)	A_muni	0.24	0	0.06
Amara ovata (Fabricius,1792)	A_ova	1.08	0	0.06
Amara plebeja (Gyllenhal,1810)	A_pleb	0.72	0	0.06
Amara similata (Gyllenhal,1810)	A_simi	0.12	0	0.26
Amara spreta Dejean,1831	A_spre	0.24	0	0
Anchomenus dorsalis (Pontoppidan,1763)	Anch_dor	0	0.10	0.13
Anisodactylus binotatus (Fabricius,1787)	Ani_bino	0.24	0	1.69
Anisodactylus nemorivagus (Duftschmid,1812)	Ani_nem	0	0	0.13
Asaphidion flavipes (Linnaeus,1761)	Asa_fla	0	0.15	0.06
Badister bullatus (Schrank,1798)	Bad_bull	1.08	0	0
Bembidion femoratum Sturm,1825	Be_fem	0	0	0.06
Bembidion lampros (Herbst,1784)	Be_lamp	0.12	0.15	0.06
Bembidion properans (Stephens,1828)	Be_pro	0.12	0.10	0.06
Bembidion tetracolum Say,1823	Be_tetra	0	0	0.39
Calathus ambiguus (Paykull,1790)	Cal_ambi	0.96	0	0
Calathus erratus (Sahlberg,1827)	Cal_erra	2.40	0	0
Calathus fuscipes (Goeze,1777)	Cal_fusc	4.56	0	0.26
Calathus melanocephalus (Linnaeus,1758)	Cal_mela	3.12	0	0
Carabus granulatus Linnaeus,1758	Ca_granu	0	0	0.06
Clivina collaris (Herbst,1784)	Cliv_col	0	0.05	0.65
Clivina fossor (Linnaeus,1758)	Cliv_fos	0	0	0.19
Elaphrus cupreus Duftschmid,1812	Ela_cup	0	0	0.13
Europhilus fuliginosus (Panzer,1809)	Eur_ful	0	0	0.13
Harpalus affinis (Schrank,1781)	H_affi	0	0	0.06
Harpalus autumnalis (Duftschmid,1812)	H_autu	0	0.05	0
Harpalus griseus (Duftschmid,1812)	H_gri	0	0	0.06
Harpalus latus (Linnaeus,1758)	H_lat	0.36	0	0
Harpalus luteicornis (Duftschmid,1812)	H_lute	1.68	0	0
Harpalus quadripunctatus Dejean,1829	H_quad	0.12	0.05	0
Harpalus rubripes (Duftschmid,1812)	H_rub	0.24	0	0
Harpalus rufipes (Degeer,1774)	H_ruf	0.24	0.05	0.13
Harpalus smaragdinus (Duftschmid,1812)	H_sma	0.24	0	0
Harpalus tardus (Panzer,1797)	H_tard	2.28	0	0
Leistus rufomarginatus (Duftschmid,1812)	Lei_rufo	0.24	1.79	0.45
Limodromus assimilis (Paykull,1790)	Platyn_as	0	6.73	2.40
Loricera pilicornis (Fabricius,1775)	Lo_pil	1.92	1.60	5.32
Nebria brevicollis (Fabricius,1792)	Ne_brevi	39.02	87.03	43.93
Notiophilus biguttatus (Fabricius,1779)	N_big	5.40	0.10	0.06
Notiophilus palustris (Duftschmid,1812)	N_pal	1.32	0.15	0.06
Oodes helopioides (Fabricius,1792)	Oo_hel	0	0	0.26
Ophonus rufibarbis (Fabricius,1792)	Op_rufb	0.12	0	0.39
Patrobus atrorufus (Strom,1768)	Pat_atr	0	0.82	13.11
Poecilus cupreus (Linnaeus,1758)	Po_cupr	0	0	0.06
Poecilus versicolor (Sturm,1824)	Po_ver	0	0	0.06
Pterostichus aethiops (Panzer,1797)	Pt_ aeth	0	0	0.19
Pterostichus anthracinus (Illiger,1798)	Pt_ anth	0.12	0.24	14.21
Pterostichus diligens (Sturm,1824)	Pt_ dil	0	0	0.06
Pterostichus melanarius (Illiger,1798)	Pt_ mela	0.60	0.39	8.76
Pterostichus minor (Gyllenhal,1827)	Pt_ min	0	0.10	0.39
Pterostichus niger (Schaller,1783)	Pt_nig	0	0.05	0
Pterostichus nigrita (Paykull,1790)	Pt_ nigr	0.12	0.24	2.27
Pterostichus oblongopunctatus (Fabricius,1787)	Pt_ oblo	0.24	0	0.58
Pterostichus rhaeticus Heer,1838	Pt_rha	0	0	0.13
Pterostichus strenuus (Panzer,1797)	Pt_ stre	1.20	0	0.13
Pterostichus vernalis (Panzer,1796)	Pt_ vern	0.12	0	0.06
Stomis pumicatus (Panzer,1796)	Sto_pum	0	0	0.19
Synuchus vivalis (Illiger,1798)	Syn_viv	0.48	0.05	0.19
Number of individuals		833	2066	1541
Number of species		42	22	56
Shannon-Weaver diversity H' (Log Base 2,718)		2.37	0.61	2.01
Pielou evenness J'		0.63	0.2	0.51
Simpson diversity D		0.19	0.76	0.24

