Original Article

REPRODUCTION AND ACCOMPANYING FAUNA OF RED MASON BEE *OSMIA RUFA* L. (SYN. *OSMIA BICORNIS* L.) IN AREAS WITH DIFFERENT LEVELS OF URBANIZATION

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Abstract

An increasing number of studies show that urbanized areas are habitats of high biological value and ecological significance. Most bee species live in areas altered by man, either in cities - fragmented urban habitats - or in large rural monocultures. Our research is based on three-year observations of population development of the solitary bee *Osmia rufa* L. in three habitat types: city, suburbs and villages. We compared reproductive parameters and diversity of accompanying nest fauna. Population growth rate was high in all habitats, exceeding five times the number of cocoons placed in the previous year. We found no significant differences in the number of cocoons and brood mortality between areas with different urbanization levels. In nests located in suburbs, parasites and cleptoparasites occupied almost three times more nest chambers than in other habitats. Changes in the habitat structure had a significant impact on the diversity and abundance of accompanying fauna. Our study shows that red mason bees are flexible and easily adapt to new conditions, despite changes caused by urbanization and agriculture.

Keywords: accompanying and parasitic fauna, agriculture areas, red mason bee, urban areas

INTRODUCTION

Urban expansion causes the destruction and fragmentation of natural habitats (Kearns et al., 1998; Biesmeijer et al., 2006; Ewers & Didham, 2006), which has a negative impact on their biodiversity (McKinney, 2002). More than 80% of urban areas are large impermeable surfaces such as buildings, roads and sidewalks, which limit the access of plants and animals to soil and water and prevent their migration (Blair & Launer, 1997).

Urbanization also increases the loss of native species (Czech et al., 2000) and the spread of alien species, as the site of Adelaide, a city

in southern Australia, where 132 of the total number of native species have died out locally and 648 alien species (mostly plants) have arrived. The process of replacing native species with foreign species leads to the homogenization of ecosystems, which has been observed in the case of birds and butterflies (Blair, 2001). The number of non-native species is increasing while the native species are decreasing in urban centers, which is related to the "urban-rural gradient" (Blair & Launer, 1997). Changes in the urban landscape reduce the number of bird species (Savard et al., 2000) and mammals (Tait et al., 2005), especially in isolated areas. Fragmentation causes changes in the structure of

species dominance, which indicates a tendency to form mono-dominants, e.g. bumblebees and butterflies (Eremeeva & Sushchev, 2005).

Many studies have confirmed that pollinator diversity and abundance were significantly negatively associated with higher urbanization levels (McIntyre & Hostetler, 2001; Zanette et al., 2005; Bates et al., 2012). Cardoso & Gonçalves (2018) showed that the richness of bee species decreased by 45% over thirty-four years. Fitch et al. (2019) documented a change in the gender ratio of ground-nesting bees along an urbanization gradient (reduction in the number of females in the city compared to urban and rural areas). Urban areas are characterized by a large spatial diversity of habitats (Savard et al., 2000; Thompson et al., 2003), which may have a positive effect on the development of space-requiring organisms, including some plant and invertebrate species (McKinney, 2008).

Green areas, and in particular the housing-estate garden, retain a surprising richness and abundance of bee species (Normandin et al., 2017). Many studies confirm that cities are inhabited by many species (Banaszak-Cibicka & Żmihorski, 2012; Baldock et al., 2015; Cariveau & Winfree, 2015; Sirohi et al., 2015; Threlfall et al., 2015; Hall et al., 2017). The occurrence of bees depends on various factors, most importantly the availability of food but also the presence of suitable breeding places. Research has shown that plant-species diversity is greater in cities than in surrounding rural areas (McKinney, 2002; Wania et al., 2006). Many different species of ornamental and exotic plants can be found in parks and gardens (Thompson et al., 2003; Frankie et al., 2005) which provide bees with sufficient nourishment. The attractiveness of the local flora causes feeding-ground activity and the number of pollen and nectar collectors to be higher suburban gardens, than in forests and plantations (Kaluza et al., 2016). The red mason bee (*Osmia rufa* L.), one of the most common early spring species in Poland with broad food preferences (Ruszkowski & Biliński, 1986; Teper, 2007), readily occupies artificial nests and forms aggregations (Giejdasz & Wilkaniec, 2003) to pollinate many agricultural and horticultural

