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The occurrence and species richnes of nicrophagous Silphidae (Coleoptera) in wooded areas in different degree of urbanization

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This study on the fauna of carrion beetles (Col., Silphidae) was conducted in various wooded areas located in Subcarpathian Voivodeship (south-eastern Poland). It covered habitats differing in anthropogenic pressure and the degree of urbanization. Wooded grounds in less urbanized rural areas were located in the Borek Stary (mid-field tree stands I and II). Wooded grounds in more urbanized areas were located in a suburban district of the city of Rzeszów and included two following sites: a cluster of trees and shrubs, and an urban park. The present study covered four growing seasons (2009-2012). Entomological catches were carried out using baited pitfall traps. At each site, four traps were placed and emptied on average every two weeks. A total of 4282 carrion beetles were found, which were classified to 13 species. In the wooded areas with lower urbanization pressure, a higher number of individuals was caught (2907 exx.) than in the urban areas. These sites were also found to have higher values of the Shannon species diversity index (H'_{ln}) and the Pielou evenness index (J'). Species preferring open areas and fields were also found to occur in greater numbers.

Keywords: carrion beetles, trees, scale of urbanization

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INTRODUCTION

Carrion beetles (Col., Silphidae Latreille, 1806), belonging to the superfamily Staphylinoidea, globally comprise more than 180 species. Most representatives of the family Silphidae are necrophagous, but we can also find predatory and herbivorous species (Ratcliffe 1996; Sikes 2008). The natural importance of necrophagous carrion beetles includes biological disposal of carrion, the cycling of elements in nature, and control of the spread of synanthropic dipterans (Illingworth 1927; Anderson & Peck 1985; Peck 1990; Goff 2009).

Carrion, termed a *bonanza resource*, is a source of highly valuable food, for which necrophagous Silphidae compete through both intra- and interspecific competition (Eggert & Müller 1992; Trumbo 2006). Apart from scavenger vertebrates (predatory mammals and birds), bacteria and fungi developing on remains (microconsumers) and insects (macroconsumers) also use such food (Ratcliffe 1996). Therefore, carrion availability has a probable impact on the diversity and numbers of carrion beetles (DeVault et al. 2011). Urbanization strongly and adversely affects natural habitats, causing local destruction of native populations of small animals or depletion of their numbers (in consequence lower carrion abundance), and hence depletion of carrion beetles (Grimm et al. 2008; Fusco et al. 2017). The studies carried out by Lomolino & Creighton (1996), Trumbo & Bloch (2000), Gibbs & Stanton (2011) prove that increasing habitat fragmentation is negatively correlated with the diversity and numbers of Silphidae (*Nicrophorus* spp.).

Inventory surveys of carrion beetles occurring in diverse wooded areas predominantly include forest biotopes (Lingafelter 1995; Kočárek & Benko 1997; Schlechter 2008; Beucke 2009; Coyle & Larsen 2011; Dekeirsschieter et al. 2011a; Lowe & Lauf 2012; Pietraszko & Warchałowski 2017), among which large-area sites, frequently covered by different forms of nature protection (national parks, landscape parks, nature reserves, protected landscape areas), constitute a large part (Shubeck 1969,1983; Shubeck et al. 1977; Shubeck & Schleppnik 1984; Růžička 1994; Kočárek 1997; Kočárek & Roháčová 2001; Stanovský et al. 2005; Díaz et al. 2010; Byk & Kudła 2011; Moise & Tanase 2013; Aleksandrowicz & Dąbkowski 2014; Mądra et al.2014; Haelwaters et al. 2015). Results of these observations, very valuable in the conservation aspect, are focused on showing species diversity and therefore they fail to capture the direct impact of human activity on the natural environment.

Other sites, among others mid-field tree stands, for example cluster of trees and shrubs, and parks, can certainly be included in wooded areas. Such areas are most frequently characterized by higher economic importance and hence they are subjected to anthropogenic pressure and usually have a lower surface area than forest areas; they also exhibit different interspecific relationships in a given biocoenosis.

Research studies carried out in urban parks in Europe (Błażejewicz-Zawadzińska & Żelazna 2008, 2011; Kočárek 2001), in Canada and the United States (Wolf & Gibbs 2004; Dunn & Danoff-Burg 2007; Brousseau et al. 2010) as well as in South America (Lopes et al. 2015) provide more complete information on the fauna of Silphidae in wooded areas.

The analysis of the cited literature references regarding carrion beetles reveals that there is a research gap with regard to the occurrence of Silphidae in selected wooded areas. Seeing the need to better identify the occurrence of Silphidae in these areas, a study was undertaken aimed at identifying the species composition and structure of Silphidae assemblages occurring in wooded areas characterized by different degrees of urbanization. An attempt was also made to answer the question if urbanization affects the biological diversity of necrophagous carrion beetles occurring in wooded areas.

MATERIALS AND METHODS

Study area

Observations were conducted in wooded areas in south-eastern Poland, situated in the following localities: Borek Stary UTM EA73 (2009-2010) and Rzeszów UTM EA74 (2011-2012) (Figure 1). The selected study sites differed from one another in the floristic aspect, but also in terms of their location and the type of adjacent land. Relevés were made at the study sites using the Braun-Blanquet method (Braun-Blanquet 1964) (see Table S1 and S2 in the supplementary materials).

Wooded study sites in low urbanization areas:

The wooded grounds characterized by a lower degree of urbanization were located in agriculturally used areas in the Borek Stary:

- Study site No. 1- Borek Stary - mid-field tree stand I – dominated by the goat willow (*Salix caprea*), located on a hill, surrounded by crop fields as well as by meadows and pastures. This

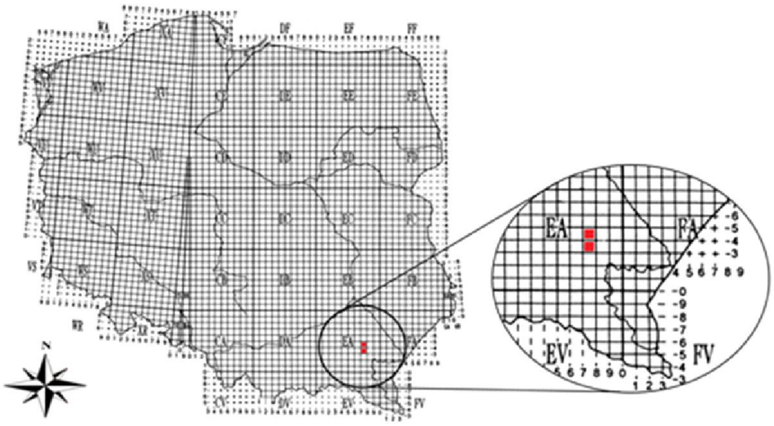

Fig. 1. Locations of the study area in the UTM system: Rzeszów (EA74) and Borek Stary (EA73).