Table 2. RDA results of Carabidae assemblages

RDA Axes	1	2	3	4	Total variance
Eigenvalues	0.557	0.037	0.002	0.379	1.000
Species-environment correlations	0.773	0.932	0.576	0.000	
Cumulative percentage variance of species data	55.7	59.4	59.6	97.4	
of species-environment relation	93.5	99.7	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.596

Table 3. DCA results of Carabidae assemblages

DCA Axes	1	2	3	4	Total inertia
Eigenvalues	0.237	0.039	0.009	0.006	0.444
Lengths of gradient	2.024	1.749	1.548	2.047	
Cumulative percentage variance of data	53.4	62.2	64.2	65.6	
Sum of all eigenvalues					0.444

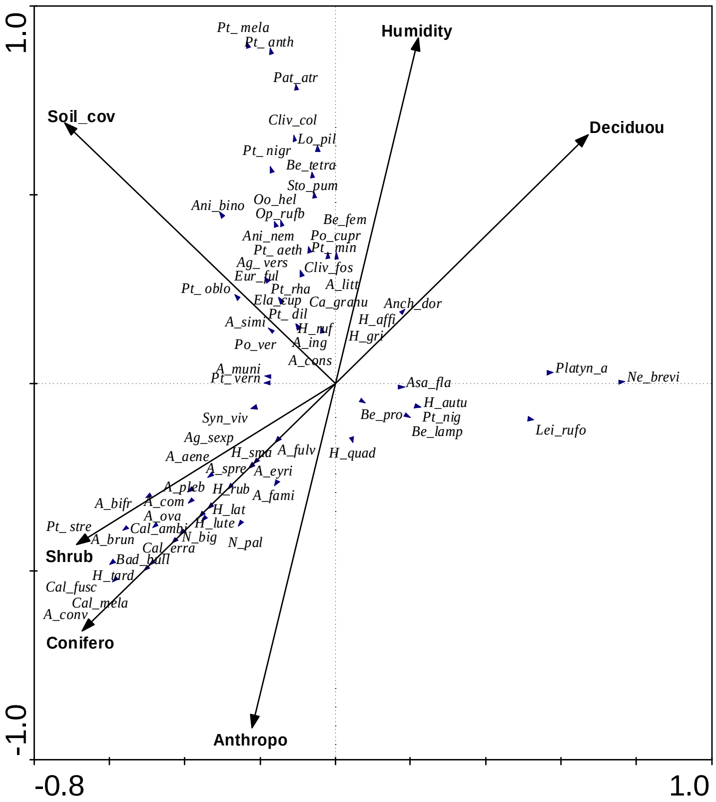

Fig. 2. RDA ordination diagram of the relationship between species dominance of Carabidae and environmental variables (presence of deciduous and coniferous trees, soil cover, anthropopressure, humidity)