crops (Biliński & Teper, 2004, 2009; Fliszkiewicz et al., 2011). *Osmia rufa* was recently introduced as an environmental complement (Everaars et al., 2011; MacIvor & Packer, 2016) and is used as a bioindicator (Szentgyörgyi et al., 2017). An important factor influencing the health and number of red masons is the accompanying fauna, including nest parasites. Many such species as *Cacoxenus indagator* (Loew, 1858) (Drosophilidae), *Monodontomerus obscurus* (Westwood, 1833) (Torymidae) and *Chaetodactylus osmiae* (Dufour, 1839) (Chaetodactylidae) parasitize on red mason broods or pollen provision and reduce the bee population by 50% or, in extreme cases even by 95% (Krunić et al., 2001, 2005). *Osmia rufa* nests can have many random residents, nest destroyers, cleptobionts or predators (Krunić et al., 2005), including rare and useful insect species (Zajdel et al., 2015). The abundance and biodiversity of *Osmia rufa* accompanying fauna depends on the abundance of bees (Krunić et al., 2005), the selection of cocoons, nest usage (Madras-Majewska et al., 2011) and the nesting time of bees at the site (Zajdel et al., 2014). Recently, Łoś et al. (2020) studied masonry bees reproductive success along an urbanization gradient, as well as their pathogens and nest parasites. This work was a benchmark for the results of our study.

Our research presents a data set on the studied population of *Osmia rufa* in areas with different urbanization levels: a city, suburbs and villages. The paper concentrates on the study of solitary bee reproduction parameters but also analyzes the biodiversity of fauna accompanying the nest. We verified two global hypotheses; the first concerned the identification of potential differences between habitats while the second differences between urbanization levels. We checked in which habitats and areas (1) more cocoons and higher population growth had been obtained, (2) more larvae and pupae had died, (3) more losses had been caused by nesting parasites and (4) higher biodiversity of accompanying fauna had been.

MATERIALS AND METHODS

Study areas

The research was conducted in the years 2014-2016 in ten habitats; four were located in the territory of the city of Warsaw (C1-C4) (Fig. 1b), three in the suburbs (20-30 km from the city center, towns of Kanie (S1), Komorów (S2) and Piaseczno (S3)) and three in rural areas (60-100 km from the city center, villages of Chrzęszczew (V1), Kąty-Wielgi (V2) and Tabory-Rzym (V3)) (Fig. 1a).

The level of habitat urbanization was determined on the basis of demographic data and aerial photographs, which were used to determine the building structure and the percentage of habitats area covered with vegetation. The habitat area was determined based on the bees' flying range from the nest, i.e. 600 m (Radmacher & Strohm, 2010). Circles with a radius of 600 m were delineated based on satellite images of the habitats (<https://maps.google.com/>). IMAGE COLOR SUMMARIZER software was used to estimate the percentage of areas covered with vegetation and, based on these results, two land categories were distinguished: A - plant-covered areas, B - impermeable surfaces (buildings, pavements, bare soil). Maps of the rural areas were supplemented or modified depending on the crops currently being

cultivated on the agricultural land (strawberry fields, young orchard, crops grown under cover, etc.). We distinguished three levels of urbanization were based on population density (<https://bdl.stat.gov.pl/BDL/start>) and plant-covered areas:

1. H - high level of urbanization (City - C) - Warsaw, the main city of the monocentric Warsaw metropolitan area, the largest population cluster in Poland, population density over 2001-3998 people per km², large areas transformed by man (wide streets, paved areas, pavements, squares, car parks, etc.), plant-covered area accounts for 25-40% (Fig. 2, Fig. 3);
2. M - medium level of urbanization (Suburbs - S) - towns belonging to the Warsaw metropolitan area (located 20-25 km from the center of the capital city), population density of 363-610 people per km², plant-covered area accounts for 80-90% (Fig. 2, Fig. 3);
3. L - low level of urbanization (Village - V) - villages with population density of 23-55 people per km², most area is arable land, plant-covered area accounts for 90-100% (Fig. 2, Fig. 3).