Study site No. 1- mid-field tree stand I (2a)

Study site No. 3 - cluster of trees and shrubs (2c)

Study site No. 2- mid-field tree stand II (2b)

Study site No. 4 – urban park (2d)

Figs. 2: a-d. Study sites: low urbanization areas (2a-2b) and high urbanization areas (2c-2d) site is not economically used, which is also evidenced by the presence of trees such as *Betula pendula*, *Prunus avium*, and *Prunus domestica* subsp. *syriaca*, whose trunk diameter reached a dozen or so centimeters. No agronomic operations were carried out there (Figure 2a);

- Study site No. 2 - Borek Stary - mid-field tree stand II – located in a terrain depression where a grey willow (*Salicetum pentandro-cinereae*) thicket had formed. This site was bordered by a small subsistence farm, fallow land, and a meadow. The soil was highly hydrated, with a high organic content. Similarly to site 1, no agronomic treatments were carried out there (Figure 2b).

Wooded study sites in high urbanization areas: The wooded areas characterized by higher urbanization density were located in a south-eastern district of Rzeszów (suburbs):

- Study site No. 3- Rzeszów - a cluster of trees and shrubs – in its floristic composition, this study site corresponds to a riparian willow forest (*Salicetum albo-fragilis*). *Salix alba* and *Salix fragilis* were predominant among trees in the area in question, while in the underbrush *Salix viminalis*. The thick ground cover was mosaic-like. Rush species (*Phalaris arundinacea*) and wet meadow taxa (among others, *Holcus lanatus*, *Poa trivialis*, *Ranunculus repens*, *Festuca rubra*, *Geranium pratense*) grew alongside one another. A multi-family residential area of medium intensity and public buildings were located in close vicinity. No agronomic operations were carried out there (Figure 2c);

- Study site No. 4- Rzeszów- an urban park - this study site is located in a park on the bank of a flowing stream. Several-dozen-year-old specimens of *Aesculus hippocastanum* and *Acer pseudoplatanus* as well as *Betula pendula* and *Magnolia acuminate* were predominant among trees. Shrubs such as, among others, *Corylus avellana*, *Crataegus monogyna*, *Euonymus europaea*, *Sambucus nigra*, and *Rubus* spp., which formed thickets of medium density, were found to be present in the bank zone of the stream. This site, which is intensively used for recreational purposes by the city's residents and students of the University of Rzeszów, is bordered by multi-family residential and services areas. Lawn mowing operations were carried out there (Figure 2d).

Material examined

Adult beetles were caught using Barber pitfall traps, placed in the middle part of the sites studied. Four traps were placed at each of the investigated sites. They were buried in the ground and filled with ethylene glycol solution to 1/3 of their volume. Poultry slaughterhouse waste was used as bait, with an average weight of 100 g. The traps were replaced at two-week intervals from May to October. One sample constituted the total content of 4 traps placed in each stand. In 2009, 2011 and 2012, 11 samples were collected in each stand per year. In 2010, there were charged 12 samples on each stand. Every year, the research was carried out at two stands. Thus, 90 samples were generated for all study period (total number of traps was 360).

Each time after removing the entomological material, the preservative fluid (ethylene glycol solution) was changed and fresh bait was put on. Entomological material was determined for the species under laboratory conditions.

Nomenclature and statistical analysis

Identification of beetles was made using a study by Mroczkowski (1955), whereas the systematics and nomenclature of carrion beetles followed a paper by Löbl & Löbl (2015). The collected entomological material was identified in terms of species composition and number of individuals. The list of Silphidae species was prepared using the data on world distribution and ecology reported by Aleksandrowicz & Komosiński (2005) and Dekeirsschieter et al. (2011b) as well as temporal activity data by Šustek (1981).

The zoocenological analysis utilized the following indices of species:

- dominance (D = n/N, where n- number of individuals of a given species, N- total number of individuals). Dominance structure was described according to the scale: ED- eudominants (above 10,0%), D- dominants (5,1-10,0%), SD- subdominants (2,1-5,0%), R- recedents (1,1-2,0%) and SR- subrecedents (below 1,0%) (Górny & Grüm 1981).

- constancy (C = q/Q, where q- number of samples containing a species, Q- total number of samples). Five constancy classes were distinguished after the following criteria for contancy index: euconstant species (species found in 75,01-100% of samples), constant species (species found in 50.01-75.00% of samples), subconstant species (species found in 30,01-50,00% of samples), accessory species (species found in 15.00-30.00% of samples) and accidental species (species found in 15.00% and less of samples) (Górny & Grüm 1981).

- density (g =s/L, where s- number of individuals of a given species, L- number of catches carried out of a given study site) (Szujecki 1983).

The following biodiversity indices were determined: Margalef's diversity index ($D_{Mg}=d_2$) (Trojan 1998), Shannon's species diversity index (H'_{ln}), Pielou's evenness index (J') (Magurran 2004) and Simpson's dominance index (λ) (Simpson 1949).

The significance of differences in the number of species recorded was evaluated using a Chi-squared test ($\chi 2$).

Then, using the same test, the significance of differences in the number of individuals was evaluated. The analysis of faunistic similarity was carried out using the Ward cluster analysis based on Euclidean distances. Statistical calculations were performed using Statistica v.12 and Microsoft Excel 2016 software.