listed. We observed a large share of open-area-related carabid beetles (42 % of individuals and 57 % of species) and the presence of forest-related species (24 %). In the trophic structure, except for the share of large zoophages (39.62%, of which 39.02% was made up by *Nebria brevicollis*), the zoophagous fauna was supplanted by hemizoophages in site A. Urban forest B, which is composed of fragments of moist beech forest, was distinctly different from the other sites while having been the most homogenous one (Fig. 3). However, this habitat was dominated by *Nebria brevicollis*, a large mesophilic zoophage characteristic for woodlands but not dense forests, which in this study was classified as eurytopic. There, the share of eurytopic beetles was over 94%. When taking a closer look at the qualitative analysis of the carabid species inhabiting site B the shares of species with different habitat preferences are almost even with just a slight dominance of open-area-related species (Tab. 4). Owing to the high humidity of this habitat, a relatively numerous group of hygrophilic species (27 %) was detected in this site. Our analysis of the trophic structure of site B, (having excluded *Nebria brevicollis*), shows a high number of small and medium zoophages and hemizoofages. The third urban forest (site C), growing on a lake shore and therefore being very humid, attracted peatbog-related species with strong hygropreference, trophically classified as medium zoophages (Fig. 3). This finding is further supported by the information presented in Table 4, where high shares of peatbog-related, hygrophilic, and mesophilic species were noted both in terms of individual numbers and numbers of species. This tree assemblage was mainly colonized by carabid species classified

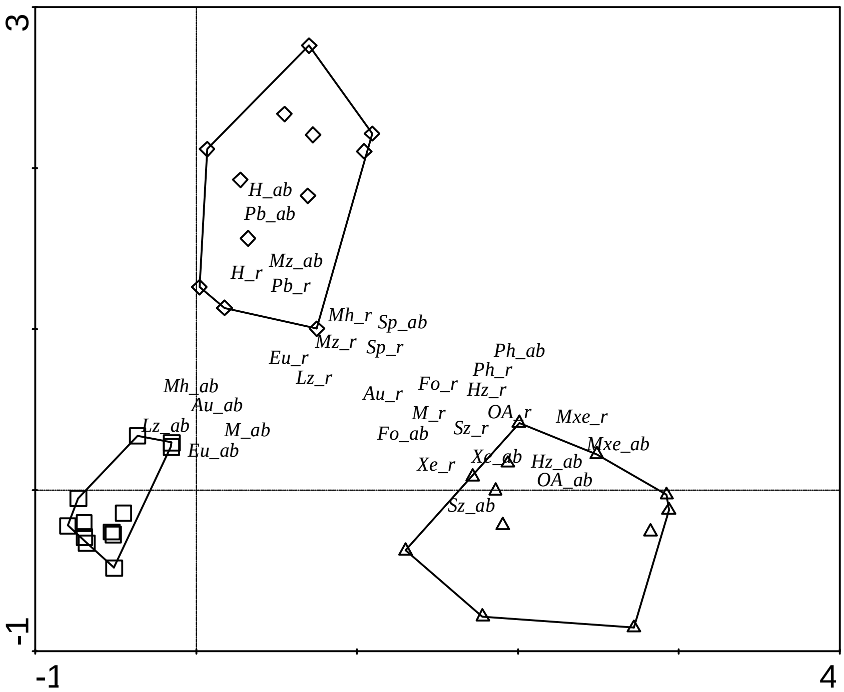

Fig. 3. DCA ordination diagram of ecological groups of Carabidae (Eu – eurytopic species, Fo – forest-related sp., OA – open-area-related sp., Pb – peatbog-related sp., H – hygrophilic sp., Mh – mesohygrophilic sp., M – mesophilic sp., Mxe – mesoxerophilic sp., Xe – xerophilic sp., Ph – phytophages, Hz – hemizoophages, Lz – large zoophages, Mz – medium zoophages, Sz – small zoophages, Au – autumn breeders, Sp – spring breeders, ab – abundance, r – richness, “- trap in the site A, %- trap in the site B, %- trap in the site C).