Fig. 1. Dispersion of sites in the village (a), suburbs and center of Warsaw area (b).

Fig. 2. Sample satellite images of habitats with different levels of urbanization - A - city, B - suburbs, C - village.

Fig. 3. Percentage of habitat coverage in three levels of urbanization.

Location, nest construction and material

In the year before the research, nest traps (100 tubes) were placed in the designated habitats to check if *Osmia rufa* was present in the environment. The occupation rate was 0-5%, so we concluded that the local red mason bee populations would not interfere with the reproductive performance of the bees introduced by us. Boxes with nesting material and cocoons were

installed at the time of natural emergence of red mason bees in mid-April. We ensured the same nesting conditions for all the bees. The boxes with nesting material were hanged on dry, south-western or southern walls of buildings, at a height of 1-1.5 m, in places with moderate exposure to sun. The nests in the city and in the suburbs were located in small home gardens. The female-to-male ratio in the experimental

population was reviewed every year and averaged 1:1.5. We assumed that one female would use two tubes for the nest (Biliński & Teper, 2004). Six hundred cocoons and nesting material in the form of 500 reed tubes (five packages of 100 tubes each, with a length of 20 cm and diameter of 6-8 mm) were placed in each habitat every year (for three years).

Bees' reproductive parameters

The bees' reproductive parameters reflect the health of the population. In our study, we determined the following parameters for each habitat:

1. Emergence rate

$$Er = \frac{Be}{Nc}$$

Er - emergence rate

Be - number of bees that emerged from cocoons (bees emerged)

Nc - number of cocoons placed at the site (total cocoons)

2. Mean number of cocoons per nest tube

$$Cff = \frac{Nc}{Nt}$$

C_{ff} - mean number of cocoons per nest tube

N_c - total number of cocoons harvested

N_t - number of nest tubes

3. Population growth rate

$$Pgr = \frac{Nco}{Ncp}$$

Pgr - population growth rate

Nco - number of cocoons harvested after the season (offspring generation)

Ncp - number of cocoons placed at the site in spring (parental generation)

4. Mortality of larvae and pupae per nest tube

$$M = \frac{Nd}{Nt}$$

M - mean number of dead larvae and pupae per tube nest

N_d - total number of dead larvae and pupae in one tube

N_t - number of nest tubes

Nest analysis

We took the nests to the lab at the end of September and made a selection of them. We cut each tube with a scalpel and recorded the number of breeding cells, in which there were cocoons (from imago), dead larvae and pupae, and accompanying fauna. Some species were incubated until the imago stage for correct identification. We found the imago and larval stages of *M. obscurus* and *M. acasta* in tubes and therefore controlled two or three cocoons adjacent to the cocoons infected with these parasites.

In the following year of the research, the cocoons harvested from a given habitat were placed in the same habitat to avoid the transmission of nest parasites to other research populations. All the nesting material was analyzed every year and new reed packages were placed in the habitats in the following spring (Madras-Majewska et al., 2011). Polish insect identification keys were used to identify the species of accompanying and parasitic insects.