RESULTS OF INVESTIGATIONS OF CARRION BEETLES

Over the four-year study period, a total of 4282 carrion beetles were collected and they were classified in 5 genera and identified to 13 species. The numerical data and indices of diversity from the individual study sites are presented in Table 1. At the sites located in the wooded areas subjected to low anthropogenic pressure, a total of 2907 individuals was captured and they were classified in 5 genera. The urban wooded areas were characterized by lower species diversity; in these areas, the number of identified beetle species was 11, but the number of individuals was much lower (1375 exx.). Statistically significant differences were found between the number of individuals caught ($p<0.05$). On the other hand, no difference was found in the number of species ($p=0,9862$). The Shannon species diversity index (H'_{ln}) and the Pielou evenness index (J') reached higher values in the mid-field tree stands in the low urbanization areas and lower ones in the urban wooded areas. A reverse trend was observed for the Margalef species richness index (D_{Mg}) and the Simpson dominance index (λ).

The total number (N), dominance (D), and ecological structure of Silphidae caught in Subcarpathian Voivodeship is analyzed in Table 2.

The list of species captured, their numbers, and dominance relationships are presented in Table 3 and 4. Differences were observed in the quantitative structure, and thereby in the distribution of dominance. Depending on the location of the study sites, the percentages of the individual species varied (Fig. 3). In overall terms, the following species were classified as eudominants and occurred at all sites: *N. vespilloides*, *N. vespillo*, and *O. thoracicum*. *N. humator* was also an eudominant, but in this class it was only found in the stands located in the areas with low urbanization pressure (agriculturally used areas). In the urban stands, it was generally included in the groups of subdominants or recedents. It was only in the urban park in 2011 that this species

Table 1. Diversity of Silphidae caught in the study areas

	Study site No. 1		Study site No. 2		Study site No. 3		Study site No. 4	
	2009	2010	2009	2010	2011	2012	2011	2012
Number of individuals	837	763	679	628	322	314	336	403
	Total = 2907				Total = 1375			
Number of species	13	12	13	12	10	9	10	11
Margalef index	4.106	3.816	4.237	3.931	3.589	3.204	3,562	3,838
Simpson index	0.156	0.164	0.164	0.167	0.226	0.249	0,225	0,269
Shannon index	2.026	1.973	2.026	1.970	1.691	1.556	1,688	1,575
Pielou index	0.790	0.794	0.790	0.793	0.734	0.708	0,733	0,657

Total	Number of individuals	Number of species	Margalef index	Simpson index	Shannon index	Pielou index
	4282	13	3,304	0,164	1,995	0,777

Table 2. Total number, dominance D, and ecological structure of Silphidae

Species	N	D [%]		I	II	III	IV	V
Oiceoptoma thoracicum	709	16,6	ED	F, C, D, M	N, P	D	IV-VII / 1-2	TransPal
Phosphuga atrata atrata	348	8,1	D	F	P	?	III-X /?	TransPal
Silpha carinata	93	2,2	SD	F, C, M	N, P	?	IV-X / 2	ESib
Silpha obscura obscura	87	2,0	R	Fd, O	N, P	?	IV-XI / 1	ESib
Silpha tristis	15	0,4	SR	Fd	N, P	?	III-XI / 1	ESib
Thanatophilus rugosus	28	0,7	SR	Fd, C, O	N, P	D	IV-X / 3	TransPal
Thanatophilus sinuatus	337	7,9	D	Fd, C, O	N, P	D	IV-X / 3	TransPal
Nicrophorus humator	612	14,3	ED	F, C, M	N	Nc	IV-X / 2	WestPal
Nicrophorus interruptus	99	2,3	SD	Fd	N	Cr	V-X / 1	TransPal
Nicrophorus investigator	27	0,6	SR	F, O, C	N	Cr	VI-VII / 1	TransPal
Nicrophorus sepultor	11	0,3	SR	F, O, C	N	?	VI-X / 1	ESib
Nicrophorus vespillo	821	19,2	ED	Fd, O, C	N	Cr, Nr	III-X / 2	Hol
Nicrophorus vespilloides	1095	25,6	ED	F, C	N	D	V-X / 2	TransPal

N- number of specimens; D- dominance: ED- eudominants (above 10,0%), D- dominants (5,1-10,0%), SD- subdominants (2,1-5,0%), R- recedents (1,1-2,0%) and SR- subrecedents (below 1,0%)

I- habitats: F- forest, Fd- fields, C- cadaver, D- dung, M- mushrooms, O- open areas; II- trophic: N- necrophagous, P- predaceous; III- daily activity: Cr- crepuscular, D- diurnal, Nc- nocturnal; IV- temporal activity: Roman numerals mean the month and Arabic numerals mean the number of generation per year; V- zoogeographical structure: TransPal- Trans Palearctic, WestPal- West Palearctic, Esib- Euro-Siberian, Hol- Holarctic; ?- not available data

was observed in greater numbers, when it reached the dominant class.

T. sinuatus was another species that occurred in the tree stands in the agriculturally used areas. In the mid-field tree stands (I and II) in 2009, it was included in the class of dominants, whereas the following year a nearly double increase in the number of specimens was recorded at the same sites, which allowed this species to be classified among eudominants. In turn, in the urban tree stands this species was found in few num-

Table 3. Species composition, numbers (N), and dominance (D) of Silphidae caught in the low urbanization area

Species	Study site No. 1				Study site No. 2			
	2009		2010		2009		2010	
	N	D [%]	N	D [%]	N	D [%]	N	D [%]
Oiceoptoma thoracicum	147	17.6	98	12.8	109	16.1	129	20.5
Phosphuga atrata atrata	43	5.1	24	3.1	25	3.7	30	4.8
Silpha carinata	8	1.0	21	2.8	10	1.5	17	2.7
Silpha obscura obscura	32	3.8	18	2.4	23	3.4	11	1.8
Silpha tristis	1	0.1	-	-	8	1.2	6	1.0
Thanatophilus rugosus	2	0.2	4	0.5	10	1.5	4	0.6
Thanatophilus sinuatus	75	9.0	130	17.0	44	6.5	70	11.1
Nicrophorus humator	147	17.6	138	18.1	161	23.7	109	17.4
Nicrophorus interruptus	32	3.8	18	2.4	21	3.1	14	2.2
Nicrophorus investigator	11	1.3	6	0.8	4	0.6	1	0.2
Nicrophorus sepultor	5	0.6	2	0.3	4	0.6	-	-
Nicrophorus vespillo	155	18.5	119	15.6	133	19.6	82	13.1
Nicrophorus vespilloides	179	21.4	185	24.2	127	18.7	155	24.7