Table 4. Ecological groups of Carabidae caught in three urban forests (A, B, and C)

	A		B		C	
Qualitative aspect	n	%	n	%	n	%
Habitat preferences						
Eurytopic species	6	14.29	5	22.73	9	16.07
Forest-related species	10	23.81	5	22.73	11	19.64
Open-area-related species	24	57.14	7	31.82	23	41.07
Peatbog-related species	2	4.76	5	22.73	13	23.21
Hygropreferences						
Hygrophilic species	3	7.14	6	27.27	11	19.64
Mesohygrophilic species	5	11.90	3	13.64	11	19.64
Mesophilic species	23	54.76	11	50.00	26	46.43
Mesoxerophilic species	9	21.43	1	4.55	6	10.71
Xerophilic species	2	4.76	1	4.55	2	3.57
Trophic structure						
Phytophages	3	7.14	0	0.00	2	3.57
Hemizoophages	18	42.86	4	18.18	17	30.36
Large zoophages	2	4.76	3	13.64	4	7.14
Medium zoophages	13	30.95	10	45.45	23	41.07
Small zoophages	6	14.29	5	22.73	10	17.86
Breeding type						
Autumn breeders	16	38.10	7	31.82	16	28.57
Spring breeders	26	61.90	15	68.18	40	71.43
Quantitative aspect						
Habitat preferences						
Eurytopic species	340	40.82	1949	94.34	885	57.43
Forest-related species	118	14.17	46	2.23	63	4.09
Open-area-related species	358	42.98	13	0.63	54	3.50
Peatbog-related species	17	2.04	58	2.81	539	34.98
Hygropreferences						
Hygrophilic species	18	2.16	63	3.05	565	36.66
Mesohygrophilic species	20	2.40	144	6.97	81	5.26
Mesophilic species	699	83.91	1857	89.88	877	56.91
Mesoxerophilic species	91	10.92	1	0.05	17	1.10
Xerophilic species	5	0.60	1	0.05	1	0.06
Trophic structure						
Phytophages	10	1.20	0	0.00	5	0.32
Hemizoophages	295	35.41	4	0.19	61	3.96
Large zoophages	330	39.62	1807	87.46	813	52.76
Medium zoophages	129	15.49	242	11.71	646	41.92
Small zoophages	69	8.28	13	0.63	16	1.04
Breeding type						
Autumn breeders	491	58.94	1863	90.17	1054	68.40
Spring breeders	342	41.06	203	9.83	487	31.60

as small zoophages and hemizoophages. Analysis of the presence of species with different breeding-period preferences (spring and autumn breeders) in three urban forests revealed that spring breeders species were much more numerous, but autumn breeders dominated in the number of individuals (Tab. 4).

DISCUSSION

The 70 species of Carabidae captured during the field observations carried out in three urban forests in Olsztyn correspond to 25 % of all species detected in Northeastern Poland (Aleksandrowicz et al. 2003). This number was comparable to the species counts reported for Poland by other authors (Kosewska et al. 2003; Żelazna and Błażejewicz-Zawadzińska 2006; Nietupski et al. 2008a, 2008b; Kosewska et al. 2011). Data from other countries (studies on ground beetles in the scope of the Globenet project) revealed lower numbers of species found in urban areas, ranging from 13 (Japan) to 44 (Bulgaria) (Magura et al. 2010. The number of captured carabid individuals in our urban forests in Olsztyn can be compared to results obtained in Denmark, Belgium, and England (Magura et al. 2010). Niemelä and Kotze (2009) draw attention to the fact that the abundance and richness of carabid species inhabiting urban areas increase as one moves from the town centre towards suburban districts. Similar data were generated by Magura et al. (2008), who analysed forested areas along an urban-rural gradient in Hungary. The present results seem to confirm the above observations with respect to the number of species. Most carabid species were captured in urban forest C, which – out of the three sites - was located furthest away from the town centre and was also least exposed to anthropogenic influences. Large differences in the numbers of captured species between the three sites may have been a consequence of the variations in microhabitats observed Each type of forest is characterised by a specific carabid assemblage, with its characteristic species and ecological group composition (Kotze et al. 2011).