Statistical analysis

A potential effect of site and urbanization level on reproductive parameters of *O. rufa* was investigated with a one-way ANOVA. The significance of differences between means was evaluated using Duncan's test, at a significance level of $p=0.05$. The distribution of the number of parasites differed significantly from normal distribution, as confirmed by the Shapiro-Wilk test ($P<0.05$), which is why the Kruskal-Wallis H test (with multiple comparisons average rank for all samples - Dunn's test with Bonferroni adjustment, $P<0.05$) was used for the statistical analysis. The calculations were carried out using PS IMAGO PRO and STATISTICA v 13.0 software. Shannon's index of general species diversity H' (Shannon, 1948) was determined for the accompanying and parasitic nest fauna identified to the species level. For other calculations, we used the number of nest cells occupied by *Cacoxenus indagator*, *Chaetodactylus osmia*, *Monodontomerus obscurus*, *Melittobia acasta*

(Walker, 1839), for which the actual number of individuals could not be determined.

The H' values had a normal distribution (Kolmogorov-Smirnov test), so Pearson correlations were applied for all habitats to determine the relationships between the biodiversity (H') of accompanying fauna and the percentage of areas covered with vegetation. The species richness of the accompanying fauna was also evaluated in EcoSim software using rarefaction curves (Gotelli & Colwell, 2001).

RESULTS

Bees' reproduction

Emergence rate was high in all the habitats,

irrespective of the area's urbanization level, and ranged from 96.33% to 98.83% (Tab. 1). Different numbers of cocoons were significantly obtained in different habitats ($F_{(9, 20)}=2.4375$, $P=0.04657$). Although the number of cocoons in the city and in the village was slightly higher than in the suburbs, these differences were not statistically significant. ($F_{(2, 27)}=2.5253$, $P=0.098$). The population growth rate for the city and villages were similar (respectively 5.65 and 5.86) and only slightly higher than in the suburbs (5.18). The percentage of occupied nest holes was high in all sites and exceeded 93.67 - 99.85 % of all holes (Tab. 1).

On average, between 0.6 and 1.60 bee larvae/pupa died in one nest hole. Brood mortality

Table 1.

Mean of cocoons in habitats and areas with different urbanization levels

Urbanization level	Habitat	Emergence rate (Eg)	Mean per tube		Population growth rate (Pg)	% of occupied tubes
			min-max	Total for site	Total for area	
				Mean $\pm$ SD	Mean $\pm$ SD	
H	C1	96.33	5.4 - 8.3	6.9* $\pm$ 3.2 ^{ab}		
	C2	97.00	8.2 - 9.2	8.6 $\pm$ 3.4 ^{ac}	7.3 $\pm$ 3.6 ^{A**}	5.65
	C3	97.33	5.7 - 8.6	7.7 $\pm$ 4.2 ^{abc}		
	C4	97.90	5.4 - 7.6	6.0 $\pm$ 3.5 ^a		
M	S1	97.83	5.3 - 5.7	5.2 $\pm$ 3.1 ^c		
	S2	98.25	6.6 - 7.4	7.0 $\pm$ 3.8 ^{abc}	6.2 $\pm$ 3.5 ^A	5.18
	S3	98.83	6.0 - 7.1	6.7 $\pm$ 3.5 ^{abc}		
L	V1	98.08	6.0 - 9.0	7.0 $\pm$ 3.1 ^{abc}		
	V2	98.75	6.6 - 8.6	7.7 $\pm$ 3.7 ^{ab}	7.4 $\pm$ 3.3 ^A	5.86
	V3	98.67	6.3 - 9.0	7.5 $\pm$ 3.1 ^{ab}		

Different letters indicate significant differences between of groups (one way ANOVA, $P<0.05$):

a*(small letters) comparison of means in habitats,

A** (CAPITALS) comparison of means in areas.

Table 2.