Table 4. Species composition, numbers (N), and dominance (D) of Silphidae caught in the high urbanization areas

Species	Study site No. 3				Study site No. 4			
	2011		2012		2011		2012	
	N	D [%]	N	D [%]	N	D [%]	N	D [%]
Oiceoptoma thoracicum	44	13.7	30	9.6	81	24.1	71	17.6
Phosphuga atrata atrata	68	21.1	106	33.8	35	10.4	17	4.2
Silpha carinata	9	2.8	13	4.1	5	1.5	10	2.5
Silpha obscura obscura	-	-	-	-	-	-	3	0.7
Thanatophilus rugosus	1	0.3	1	0.3	4	1.2	2	0.5
Thanatophilus sinuatus	9	2.8	3	1.0	2	0.6	4	1.0
Nicrophorus humator	16	5.0	5	1.6	19	5.7	17	4.2
Nicrophorus interruptus	2	0.6	1	0.3	5	1.5	6	1.5
Nicrophorus investigator	1	0.3	-	-	3	0.9	1	0.2
Nicrophorus vespillo	57	17.7	88	28.0	73	21.7	114	28.3
Nicrophorus vespilloides	115	35.7	67	21.3	109	32.4	158	39.2

bers, reaching only the class of recedents and subrecedents.

In the stands located in the high urbanization areas, *P. atrata atrata* was a species that occurred in greatest numbers, than in the stands located in the low urbanization areas. In the city, 226 individuals of this species were captured, whereas at the wooded sites in the low urbanization areas (used agriculturally), the number of beetles

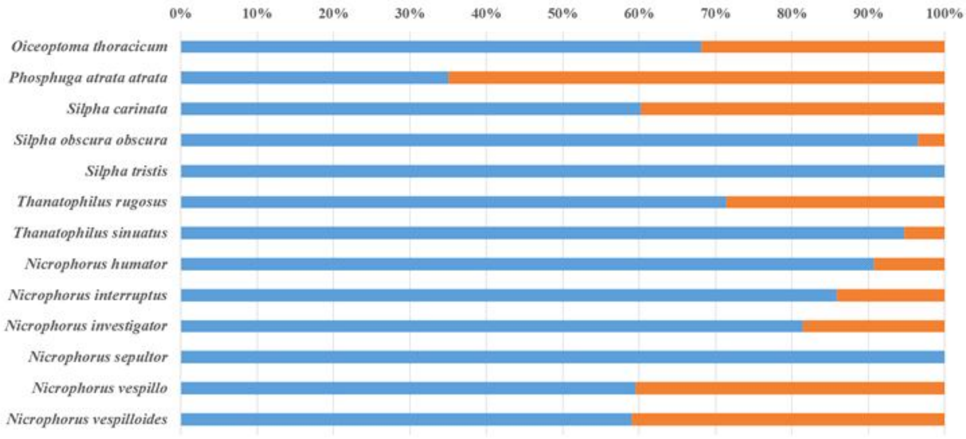

Fig. 3. Percentages of the individual Silphidae species caught in the areas with a lower (blue color) and higher (orange color) degree of urbanization.

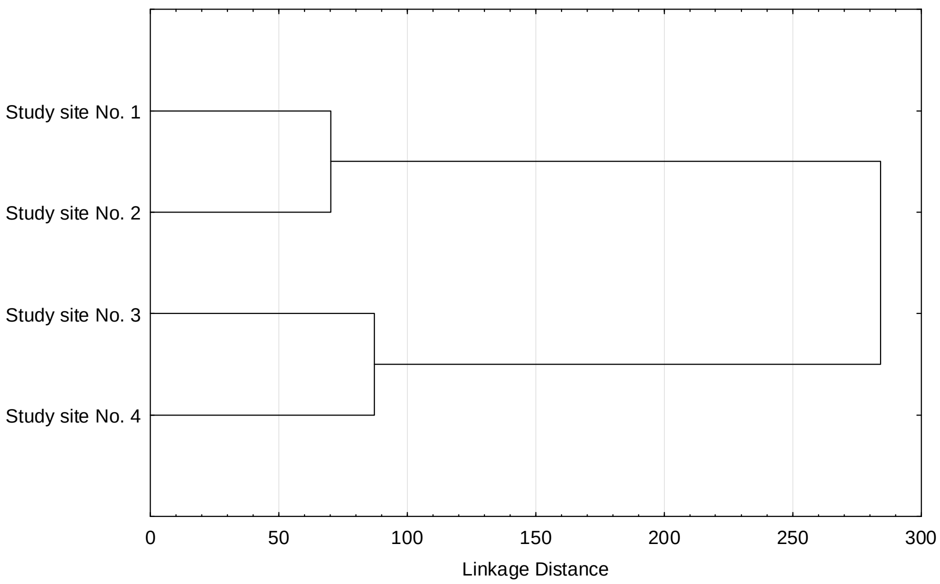

Fig. 4. Euclidean distance-based cluster analysis using Ward's method that estimates the similarities of Silphidae communities at the investigated study sites. Description of the study sites in the text.

Table 5. Differences in the index of constancy C[%] of Silphidae caught in the areas with a lower (site 1 and 2) and higher (site 3 and 4) degree of urbanization.

Species	Study site No. 1		Study site No. 2		Study site No. 3		Study site No. 4	
	2009	2010	2009	2010	2011	2012	2011	2012
Oiceoptoma thoracicum	100,0	100,0	100,0	100,0	90,9	81,8	90,9	81,8
Phosphuga atrata atrata	72,7	58,3	63,6	66,7	100,0	90,9	100,0	54,6
Silpha carinata	45,5	83,3	81,8	66,7	45,5	45,5	45,5	63,6
Silpha obscura obscura	72,7	66,7	81,8	41,7	-	-	-	27,3
Silpha tristis	9,1	-	63,6	41,7	-	-	-	-
Thanatophilus rugosus	18,2	33,3	63,6	33,3	9,1	9,1	27,3	9,1
Thanatophilus sinuatus	100,0	91,7	90,9	91,7	36,4	18,2	18,2	27,3
Nicrophorus humator	100,0	100,0	100,0	83,3	54,6	36,4	90,9	81,8
Nicrophorus interruptus	45,5	33,3	45,5	33,3	18,2	9,1	36,4	45,5
Nicrophorus investigator	45,5	25,0	27,3	8,3	9,1	-	27,3	9,1
Nicrophorus sepultor	27,3	16,7	27,3	-	-	-	-	-
Nicrophorus vespillo	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Nicrophorus vespilloides	100,0	100,0	100,0	100,0	100,0	90,9	90,9	100,0

Table 6. Differences in the index of density (g) of Silphidae caught in the areas with a lower (site 1 and 2) and higher (site 3 and 4) degree of urbanization.

