Population Structure of Ground Beetles (Coleoptera, Carabidae) as an Indicator of the Sustainability of Roadside Urbocenoses Development

Olga Khotuleva[a], Igor Zykov[b], Galina Egorova[c] and Yulia Yushchenko[d]
State University of Humanities and Technology, GGTU, Department of Biology and Ecology Orekhovo-Zuevo, Moscow region, Russia
1khotuleva@yandex.ru, 2zykov-oz@yandex.ru, 3egorovagalv@mail.ru, 4yushenkojulia@yandex.ru

Key words: Ground beetles, Urbanization, Sustainable development.

Abstract: Considering different approaches to biodiversity assessment for sustainable urban development, an ecological-faunistic study of the peculiarities of the structure, regularities of formation and changes in the carabidofauna of roadside cenoses under the conditions of an industrial city in central Russia (using the example of Orekhovo-Zuevo, Moscow region) was carried out. An assessment of the state and stability of the studied ecosystem is given. A decrease in numbers, a decrease in species diversity, and a change in the composition of life forms of ground beetles (Coleoptera, Carabidae) in roadside urban communities compared to biotopes away from motorways were observed. The number of dominants with a high dominance index is approximately the same in all sites. An increase in the dominance index together with a low value of the species diversity index indicates instability of the system. According to the biotope preference, in all the studied biotopes, in terms of species and numerical abundance species of meadow-field and field open predominate, in the spectrum of life forms in terms of species abundance zoophages predominate, in terms of numerical abundance - mixophytophages. Biotopes located in pairs on both sides of roads have similar dynamic density indices. It was found that motorways were not an insurmountable obstacle for ground beetles. Separate closed territories within building blocks boarded by motorways, can be considered as partially isolated island habitats.

1 INTRODUCTION

Currently, the global strategy for sustainable urban development for the period up to 2030 provides not only protection and restoration of terrestrial ecosystems, but also stops the process of biodiversity loss. In this regard, the assessment of the biodiversity of terrestrial biocenoses, including the use of animal indicator species, is becoming increasingly important in the modern world. One of the most convenient and widely used biological indicators are ground beetles (Coleoptera, Carabidae). They are widespread in all types of biotopes in natural and anthropogenic landscapes and have characteristics such as high species diversity, selectivity to soil and plant conditions, a variety of ecological associations, and the sensitivity of many species to anthropogenic influences.

Urbanization is a process that completely changes the natural environment. The construction of buildings, roads, communications, and abundant industrial emissions lead to the destruction of soil and vegetation, and wildlife. The emerging techno-genesis makes up a significant part of the city. Urban ecosystems are a set of landscapes that are, to varying degrees, suitable for the existence of living organisms. A characteristic feature of urban ecosystems is the almost complete restructuring of the primary relief and soil and the mosaic-like arrangement of biotopes, whose boundaries are often determined by the position of motorways.

[a] https://orcid.org/0000-0002-9532-6761
[b] https://orcid.org/0000-0002-6027
[c] https://orcid.org/0000-0003-1559-1221
[d] https://orcid.org/0009-0004-8825-6381

Roads can be a serious barrier for mesoherpetobionts, which include ground beetles and other arthropods (Yakushkina, Malkova, 2019). As a result of vehicle traffic, insects often die on transport routes without soil; roads isolate their habitats and give them an island character (Klausnitzer, 1990). At the same time, roads represent an ecological channel along which insects can spread widely (Turin H., den Boer P.J., 1988).

Most of the works on roadside cenoses were carried out in natural landscapes and agrocenoses (Butovsky, 1991, 1992; Butovsky, Minor, 1998, Butovsky, Eremina, 1999; Zherebtsov, Sukhodolskaya, Timofeeva, 2007). In these works, it was noted that the carabid population on different sides of the road had significant differences. First, they differ in the number of species. The total number of individuals in the biotopes also differs on both sides of the road, despite the commonality of the dominants. In roadside cenoses, a low number of ground beetles is observed compared to biotopes away from roads; near roads, species diversity decreases and the composition of life forms changes. In addition to the influence of vehicles, the carabid fauna is affected by several other factors: mowing of lawns, pruning of trees and shrubs, proximity of industrial plants, boiler houses and other urban structures. Therefore, the results of the study of carabid complexes collected along motorways in natural landscapes cannot be extended to urban roadside communities (Zykov, Khotuleva, Egorova, 2020).

