Peculiarities in the Organization of the Population of Ground Beetles (Coleoptera, Carabidae) in the Gradient of Urbanization

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Abstract. Gardening of urbanized areas by creating a system of protective plantings of different types is important to solve the problem of the protection of the environment and the preservation of biological diversity. Relationships between herpetobionts and plants in protective plantations can be demonstrated from the example of representatives of the family of the ground beetle (Coleoptera: Carabidae). We analysed the traits of the taxonomic composition and ecological structure of complexes of ground beetle in different types of plantings in the urbanized territory of Volgograd taking into account the gradient of technogenic and recreational impact. Amara and Harpalus genera were the leaders in the fauna diversity of ground beetles in recreational plantings and forest belts. An increase of the level of technogenic and recreational press on urban plantings was accompanied by an increase in the number of predatory ground beetles. The common dominant species in the plantations of different categories in the urbanized territory of Volgograd were Calathus distinguendus and C. ambiguus. Meadow-field species predominated in species abundance in the ecological structure of ground beetle complexes inhabiting habitats with an elevated level of anthropogenic press, and eurybiont species predominated in numerical abundance in the same ecological structure. The spectrum of life forms of the fauna of Carabidae was represented by two classes: zoophages and myxophytophages, with the dominance of the quantitative abundance of predatory ground beetles.

1. Introduction

The problem of the protection of the environment and the preservation of biological diversity touched significantly to anthropogenically transformed landscapes which were subjected to increasing technogenic and recreational impact [4, 5, 7, 11, 12, 15, 16, 18, 24-26]. Gardening of urbanized areas by creating a system of protective plantings of different types and categories becomes particularly important in solving the problem. The named systems are recreational and landscaping (forest parks, parks, squares) plantings, landscapes of special purpose (field shelter and roadside forest belts), etc. [4, 5, 17, 20, 21]. They absorb and neutralize the harmless of technogenic pollutants, as well as they contribute to the regulation of the microclimate, reduce the degree of recreational impact, and create ecological balance, etc. [17, 18, 22, 24-26].
The creation of protective plantings for various purposes, which differ in a number of parameters such as area, design parameters, floristic composition, age, nature of soils, etc. is accompanied by a substantial transformation of the urbanized landscape [4, 5].

The complex of anthropogenic factors determines the mosaic of ecological conditions in the plantations of urban agglomerations and, as a result, the change in biological diversity, abundance and spatial distribution of insects inhabited on the soil surface, which react most sensitively to environmental pollution [6, 11, 18]. The coevolutionary relationships that arise between herpetobionts and plants in protective plantations can be clearly demonstrated from the example of representatives of the family of the ground beetle (Coleoptera: Carabidae) [13, 16, 17, 20, 22]. It is a widespread and large group of insects that occur in areas of varying degrees of impairment. The peculiarities of changes in the species composition, abundance, and ecological structure of fauna of Carabidae under the influence of anthropogenic factors are well characterized [3, 6, 9, 13]. At the same time, studies of fauna and ecological features of ground beetles in protective plantings of urbanized areas are at the every source.

In this paper, we analysed the features of the taxonomic composition and ecological structure of complexes of ground beetle in different types and categories of plantings in the urbanized territory of Volgograd taking into account the gradient of technogenic and recreational impact.

2. Methodics

Researches were realized in 2015-2017 in recreational and planting plantations and forest belts located in the outer green bastion of the city. They are characterized by a wide representation of woody plants of the generic complex Ulmacea (U. pumila L., U. laevis Pull., U. glabra Huds.). They are accompanied by Robinia pseudoacacia L., Fraxinus excelsior L., Fr. lanceolata Borkh., Populus (P. alba L., P. nigra L.), Acer negundo L., A. tataricum L., Pinus sylvestris L., P. pallasiana D. Don. Shrubs occur only in certain habitats. Ligustrum vulgare L., Lonicera tatarica L., Cotinus coggygria Scop., Prunus virginiana L., Syringa sp. are more numerous among them. Riebes aureum Pursh., Amelanchier roindifolia Dum., Crataegus sp. etc are numerous in forest belts. The grass cover is also rich in species, but the major part is Gramineae sp., Chenopodiaceae sp.

Catching of ground beetles in different types of plantations was carried out during the vegetation period (late April-September) using Barber's soil traps [23]. Plastic cups with a volume of 250 ml with a fixing liquid of ethylene glycol were used as traps. In each biotope, 10 traps were placed along a straight line with a distance of 10 meters between them. The excavation of beetles was carried out simultaneously in all habitats with an interval of 7-10 days. 15 samples were taken for each season of research in biotopes in common[1, 8, 10].

We used the scale of D. Mossakowski, 1970 (with changes) to characterize the exchange of species. A comparative assessment of the species diversity of complexes of Carabidae was carried out with the determination of the Margalef diversity spectrum, the dynamics of the number distribution was realized according to Shannon method, an estimate of the degree of its uniformity was carried out according to Piel method, and also measures of Berger-Parker dominance were evaluated. The similarity of the faunal composition of the complexes was determined by a cluster analysis based on the index of Chekanovsky and Sersensen. Its graphical representation was carried out by the method of single joining by the maximum value of similarity. The reliability of the analysis was justified by the Pearson correlation criterion and the Wilcoxon rank coefficient [2, 8, 10, 14].