Species	Study site No. 1		Study site No. 2		Study site No. 3		Study site No. 4	
	2009	2010	2009	2010	2011	2012	2011	2012
Oiceoptoma thoracicum	13,4	8,2	9,9	10,8	4,0	2,7	7,4	6,5
Phosphuga atrata atrata	3,9	2,0	2,3	2,5	6,2	9,6	3,2	1,5
Silpha carinata	0,7	1,8	0,9	1,4	0,8	1,2	0,5	0,9
Silpha obscura obscura	2,9	1,5	2,1	0,9	-	-	-	0,3
Silpha tristis	0,1	-	0,7	0,5	-	-	-	-
Thanatophilus rugosus	0,2	0,3	0,9	0,3	0,1	0,1	0,4	0,2
Thanatophilus sinuatus	6,8	10,8	4,0	5,8	0,8	0,3	0,2	0,4
Nicrophorus humator	13,4	11,5	14,6	9,1	1,5	0,5	1,7	1,5
Nicrophorus interruptus	2,9	1,5	1,9	1,2	0,2	0,1	0,5	0,5
Nicrophorus investigator	1,0	0,5	0,4	0,1	0,1	-	0,3	0,1
Nicrophorus sepultor	0,5	0,2	0,4	-	-	-	-	-
Nicrophorus vespillo	14,1	9,9	12,1	6,8	5,2	8,0	6,6	10,4
Nicrophorus vespilloides	16,3	15,4	11,6	12,9	10,5	6,1	9,9	14,4

caught was more than half lower (122 exx.). At the site with a cluster of trees and shrubs as well as in the urban park, this species formed a class of eudominants. A decline in the number of specimens was noted only in the urban park in 2012, and hence this species was classified among subdominants. *S. tristis* and *N. sepultor* were species that were not recorded in the inventory surveys conducted in the city.

In the low urbanization areas, 5 species classified as euconstants were recorded (C>75.00%), that is, absolutely constant species. In the city, in turn, 4 species classified in the same class were found, but only 3 of them were common taxa: *O. thoracicum*, *N. vespillo*, and *N. vespilloides*. The following were included among the species that differentiated the constancy classes: *T. sinuatus* and *N. humator* (in the agriculturally used areas) and *P. atrata atrata* (in the city). The obtained results are in agreement with the distribution of dominance of the above-mentioned species at the individual sites, which is associated with their high numbers. Constants (C=50.01-75.00%) and subconstants (C=30.01-50.00%) occurred in greater numbers in the low urbanization areas. They were represented by 3 species. Accessory species were represented by 2 taxa. Accidental species were not observed. At the sites in the high urbanization areas, on the other hand, a higher percentage of accessory species (C=15.01-30.00%) and accidental species (C<15.00%) was observed (Table 5).

N. vespilloides was characterized by the highest average density (mean 14.1 individuals per catch).

Table 7. Shares of zoogeographical elements in the Silphidae community of the wooded areas: S – number of species, N – number of specimens, % – percentage share in the community.

Zoogeographical element	S	%	N	%
Trans Palearctic	7	53.8	2634	61.7
Euro-Siberian	4	30.8	206	4.8
West Palearctic	1	7.7	612	14.3
Holarctic	1	7.7	821	19.2
Total	13	100	4282	100

Table 8. Comparison of results with other studies regarding Silphidae abundance and diversity indices in various types of wooded area taking into account common species found in the present study

References	Location/ Type of wooded area	No. of species	No. of specimens	Common species with presented study	Shannon Index*	Simpson Index*
Traps with bait / non-urban area						
Růžička 1994	Czech Republic-mixed forest	9	7415	8	1,332	0,340
Kočárek & Benko 1997	Czech Republic-deciduous forest	9	550	9	1,561	0,265
Kočárek & Benko 1997	Czech Republic-spruce forest	6	1566	6	1,201	0,412
Haelewaters et al. 2015	Belgium-mixed forest	9	54	8	1,647	0,258
Traps with bait / urban area						
Błażejewicz-Żelazna & Zawadzińska 2008	Poland-beech wood	10	382	9	1,659	0,236
Błażejewicz-Żelazna & Zawadzińska 2008	Poland-mixed forest	7	324	7	0,768	0,672
Traps without bait / non-urban area						
Kočárek & Rohá?ová 2001	Czech Republic-spruce forest[a]	6	227	5	1,149	0,370
	Site 1[b]	3	20	3	1,040	0,375
	Site 2[b]	4	46	4	1,076	0,391
	Site 3[b]	5	73	5	0,949	0,496
	Site 4[b]	5	88	4	1,147	0,369
Byk & Kudła 2011	Poland-mixed forest[a]	10	4750	9	1,403	0,290
	Site 1[b]	7	222	6	0,821	1,284
	Site 2[b]	9	1026	8	1,206	0,349
	Site 3[b]	7	2170	7	1,108	0,388
	Site 4[b]	8	1332	7	1,137	0,369

*- these indicators were calculated by the authors themselves on the basis of quantitative data presented in the article; a- total value of the index; b- value of the index at the study site

Supplementary Materials:

Table S1. *Floristic composition of wooded areas with a lower degree of urbanization;*
Table S2. *Floristic composition of wooded areas with a higher degree of urbanization*

Table S1. Floristic composition of wooded areas with a lower degree of urbanization