The Shannon-Weaver index of carabid-species diversity (H'), although reaching different values in the three urban forests, was lower than in other studies on urban tree assemblages (Żelazna and Błażejewicz-Zawadzińska 2006). Gerisch (2011) claims that differences in the species diversity are mainly caused by environmental variation, including the one caused by fragmentation of habitats. The H' index attained the highest value in urban forest A, which was under the strongest anthropogenic stress. This finding supports a study carried out by Magura et al. (2004), who, in contrast to Grey (1989), did not observe the total diversity to diminish in an environment exposed to human interference. However, Shanon-Weaver's index does not always reflect the high ecological value of a given habitat. High species diversity is not essential for the occurrence of rare species (Butterfield et al 1995). Our ecologically most valuable stenotopic species were captured in the urban forest growing on the lake shore, where the H' index was relatively low. Simpson's species-richness index (D) attained an extremely high value (0.76) in urban forest B. This index, also known as the dominance-concentration ratio, includes little information on the presence of rare species, because their share of the total sample is small, but emphasizes the role of common species. Hence, when analysing the structure of dominance in a given site, it may be possible to find an explanation for such high D values. According to Czechowski (1982), species-dominance structures are often disrupted in habitats exposed to environmental pressure, e.g. in towns. Similarly, Elek and Lovei (2007) as well as Angold et al. (2006) claim that an evident dominance of a single species and disturbances in the arrangement of dominance classes are typical of carabid coenoses populating urban areas. In our site B, 87 % of ground beetles belonged to the species *Nebria brevicollis*. Thus, this carabid assemblage appears to be largely unstable. However, this instability may not be attributed to anthropogenic pressure. The high abundance of *Nebria brevicollis* was possibly associated with the specific characteristics of the urban forest in question, which was part of a moist and dark beech forest with poor undergrowth. Numerous publications focus on the litter layer, which is necessary for the occurrence of many species characteristic for forests (Kwiatkowski 2011, Skłodowski 2006). In our study, this component was very poorly developed and possibly only non-specific species like *Nebria brevicollis* could thrive very well. It is not a coincidental finding because Kosewska et al. (2011) noticed a similarly high domination of this species (over 60%) at that site.

Most probably, there is one habitat-related factor which is strongly correlated with the presence of dominant species and which was not included in the analysis. There may have been some specific trophic base favoured by *Nebria brevicollis* or certain places suitable for that species.

The collected material comprised carabids belonging to four habitat-preference types: eurytopic, forest-, open-area-, and peatbog-related species. In all three urban forests, owing to the high abundance of *Nebria brevicollis*, eurytopic species were most numerous. After excluding this species from analyses, however, characteristic ecological tendencies became apparent. Many authors, e.g. Eversham et al. (1996) and Elek and Lövei (2007), point to a high share of open-area-related and eurytopic species in urban forests. According to them, urban forests are characterised by a high level of heterogeneity, which helps species with specific requirements such as forest- or peatbog-related carabids to survive and sustain within town borders.