2 RESEARCH METHODOLOGY

The material was collected in the city of Orekhovo-Zuevo, Moscow region, from June to September 2022 using Barber traps according to the standard method. The traps were placed along two transects away from the city center on both of four-lane (transect 1) and two-lane (transect 2) motorways. Transect 1 is 1.3 km long and transect 2 is 0.8 km long. The sites had approximately the same living conditions and represented elements of local area improvement with herbaceous and woody vegetation. The right sides of transects 1 and 2 were perpendicular to each other and formed the boundary of a residential area. Statistical analysis of the data was carried out using the Jaccard faunal similarity indices (Kf), quantitative similarity (Kn), biocenotic similarity coefficient (K), Berger-Parker dominance index (Berger, Parker, 1970 after Magarran, 1992). Species diversity was assessed using the Shannon (1948, after Magarran, 1992) and Simpson indices (Simpson, 1949, after Magarran, 1992), Williams polydominance indices and the probability of interspecific encounter (Magarran, 1992).

3 RESEARCH RESULTS

To study the fauna and ecological structure of ground beetle complexes in roadside landscapes, the analysis of data on the species composition and abundance of four biotopes in urban areas of Orekhovo-Zuyevo was carried out. 6456 specimens of ground beetles belonging to 14 genera and 34 species were collected. Data on the species composition of ground beetles, dominance structure and abundance are presented in Table 1.

Table 1: Species composition, dominance structure and population size of ground beetles in urban roadside communities.

No	Species	Transect 1		Transect 2	
		right side	left side	right side	left side
1	*Carabus nemoralis* Müller		0,2		
2	*Notiophilus biguttatus* F.		0,2		
3	*Notiophilus palustris* Duft.			2.0	
4	*Broscus cephalotes* L.				0,4
5	*Bembidion quadrimaculatum* L.				

6	*Poecilus lepidus* Leske	4,8	1,6	4,0	5,8
7	*Poecilus versicolor* Sturm.	1,2	0,3		1,1
8	*Pterostichus niger Schall.*			1,5	
9	*Pterostichus oblongopunctatus* F.			0,5	0,4
10	*Pterostichus melanarius* Jll.	12,5	6,1	7,1	
11	*Calathus fuscipes* Gz.	2,6	4,6	6,7	
12	*Calathus erratus* Sahlb.	8,6	7,1	5,6	7,6
13	*Calathus melanocephalus* L.	9,3	43,4	14,9	12,4
14	*Calathus halensis* Schall.	0,2			
15	*Synuchus vivalis* Jll.	1,2	1,3	2,0	0,7
16	*Amara plebeja* Gyll.	1,2	0,2	3,0	
17	*Amara eurynota* Panz.			0,2	
18	*Amara spreta* Dej.	0,4	0,2	1,5	1,8
19	*Amara bifrons* Gyll.	12,5	4,4	10,7	34,5
20	*Amara consularis* Dufit.			0,8	0,4
21	*Amara fulva* Deg.	1,8	6,7	3,5	14,9
22	*Amara majuscula* Chaud.		1,0	0,5	0,7
23	*Curtonotus aulicus* Panz.			0,5	1,1
24	*Harpalus rufipes* Deg.	39,6	21,5	30,7	14,5
25	*Harpalus tardus* Panz.	1,6	0,4	0,5	
26	*Harpalus xanthopus* Gemm.				0,3
27	*Harpalus affinis* Schr.	1,8	0,3	0,5	2,2
28	*Harpalus distinguendus* Duft.		0,3		
29	*Harpalus latus* L.	0,2	0,2	2,6	0,7
30	*Acupalpus flavicollis* Sturm.			0,5	
31	*Badister bipustulatus* F.	0,2	0,2	0,5	
32	*Badister lacertosus* Sturm.	0,2			
33	*Badister unipustulatus* Bon.	0,2			
34	*Loricera pilicornis* F.		0,2		
	Number of species	19	21	23	17
	Abundance	1136	1267	448	688

The highest absolute abundance was observed in biotopes along transect 1. The Berger-Parker index (Berger and Parker, 1970) was used as an indicator of dominance.