Cover-age	Borek Stary	
	Study site No. 1	**Study site No. 2**
A	40%. *Salix caprea* 3, *Betula pendula* 1, *Prunus avium* 1, *Prunus domestica* subsp. *syriaca* 1	70%. *Populus nigra* 4, *Alnus glutinosa* 1, *Fraxinus excelsior* 1, *Salix alba* 1
B	70%. *Salix cinerea* 4, *Populus tremula* 2, *Rubus plicatus* 1, *Sambucus nigra* 1, *Acer campestre* +, *Crataegus monogyna* +, *Fraxinus excelsior* +, *Ribes nigrum* +, *Rosa canina* +, *Tilia cordata* +, *Viburnum opulus* +	40%. *Rubus caesius* 2, *Salix cinerea* 2, *Alnus glutinosa* 1, *Frangula alnus* 1, *Salix aurita* 1, *Rubus idaeus* +
C	80%. *Calamagrostis epigejos* 4, *Deschampsia caespitosa* 2, *Poa trivialis* 2, *Urtica dioica* 2, *Angelica sylvestris* 1, *Heracleum sphondylium* 1, *Ranunculus repens* 1, *Solidago gigantea* 1, *Agrostis capillaris* +, *Athyrium filix-femina* +, *Campanula persicifolia* +, *Crataegus monogyna* +, *Dactylis glomerata* +, *Epilobium parviflorum* +, *Equisetum arvense* +, *Galeopsis tetrahit* +, *Geum urbanum* +, *Lathyrus pratensis* +, *Lysimachia nummularia* +, *Lysimachia vulgaris* +, *Phalaris arundinacea* +, *Poa nemoralis* +, *Prunus avium* +, *Quercus robur* +, *Rhamnus catharticus* +, *Stellaria graminea* +, *Viburnum opulus* +, *Rosa canina* r	100%. *Dactylis glomerata* 4, *Galium mollugo* 4, *Festuca rubra* 2, *Poa trivialis* 2, *Taraxacum officinale* 2, *Arrhenatherum elatius* 1, *Festuca pratensis* 1, *Poa pratensis* 1, *Achillea millefolium* +, *Aegopodium podagraria* +, *Agrostis stolonifera* +, *Anthoxanthum odoratum* +, *Anthriscus sylvestris* +, *Bromus wildenowii* +, *Calamagrostis epigejos* +, *Capsella bursa-pastoris* +, *Cirsium arvense* +, *Convolvulus arvensis* +, *Crepis biennis* +, *Elymus repens* +, *Erigeron annuus* +, *Galinsoga parviflora* +, *Geranium dissectum* +, *Geum urbanum* +, *Glechoma hederacea* +, *Hypochaeris radicata* +, *Lamium purpureum* +, *Lolium perenne* +, *Melandrium album* +, *Oxalis stricta* +, *Plantago lanceolata* +, *Polygonum aviculare* +, *Ranunculus repens* +, *Rosa canina* +, *Setaria glauca* +, *Solidago gigantea* +, *Urtica dioica* +, *Vicia cracca* +

A-tree layer, **B**- shrub layer, **C**- herb layer

This species was found in greatest numbers at the sites in the low urbanization areas. The highest density value was recorded at Site 1 (16.3 in 2009 and 15.4 in 2010). A high average density (>10.0 individuals per catch) was also found in the case of *O. thoracicum*, *N. humator*, and *N. vespillo*; similarly to *N. vespilloides*, they were characterized by a high frequency of occurrence in the low urbanization areas (Table 6).

The results of the analysis of faunistic similarity of carrion beetle assemblages at the study sites show two main agglomerations. The first one comprises beetles assemblages occurring at the

Table S2. Floristic composition of wooded areas with a higher degree of urbanization

Coverage	Rzeszów	
	Study site No. 3	**Study site No. 4**
A	60%. *Salix alba* 3, *Salix fragilis* 2, *Acer campestre* 1, *Betula pendula* 1, *Junglans nigra* +;	40%. *Aesculus hippocastanum* 3, *Acer pseudoplatanus* 2, *Betula pendula* 2, *Betula nigra* +, *Fraxinus excelsior* +, *Magnolia* sp. +;
B	25%. *Salix viminalis* 2, *Salix alba* 1, *Crataegus monogyna* +, *Fraxinus excelsior* +;	10%. *Corylus avellana* 1, *Carpinus betulus* +, *Crataegus monogyna* +, *Euonymus europaeus* +, *Ligustrum vulgare* +, *Padus avium* +, *Rubus* sp. +, *Sambucus nigra* +, *Sorbus aucuparia* +;
C	90%. *Holcus lanatus* 3, *Artemisia vulgaris* 2, *Phalaris arundinacea* 2, *Cirsium arvense* 1, *Elymus repens* 1, *Festuca rubra* 1, *Poa trivialis* 1, *Potentilla anserina* 1, *Ranunculus repens* 1, *Solidago gigantea* 1, *Tanacetum vulgare* 1, *Arctium lappa* +, *Bromus hordeaceus* +, *Calystegia sepium* +, *Capsella bursa-pastoris* +, *Chamomilla discoidea* +, *Crepis biennis* +, *Daucus carota* +, *Equisetum arvense* +, *Erigeron annuus* +, *Festuca pratensis* +, *Geranium dissectum* +, *Geranium pratense* +, *Hiercium umbellatum* +, *Lathyrus pratensis* +, *Lolium perenne* +, *Lotus corniculatus* +, *Medicago lupulina* +, *Medicago sativa* +, *Silene latifolia* +, *Oenothera biennis* +, *Plantago lanceolata* +, *P. major* +, *Potentilla reptans* +, *Rorippa sylvestris* +, *Rumex crispus* +, *Taraxacum officinale* +, *Trifolium dubium* +, *Trifolium pratense* +, *Trifolium repens* +, *Matricaria maritima subsp. inodora* +, *Tussilago farfara* +, *Vicia grandiflora* +, *Vicia hirsuta* +, *Calamagrostis epigejos* r, *Chelidonium majus* r, *Sinapis arvensis* r.	80%. *Reynoutria japonica* 3, *Festuca rubra* 2, *Aegopodium podagraria* 1, *Cerastium holosteoides* 1, *Ficaria verna* 1, *Fragaria vesca* 1, *Glechoma hederacea* 1, *Lolium perenne* 1, *Lysimachia nummularia* 1, *Poa pratensis* 1, *Taraxacum officinale* 1, *Urtica dioica* 1, *Achillea millefolium* +, *Agrostis stolonifera* +, *Anemone nemorosa* +, *Bellis perennis* +, *Capsella bursa-pastoris* +, *Carex pairae* +, *Carex sylvatica* +, *Chaerophyllum hirsutum* +, *Chenopodium polyspermum* +, *Cirsium vulgare* +, *Crepis biennis* +, *Dactylis glomerata* +, *Daucus carota* +, *Deschampsia caespitosa* +, *Elymus repens* +, *Erigeron annuus* +, *Gagea lutea* +, *Geranium phaeum* +, *Geum urbanum* +, *Impatiens parviflora* +, *Silene latifolia* +, *Plantago major* +, *Poa annua* +, *P. trivialis* +, *Polygonum aviculare* +, *Potentilla reptans* +, *Rumex crispus* +, *Scilla bifolia* +, *Sonchus arvensis* +, *Stellaria media* +, *Trifolium pratense* +, *Trifolium repens* +, *Veronica chamaedrys* +, *Vicia grandiflora* +, *Vicia sepium* +, *Viola odorata* +, *Arctium lappa* r, *Chelidonium majus* r, *Geranium dissectum* r, *Junglans regia* r, *Medicago lupulina* r, *Rorippa sylvestris* r.