Mortality (dead larvae and pupae) in habitats with different urbanization levels

Urbanization level	Habitat	Mean per tube		
		min-max	Total for site mean $\pm$ SD	Total for area $\pm$ SD
H	C1	1.07 - 1.87	1.59 $\pm$ 1.6 ^{c*}	1.31 $\pm$ 1.60 ^{A**}
	C2	0.84 - 1.42	1.31 $\pm$ 1.2 ^{abc}	
	C3	1.42 - 1.84	1.55 $\pm$ 1.6 ^{bc}	
	C4	0.46 - 1.39	0.89 $\pm$ 1.6 ^{abc}	
M	S1	0.29 - 0.78	0.60 $\pm$ 1.2 ^a	1.04 $\pm$ 1.60 ^A
	S2	1.80 - 2.04	1.60 $\pm$ 1.8 ^c	
	S3	0.68 - 1.24	1.00 $\pm$ 1.5 ^{abc}	
L	V1	0.71 - 1.06	1.11 $\pm$ 1.3 ^{abc}	0.85 $\pm$ 1.20 ^A
	V2	0.60 - 0.95	0.70 $\pm$ 1.1 ^a	
	V3	0.60 - 1.09	0.75 $\pm$ 1.0 ^{ab}	

Different letters indicate significant differences between of groups (one way ANOVA, $P < 0.05$):

a*(small letters) comparison of means in habitats,

A** (CAPITALS) comparison of means in areas.

Fig. 4. Individual based rarefaction curves for A/C fauna for three levels of urbanization (H, M and L).

Table 3.
Damage caused by the 3 most significant parasitic species (*C. indagator*, *M. obscurus*, *Ch. osmiae*)
in habitats with different urbanization levels

Urbanization level	Habitat	Cells occupied by parasites per tube			Total for area	
		min-max	Total for site		Me	Mean $\pm$ SD
			Me	Mean $\pm$ SD		
H	C1	0.14 - 1.19	0.18 ^{a*}	0.17 $\pm$ 0.02	0.25 ^{A**}	0.56 $\pm$ 0.61
	C2	1.26 - 1.94	1.39 ^{ab}	1.53 $\pm$ 0.36		
	C3	0.08 - 0.56	0.28 ^{ab}	0.31 $\pm$ 0.24		
	C4	0.16 - 0.37	0.23 ^{ab}	0.25 $\pm$ 0.1		
M	S1	2.51 - 3.03	2.93 ^b	2.8 $\pm$ 2.7	1.10 ^B	1.58 $\pm$ 1.09
	S2	0.47 - 1.10	0.69 ^{ab}	0.75 $\pm$ 0.31		
	S3	0.25 - 2.21	1.03 ^{ab}	1.16 $\pm$ 0.99		
L	V1	0.32 - 0.45	0.38 ^{ab}	0.38 $\pm$ 0.06	0.45 ^{AB}	0.64 $\pm$ 0.44
	V2	0.27 - 1.44	0.92 ^{ab}	0.87 $\pm$ 0.59		
	V3	0.28 - 1.19	0.51 ^{ab}	0.66 $\pm$ 0.48		

*Different letters indicate significant differences between groups (Kruskal-Wallis test, $P < 0.05$):

a*(small letters) comparison of mean of ranks in habitats

A** (CAPITALS) comparison of medians in areas.

Fig. 5. Changes in Shannon's index of A/C-fauna depending on the percentage of plant-covered area in the habitat.

Table 4.

Species, families and orders of A/C-fauna of red mason bees (fauna classification according to Krunić et al., 2005)