The number of dominant species was approximately the same in all sites and consisted of 5 species: *Calathus fuscipes, Calathus erratus, Calathus melanocephalus, Amara bifrons, Harpalus rufipes* (Table 2)

Table 2: List of dominant ground beetle species in urban landscapes.

	Dominant species	Transect 1		Transect 2	
		right side	left side	right side	left side
1	*Notiophilus palustris* Duft.			+	+
2	*Poecilus lepidus* Leske.	+		+	++
3	*Pterostichus melanarius* Jll.	++	++	++	
4	*Calathus fuscipes* Gz.	+	+	++	+
5	*Calathus erratus* Shalb.	++	++	++	++
6	*Calathus melanocephalus* L.	++	++	++	++
7	*Synuchus vivalis* Jll.			+	
8	*Amara bifrons* Gyll.	++	+	++	++
9	*Amara fulva* Deg.		++	+	++
10	*Harpalus rufipes* Deg.	++	++	++	++
11	*Harpalus affinis Schr*.				+
12	*Harpalus latus L.*			+	

Symbols: ++ - dominant species; + - subdominant species.

When processing the material collected in the traps, species with an abundance of more than 5% were classified as dominant, subdominant – from 2 to 5%, and precedent – less than 2% (Renkonen, 1944).

4 DISCUSSION OF THE RESULTS

Several statistical methods were used to evaluate the biodiversity and the degree of sustainability of the ecosystems under recreational conditions. The Berger-Parker dominance index reaches high numerical values in some cenoses, which, together with the low value of the species diversity index, indicates the instability of the system.

According to biotope preference, meadow and open field species predominate in all investigated biotopes in terms of species and numerical abundance. On the spectrum of life forms, zoophages dominate in terms of species abundance and mixophytophages in terms of numerical abundance.

The similarity of the studied biotopes, and whether ground beetle complexes within neighborhoods can be considered as isolated communities, was determined in experiments with marked individuals during the study of their population structure.

In June, the traps on the right side of transects 1 and 2 were not filled with formaldehyde. Traps were sampled twice a day (morning and evening), individuals were marked and released. Since July, marked individuals have been found on both sides of the road. Motorways do not appear to be an obstacle to the migration of ground beetles. However, not all species have this ability. The most mobile species are *Calathus erratus, Calathus melanocephalus and Harpalus rufipes*.

The diversity of communities in each area was assessed using indices characterizing α-diversity: dynamic density, species diversity indices, species uniqueness, polydominance, and the probability of interspecific encounters (Table 3).

Table 3: α-diversity indices of ground beetle populations in different biotopes.

Studied biotopes	Indices

		Dynamic density	Simpson's species diversity (D)	Shannon species diversity (H)	Polydominance (1/D)	Probability of interspecies encounters (1-D)	Uniqueness index (w)
Transect 1	left side	23,7	0,21	3,29	4,76	0,79	0,32
	right side	26,4	0,26	2,21	3,85	0,74	0,58
Transect 2	left side	10,2	0,14	2,93	7,14	0,86	0,20
	right side	14,3	0,17	1,72	5,88	0,83	0,50

The degree of difference (or similarity) between some habitats is characterized by β-diversity, which is assessed using the Jaccard indices of faunal similarity (Kf), quantitative similarity (Kn) and the coefficient of biocenotic similarity (K) (Magarran, 1992).

The analysis of the dynamic density data shows that biotopes located in pairs on both sides of the road have similar indices. They are quite low for biotopes along transect 2, and higher - along transect 1.