A- tree layer, **B**- shrub layer, **C**- herb layer

wooded sites located in the agriculturally used areas, that is, with a lower degree of urbanization, whereas the other one includes beetle assemblages found at the wooded sites in the suburban area (with a higher degree of urbanization). However, the differences between the two agglomerations may be related to the proportion of species preferring open areas and crop fields that surrounded the study sites (Fig. 4).

As far as trophic requirements are concerned, necrophagous species definitely prevailed. The representatives of the subfamily Silphinae also show different trophic type, notably predation. Only one species, *P. atrata atrata*, was classified as predaceous.

Analysis across zoogeographical elements showed the predominance of Trans Palearctic species (7 species or 53.8%). It was also a dominant category in terms of the number of specimens (2634 specimens or 61.7%). Fewer species were classified as Euro-Siberian (4 species or 30.8%). West Palearctic and Holarctic constituted 15.4% of the total number of captured species (1 species) (Table 7).

DISCUSSION

Carrion beetles caught in various wooded areas of south-eastern Poland accounted for 59% of domestic Silphidae fauna (L•bl & L•bl 2015).
One of the more important factors that affect the qualitative and quantitative structure of the beetles in question is the presence of food resources. This is a factor that impacts not only the numbers of beetles caught, but due to the high migration capacity of Silphidae, food availability can also affect the occurrence of these beetles in the qualitative aspect [Kočárek & Roháčová 2001; Ikeda et al. 2008).

Thus far, mid-field tree and shrub stands have not been studied to investigate Silphidae inhabiting such sites. Due to the fact that such habitats can be treated as substitutes for forest biotopes, the results of the entomological survey of the tree stands were referred to, among others, observations conducted in such areas.

On the other hand, in a study on assemblages of carrion beetles found in mountainous and submountainous areas of south-eastern Poland, 9 species were demonstrated, whereas 7 species were found directly in a beech forest (Pietraszko & Warchałowski 2017). The identified species were also found at the selected sites of south-eastern Poland.

At forest sites, Růžička (1994) recorded 9 Silphidae species and 8 of them were found in the present study. A species that was not found in the study concerning the Subcarpathian region was *Necrodes littoralis*. This can be associated with the local distribution of this species. This finding can be confirmed by the observations of Růžička (1994) who demonstrated only 2 individuals and those of Matuszewski et al. (2013) who recorded even more than 100 individuals at particular sites. In turn, *Silpha tristis* was a species that was not shown by Růžička (1994) in his study, but it was observed in the tree stands in the Subcarpathian region. This species was found in the two stands located in the low urbanization areas. It is a species that prefers fields and open areas, from whence it probably migrated in search of food. It was not found in the city's tree stands.

A study conducted by Kočárek & Benko (1997) showed 9 Silphidae species to occur in deciduous forests and 6 taxa recorded in coniferous forests. The only species that was not found in the present study was *Aclypea opaca*, a phytophagous beetle considered to be a pest of beets (Burakowski et al. 1978).

Kočárek & Roháčová (2001) also recorded 6 species in fir forests, out of which 5 were common with the present study. In oak and beech groves, Schlechter (2008) recorded 8 species of carrion beetles. Seven species of Silphidae were identified during the sampling period in a forest biotope in Belgium (Dekeirsschieter et al. 2011a). In all these cases, only one species, *N. littoralis*, was not found in the Subcarpathian region.

In a great majority of cases, green spaces associated with urban agglomerations are of anthropogenic origin, less frequently of natural origin, and the way in which they are used and their location have a significant effect on the diversity of both flora and fauna. An example can be parks (including forests parks) which, apart from recreational, tourist, aesthetic, and educational functions, also perform important ecological functions (Dunnet et al. 2002; Kwak et al. 2003; Morancho 2003).

Compared to the stands in the low urbanization areas, fewer carrion beetle species and individuals were captured in Rzeszów. One of the main factors influencing the qualitative and quantitative structure of Silphidae was the use of baited traps by the particular authors.

Błażejewicz-Zawadzińska & Żelazna (2008, 2011) showed 10 Silphidae species to be present in an urban park. *O. thoracicum*, *N. vespilloides*, and *N. vespillo* were the species that occurred in greatest numbers, and in Rzeszów these species were also included in the group of eudominants and dominants. These authors also found the presence of *N. sepultor* (in the present study, this species was recorded only in the tree stands in the agriculturally used areas) and *N. vestigator* (not found in this study). Moreover, S. *carinata*, *S. obscura obscura*, and *P. atrata atrata* were found to be present in Rzeszów, but the above-cited authors did not record these species. The other species were common. Kočárek (2001) showed 8 Silphidae species and all of them were common with the species recorded in Rzeszów.