Habitat humidity often determines survival of epigeic organisms (Thiele 1997). Being the most easily adaptable, mesophilic species dominated in the investigated urban forests, but as habitat humidity grew, an increase in the number of hygrophilic carabids was noticed. It is not very surprising, especially in natural habitats, but it is less obvious in urban forests exposed to various disturbances. Sadler et al. (2006), who examined carabid assemblages populating urban and suburban areas, observed that, while human activity was one of those environmental variables that significantly affected carabid assemblages in tree and shrub habitats, soil moisture was a non-significant factor. In our study, redundancy analysis (RDA) elucidated the impact of several environmental factors on the species composition of carabids and revealed the significance of both anthropogenic pressure and habitat humidity. An investigation of Kwiatkowski (2011), who studied carabid beetles in humid forest habitats, indicates that habitat humidity is a factor that strongly differentiates communities of Carabidae. Although forest habitats in towns are fragmented and constantly exposed to human activity, rational land management and either introduction or sustenance of areas with high moisture (e.g. ponds, lakes, wetlands) may substantially contribute to possible occurrence of rare, stenotopic species and enrich the biodiversity.

Trophic analysis of carabid assemblages demonstrated dominance of predatory species and hemizoophages in the analysed urban forests. After excluding the large zoophage *Nebria brevicollis* we observed that zoophages were replaced by hemizoophages under increasing anthropogenic stress. Czechowski (1982), who investigated urban greenery in Warsaw, Poland, noticed the same trend under urban pressure. Weller and Ganzhorn (2003) concluded that communities of trees in towns, exposed to unfavourable anthropogenic factors, are characterised by the dominance of species with smaller body size (e.g. *Nebria bervicollis* or *Pterostichus* oblongopunctatus) than larger ones (e.g. *Carabus coriaceus* or *Pterostichus niger*), which are more numerous in forests on the outskirts of towns. Kotze and O'Hara (2003) report that observations carried out for dozens of years reveal a steady decrease in the abundance of the Carabidae species characterized by larger bodies and notice that the process is more intensive than for smaller carabid species. This can be explained by the poorer mobility and lesser reproduction potential of larger beetles.

When analyzing developmental types of Carabidae in the studied urban forests, it was found out that spring breeder species were markedly dominant. According to findings reported in the relevant literature, early reproduction is advantageous in disturbed habitats, as it can diminish decrease larval mortality and enhance the reproductive success (Thiele 1977, Gerisch 2011).

CONCLUSIONS

Fragmentation of habitats, manifested as an effect of various environmental factors, has a decisive influence on the formation of ground-beetle assemblages.

Species diversity of plants, especially herbaceous ones covering the soil surface, has a positive effect on the species diversity of carabid beetles.

Among the analysed environmental variables, growing anthropopressure and habitat humidity had the strongest influence on the composition of carabid assemblages. Habitat humidity also provides for the occurrence of valuable stenotopic species.

Urban forests are habitats suitable for various ecological groups of carabids. Despite strong anthropogenic pressure, open-area- and forest-related as well as eurytopic carabid species were observed along with species with a strong hygropreference. Therefore, urban forests may be perceived as a refuge generally protecting the diversity of Carabidae.

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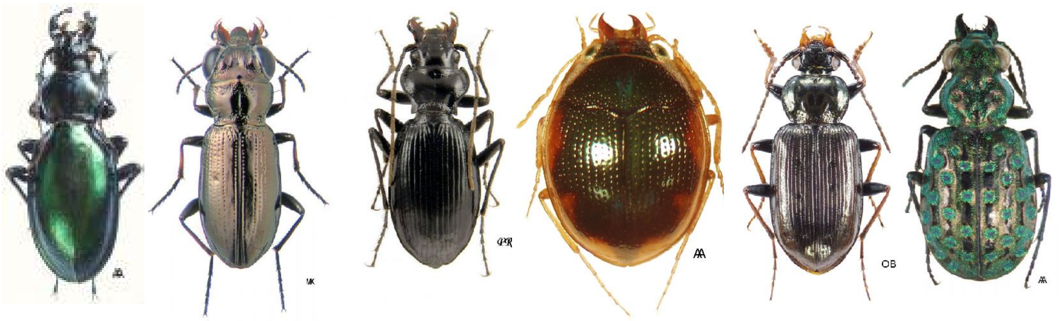
Recived: 20.03.2013
Accepted: 31.05.2013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