The analysis of species diversity using the Shannon and Simpson indices shows that the lowest species diversity, according to Table 2, is found in the biotope located on the left side of transect 2. In this biotope, both species diversity indices have low values. A low value of the Shannon index determines the isolation of the ground beetle communities of the biotope. The index has the highest values in the biotopes to the right sides of transects 1 and 2. These biotopes differ significantly in the degree of anthropogenic impact. The Simpson index has the highest values in the biotopes along transect 1, which are subject to a stronger anthropogenic impact. In these biotopes there is a small number of dominants with a high dominance index.

In addition, the Williams polydominance indices and the probability of interspecific encounters, which characterize the evenness of the population, were used. It is known that the higher the evenness of the community, with initially equal abundance and number of species, the higher the species diversity. In our studies, the polydominance index and the probability index of interspecific encounters had the highest values in the biotopes along transect 2, which were not subject to grass cutting and tree pruning.

The highest uniqueness index was recorded in the biotopes to the right side of transects 1 and 2. These biotopes are separated from each other and from the other two by roads. This distribution confirms the greater interaction of carabid complexes within the neighborhood than with complexes of species separated by motorways.

As a result of the analysis of α-diversity, the following patterns were observed: the spatial distribution of ground beetles in urban microcenoses is more objectively assessed by the Shannon index and the uniqueness index, and the degree of anthropogenic disturbance of the territory is assessed by the Simpson indices, polydominance and the probability of interspecific encounters.

5 CONCLUSION

It should be noted that neither the proximity of motorways nor the diversity of anthropogenic impact in urban localities have a great influence on carabid complexes. This may be explained by the fact that urban biotopes are inhabited by eurybiontic, plastic species easily adapting to diverse conditions. Nevertheless, a certain regularity is observed in the distribution of carabid fauna: species composition and abundance of ground beetles depend on habitat conditions in biotopes. Motorways are not an insurmountable obstacle for ground beetles, but, to some extent, serve as a barrier to mass penetration of species into neighboring habitats. Separate enclosed green areas within the neighborhoods of buildings, bounded on all sides by motorways, can be considered as some partially isolated, island habitats.

REFERENCES

Butovsky, P.O., 1990. Transport pollution and entomofauna. *Agrochemistry*, No. 4. pp. 139-150.

Butovsky, P.O., 1991. Distribution of imago ground beetles' life forms in roadside agrocenoses. *Ecology*, No. 4. pp. 28-34.

Butovsky, P.O., 1992. The impact of vehicles on the sexual structure of ground beetle populations (Coleoptera, Carabidae) in the strawberry agrocenosis. *Biological Sciences,* No. 1. P. 86-92.

Butovsky, R.O., Minor, M.V., 1998. Complex of ground beetles as an indicator of auto transport impact on the agroecosystem.Problems of entomology in the European part of Russia and adjacent territories: Abstracts of the 1st international meeting June 7–11, 1993. Samara: Samara University Publishing House. pp. 92-93.

Butovsky, R.O., Eremina, O.Yu., 1999. The highway influence on the number of ground beetles in forest biocenoses. *Ecological problems of wildlife conservation.* P. 94-95.

Klausnitzer, B., 1990. Ecology of urban fauna. 246 p.

Magarran, E., 1992. Ecological diversity and its measurement. 178 p.

Turin, H., den Boer, P. J., 1988. Changes in the distribution of carabid beetles in The Netherlands since 1880. II. Isolation of habitats and long-term time trends in the occurrence of carabid species with different powers of dispersal (Coleoptera, Carabidae). *Biol. Conserv,* 44. P.179–200.

Yakushkina, M.N., Malkova, A.S., 2019. Auto transport influence on the species composition and abundance of ground beetles in roadside biotopes. *Samara Scientific Bulletin*, vol. 8, no. 1(26). P.129-134.

Zherebtsov, A.K., Sukhodolskaya, R.A., Timofeeva, G.A., 2007. The highway influence on the population of ground beetles in a large city. *Ecological problem of urbanized territories: Materials of a scientific and practical conference.* pp. 96-98.

Zykov, I., Khotuleva, O., Egorova, G., 2020. The Estimation of the Initial Stage of Succession of Green-pine Trees Windfall in the Eastern Moscow Suburbs. *International Applied Research Conference: Biological Resources Development and Environmental Management*, P. 860–867.