Research on the occurrence of Silphidae at wooded sites in urban areas, thus in areas with a higher degree of urbanization, has also been carried out in the Western Hemisphere. Nonetheless, due to the different ranges of the individual species, the below cited publications are only included for presentation purposes. Wolf & Gibbs (2004) found 7 species in 30 wooded locations. The same number was found by Brousseau et al. (2010) in balsam fir forests. Beetles caught by Lopes et al. (2015) in an urban park were classified in the second ranking order of insects captured, in terms of numbers, whereas Silphidae accounted for 33% of this assemblage.

Generally, higher values of the species diversity indices obtained in the present study were observed in wooded areas subjected to lower urbanization pressure. The highest value of H'_{ln}=2.026 was recorded in 2009 at sites 1 and 2. Slightly lower H'_{ln} values were found at the same sites in the following year (respectively, site 1- H'_{ln}=1.973, and site 2- H'_{ln}=1.970). The obtained results differ from the H'_{ln} values shown in Table 8. In the studies of other authors conducted in areas subjected to lower urbanization pressure (forests), the values of this index were much lower (Růžička 1994; Kočárek & Benko 1997). Haelewaters et al. (2015) showed the highest value of this index, but this result can be the effect of averaging a higher number of species and a low number of individuals. On the other hand, higher H'_{ln} values were observed in the case of samples collected using baited traps, which translates, among others, into a higher catch rate for individuals (not only the dominant species) as well as in areas subjected to lower urbanization pressure.

Assemblages with a quite good internal structure (species distribution) are characterized by higher values of the index H'_{ln}. This indicator includes both the number of species and their percentage, and hence its values were found to be higher at the sites where both the number of species and the number of individuals were highest (sites 1 and 2 in areas subjected to lower urbanization pressure).

In areas with higher urbanization pressure, this index reached even lower values, whereas its lowest value was found at site 3 in 2012. The obtained values of H'_{ln} at the study sites in areas subjected to higher urbanization pressure (the H'_{ln} values ranging 1.556-1.691) are comparable to the results obtained by Błażejewicz-Zawadzińska & Żelazna (2008) (H'_{ln} =1.659), which is associated with a similar qualitative and quantitative structure of Silphidae caught.

An additional aspect of diversity, Pielou's evenness (J'), describes the percentage of particular species in a community. The overall value of this index in the carrion beetle assemblage was J'=0.777, which may be attributable to the percentage of the less numerous species. This index is calculated, among others, based on the H'_{ln} index value and therefore the distribution of its values at the individual sites was similar to the index H'_{ln}. The highest values of J' were observed at the sites subjected to lower urbanization pressure, while the lowest one was shown at site 4 (urban park) (J'=0.657).

A similar trend was noted for the Margalef index (D_{Mg}), which is another index that describes relative species richness. It was 3.304 for the entire assemblage, whereas the highest values was found at site 2 in 2009 (D_{Mg}=4.237).

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An additional index used to analyze the Silphidae assemblage was the degree of species dominance (λ). This parameter assigns a lower weight to the occurrence of rare species, paying greater attention to common species. It takes on higher values in communities dominated by one or several species. The highest value of this index was found at site 4 in 2012 (λ=0.269) where three eudominants were shown to be present: *N. vespilloides* (39.2% of the assemblage), *N. vespillo* (28.3%), and *O. thoracicum* (17.6%). These species accounted for 85.1% of the entire assemblage (403 individuals). The other species (60 individuals) constituted 14.9%. Similar results were obtained by Błażejewicz-Zawadzińska & Żelazna (2008) (λ=0.236) as well as by Kočárek & Benko (1997) (λ=0.265), which was related to the dominant proportion of one or several species. The lower the value of this index, the more even distribution of individuals among species. At the sites subjected to lower urbanization pressure, the dominance structure was more balanced (lower λ values) than in higher urbanization pressure areas.

The adopted research methodology is also an important factor affecting the value of the diversity indices in question. The most similar method was adopted in the studies by Błażejewicz-Zawadzińska & Żelazna (2008) as well as by Kočárek & Benko (1997) where traps contained bait and were replaced every two weeks on average. In spite of using bait, Haelewaters et al. (2015) found a very low number of individuals. The reason could have been the use of traps without preserving substances (which enabled beetles to escape) and collection of a lower number of samples (4 samplings within a period of 4 months). As shown by a study by Niemelä et al. (1990), only observations conducted throughout the entire season allow the fauna of a given area to be identified. Byk & Kudła (2011) found a very high number of individuals. However, this study was carried out in the Białowieża Primeval Forest, in 13 habitat types represented by 12 sites. In this one-year study, the authors set up 810 traps in total. A high number of all individuals translates into a high value of the index H'_{ln}, which reached a higher number both in overall terms and in comparison with other studies. Nevertheless, when we compare H'_{ln} from the individual Forest Districts, these values are distinctly lower, with a higher dominance index (λ). Interestingly, *O. thoracicum*, which is generally one of the most frequently occurring species in wooded areas (eudominants and dominants), was classified overall as the subdominant class in the study by Byk & Kudła (2011). The percentage of species preferring open spaces and fields was small. In turn, *D. quadrimaculata*, a predatory species which is a carnivore feeding on larvae of Geometridae and Lymantriidae butterflies, was a species that was not found in the present study.

Both the results obtained in this study and those presented in Table 8 induce us to conclude that factors such as the presence of food resources (baited traps), habitat diversity, and the adopted sampling methodology have a great impact on the qualitative and quantitative structure of Silphidae captured. Small wooded areas (mid-field tree stands, clusters of trees, urban parks) are characterized by a higher proportion of open area species that migrate from adjacent biotic communities seeking food and shelter.

CONCLUSIONS

1. Areas subjected to lower urbanization pressure promote increased biodiversity of the entomofauna of necrophagous Silphidae.

2. In low urbanization areas (in this study, these were agriculturally used sites), the assemblage of species characteristic of wooded and forested areas is enhanced by species characteristic of open areas and fields.

3. Sites with a higher degree of urbanization predispose the occurrence of ubiquitous species with a broad ecological amplitude.

4. Diverse wooded stands perform the function of substitutes for forest biotopes, which is translated into the percentage of species preferring wooded areas and forests.

5. The structure of carrion beetle fauna is essentially determined by the following factors: availability of food resources (in the case of entomological catches, these are baited traps, among others) as well as the type of and degree of land use in a given area and the research methodology adopted.

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