	Species	City			Suburbs			Village		
		2014	2015	2016	2014	2015	2016	2014	2015	2016
Cleptoparasites	<i>Cacoxenus indagator</i> Loew, 1858	+	+	+	+	+	+	+	+	+
	<i>Chaetodactylus osmiae</i> (Dufour, 1839)	+	+	+	+	+	+	+	+	+
	Chrysopidae sp.								+	+
Parasitoids	<i>Monodontomerus obscurus</i> Westwood, 1833	+	+	+	+	+	+	+	+	+
	<i>Melittobia acasta</i> * (Walker, 1839)			+						
	<i>Trichodes apiarius</i> (Linnaeus, 1758)					+		+	+	+
Predators	<i>Raphidioptera</i> sp.						+			
	Birds (<i>Picidae</i> sp.)		+	+						
	<i>Tribolium castaneum</i> (Herbst, 1797)							+	+	+
Nest destroyers	<i>Ptinus fur</i> (Linnaeus, 1758)						+			
	<i>Reduvius personatus</i> (Linnaeus, 1758)									+
	<i>Rhyparochromus vulgaris</i> (Schilling, 1829)			+			+			
	<i>Dermestes lardarius</i> Linnaeus, 1758	+	+			+		+		
	<i>Megatoma undata</i> (Linnaeus, 1758)		+			+	+	+	+	+
	<i>Plodia interpunctella</i> (Hübner, 1813)	+				+			+	+
	<i>Auplopus carbonarius</i> (Scopoli, 1763)	+	+	+	+	+	+	+	+	+
Cleptobionts	<i>Camponotus fallax</i> (Nylander, 1846)	+						+		
Accidental nest residents	<i>Pyrhocoris apterus</i> (Linnaeus, 1758)		+	+		+		+		
	<i>Oulema melanopus</i> (Linnaeus, 1758)						+			
	<i>Megachile rotundata</i> (Linnaeus, 1758)									+
	<i>Coelioxys echinata</i> * (Foerster, 1853)									+
	<i>Ancistrocerus parietum</i> (Linnaeus, 1758)									+
	<i>Forficula auricularia</i> (Linnaeus, 1758)	+	+				+		+	
	<i>Vespula vulgaris</i> (Linnaeus, 1758)			+					+	
	<i>Psocoptera</i> sp.	+		+	+		+	+		+
	<i>Lepidoptera</i> sp.					+		+		
No. of species per year		9	9	10	5	10	10	12	11	14
Total no. of species in the area			15			16			20	

*Cleptoparasite *Megachile rotundata*, accompanying *O. rufa*

varied among different habitats ($F_{(9, 20)}=2.4845$, $P=0.4323$) (Tab. 2). More larvae/pupa died in nests located in the city than in the suburbs (respectively 1.31 and 1.00), while the lowest number of larvae died in the villages (0.85), but these differences were not statistically significant ($F_{(2, 27)}=2.6731$, $P=0.08726$).

The level of parasitization of nest cells by the three most significant parasite species (*C. indagator*, *M. obscurus*, *Ch. osmiae*) varied in different habitats ($H_{(9, 30)}=20.86237$, $P=0.0133$) (Tab. 3). Significantly fewer cells were occupied by parasites in the city than in the suburbs $H_{(2, 30)}=7.554839$, $P=0.0229$. We found no significant differences between larval mortality in the city and the villages, and between the suburbs and the villages (Tab. 3).

Biodiversity of accompanying fauna

Tab. 4 shows that the number of associated fauna species increased year by year. The lowest number of species was recorded in nests located in the city (9-10). The greatest species diversity was found in the rural areas (12-14).

The results in Fig. 5 show that Shannon's index increases with the plant coverage ratio. In rural areas, where plant coverage exceeded 90%, the biodiversity index was two to four times higher than in habitats with plant coverage of 25 - 40%. It was also found that more species of A/C-fauna lived in mason bee nests located in areas with a low urbanization level than in other areas (Fig. 4). We found a highly significant correlation between H' and % green area in habitats ($P=0.002$) (Fig. 5). The value of the correlation coefficient is 0.85660. The chart also shows the 95% confidence interval of the regression line (the area marked by dashed lines).

DISCUSSION

Variation in species richness, especially in the Apoidea superfamily, occurs in all biotopes of the urbanization gradient from rural areas to urban agglomerations (Ahrné et al., 2009; Fetridge et al., 2008; Matteson et al., 2008; Banaszak-Cibicka & Żmihorski, 2012; Fortel et al., 2014; Hudewenz & Klein, 2015; Verboven et al., 2014;

Baldock et al., 2015; Cariveau & Winfree, 2015; Sirohi et al., 2015; Threlfall et al., 2015; Hall et al., 2017). Urbanization may negatively affect individuals and bee diversity (Bates et al., 2011). Asymmetry of body can be caused by environmental pollution, parasites and food shortages (De Anna et al., 2013). Banaszak-Cibicka et al. (2018) concluded that the body size of bees did not differ among urban, suburban and rural habitats, and urban bees were less asymmetric compared to bees found in rural areas. This proves that, the urban landscape provides bees with quality habitats.

We investigated only one species of bees, *Osmia rufa*, but their afterborn nest material was meticulously examined for three years. A different number of cocoons were obtained from the urban, suburbs and rural within the habitats. Łoś et al. (2020) found that urban sites have the highest indices of reproductive success and the lowest number of breeding failures compared to suburban and rural sites. Our research has shown that *Osmia rufa* population develop just as well in every area regardless of the level of urbanization. Good reproductive results of red mason bee are evidenced by the high emergence rate, i.e. the percentage of bees that emerged cocoons in spring. In all areas types, the index was always above 90%. Other studies show that the habitat type has a significant influence on reproductive performance (Fliszkiewicz et al., 2014). In our research, nests were located in landscapes strongly transformed by man, both in the city (streets, high buildings) and in the countryside (large agricultural areas), and yet population growth in all habitats was almost five times higher than the number of initially placed cocoons. These results seem to be very high, compared to the results by Fliszkiewicz et al. (2014) who had achieved a much lower reproduction grow rate than ours although in such more favorable landscapes as a meadow or an orchard, 3.91 and 3.17 respectively.

We showed that the mortality of red mason larvae and pupae was habitat dependent. Although the highest mean mortality was in the city, the mean in the suburbs and the lowest in the countryside, we found no significant differ-

ences between areas with different urbanization levels. However, Łoś et al. (2020) found that the sites in the city had a lower number of “mummies” (dead larvae) than suburban and rural habitats.

Although our research showed that the level of urbanization did significantly affect the number of cocoons and brood mortality, we obtained the results at the statistical trend level. In our research, we had a small number of repetitions. We can assume that if we had performed the study on a larger number of habitats, we would have obtained statistical differences among areas with different levels of urbanization.

Red mason bee nests are inhabited by various species of insects and arachnids. Some of them belong to the ever-present accompanying fauna - *C. indagator*, *M. obscurus* and *Ch. osmia* (Krunic et al., 1995; Krunic et al., 2005; Fliszkiewicz et al., 2012; Zajdel et al., 2014; Zajdel et al., 2015) and most often contribute to the death of the brood. Although the parasite damage in the suburbs was almost three times higher than in the city and the countryside, we found no significant differences between the suburbs and villages. The presence of parasites is negatively correlated with reproductive success and may be a limiting factor for the *O. rufa* population (Łoś et al., 2020). In the future, it would be useful to investigate why parasites occupy so many breeding chambers in peri-urban areas, with particular emphasis on habitat fragmentation and the presence of flowering plants in the habitat along an urbanization gradient. According to Goodell (2003), limited access to the food base may affect the reproductive success and intensify parasitism. Furthermore, pollen availability is very important for body size (Johnson, 1988; Bosch & Vicens, 2002; Seidelmann, 2006) and increases the efficiency of pollination work and affects reproductive performance (Seidelmann et al., 2010).

There are not many studies that show that the habitat type (Fliszkiewicz et al., 2012; 2014) and urbanization level (Łoś et al., 2020) have a significant influence on the reproductive performance of *Osmia rufa*. In our research, nests were located in a landscape strongly trans-

formed by man, both in the city with streets and high buildings and in the countryside with large agricultural areas, and yet population growth in all habitats was high, in comparison with different more natural habitats including forest, meadows and gardens (Fliszkiewicz et al., 2014). The red mason bees has a small flight range (Radmacher & Strohm, 2010) and this may be the reason for its success in fragmented habitats, as long as they find food (Goodell, 2003; Seidelmann, 2006).

Our research shows that despite the changes brought about by urbanization and agriculture, *Osmia rufa* show great flexibility and adaptability to new conditions. Additional studies in other bee species and habitats are required to discover if these findings are more widely applicable.

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