An analysis of the ecological structure of the communities was carried out with the identification of biotopic groups and life forms of the imago [19, 23].

The data of the State environmental monitoring for areas near the forest park, park, and square along the 2nd Longitudinal motorway (with length more than 50 km), as well as for the territory near roadside and field protective forest belts are given.

3. Results and Discussion

The characteristics of environmental factors in the researched plantations are presented in the table 1.
Table 1. Ecological traits of ecotopes.

| Parameter                          | Recreation and greening plantings | Forest belts |
|------------------------------------|-----------------------------------|--------------|
|                                    | Forest park | Park | Square | Roadside | Field protective |
| Time of existence, years           | 60          | 70   | 6      | 11       | 16               |
| Number of species of woody plants  | 36          | 23   | 4      | 6        | 16               |
| Number of species of herbaceous plants | 9        | 8    | 6      | 11       | 17               |
| Area, ha                          | 225         | 18   | 120    | 55       | 580              |
| Recreational load                  | medium      | high | very high | high    | low              |
| Soils                             | light chestnut soil, heavy loam   | light chestnut soil, loam | light chestnut soil, heavy heavy loam, solonetzic | light chestnut soil, heavy loam |
| The flow of cars per hour          | 2420        | 2422 | 3288   | 2930     | 237              |
| Pollution index (soil)             | 8.9         | 8.9  | 10.7   | 5.0      | 4.6              |
| Gross content of As, mg / kg       | 7.43        | 4.39 | 5.56   | 7.70     | 5.33             |
| Gross content of Zn, mg / kg       | 93.49       | 54.42| 106.76 | 80.85    | 18.7             |
| Gross Pb content, mg / kg          | 12.93       | 0.93 | 14.72  | 23.50    | 7.46             |
| Suspended particles, 10 μm, mg/m³  | 0.33        | 0.22 | 0.24-0.27 | 0.33     | 0.15             |
| Carbon monoxide, mg/m³             | 4.0         | 2.0  | 2.0-4.0 | 4.0      | 2.0              |
| Nitrogen dioxide, mg/m³            | 0.07        | 0.04 | 0.05-0.07 | 0.07     | 0.04             |

Note. Pollution index and concentrations of pollutants were taken from the State Environment Report for Volgograd Region in 2017, recreational load was assessed as low if there were less than 10 people / ha, medium – 10-50 people / ha, high – 50-100 people / ha -, and very high – over 100 people / ha.

The table 1 demonstrates that the plantations exist for a long time, for decades, in a large area. Sustainable ecosystems were formed under the influence of biotic, abiotic and anthropogenic factors during that period. The forest park and the park are the richest in the species of woody and herbaceous plant, the least rich in squares along the highway and roadside forest belts. Protective forest belts occupy an intermediate position.

Ecotopes vary in recreational load. Squares were experienced the greatest load, the park and roadside forest belts had the highest load, the forest park had the middle one, and the field protective forest belts had the lowest load. The greatest motor load was in the squares, the lowest load was in the forest field protective belts. The highest pollution index was typical for a park, while the content of heavy metals (Zn and Pb) there was maximum. However, such a pollution index value is permissible (less than 16).

The best state of the atmospheric air is a characteristic of the field protective forest belts. In urban conditions, fairly high concentrations of dust (near the forest park, the park, roadside forest belts), as well as high concentrations of nitrogen dioxide and carbon dioxide (square) were found. The presence of harmful (polluting) substances in the air is caused by the development of motor transport (square, roadside forest belts) and the influence of metallurgical and chemical enterprises (forest park, park). The state of atmospheric air near the field protective forest belts corresponds to the background areas.

There were 74 species of ground beetles which belong to 26 genera (Table 2) in protective plantings of the urbanized territory of Volgograd. Two genera, which account was about 34% of the total diversity
of the family Carabidae, form the basis of the taxonomic structure of the Carabidae fauna. These are the genera *Harpalus* (14 species, 18.9%) and *Amara* (11 species, 14.9%).

A number of specific features characterized a complex of ground beetles lived in protective plantings of various types and categories. First of all, it concerns the variation of the richness of species of beetle groups. Faunal diversity reaches its maximum value in forest belts (62 species, 85.1%). At the same time, the taxonomic composition of ground beetles in field protective forest belts is 1.5 times higher than that in roadside forest belts.

**Table 2.** Composition of species and ecological characteristics of ground beetles in protective plantings of urbanized territory.

| Species                        | Biotopic characteristic | Kind of plantings | Forest belts |
|-------------------------------|-------------------------|-------------------|--------------|
|                               |                         | Recreation and greening plantings | Forest park | Park | Square | Roadside | Field protective |
| *Cicindela hybrida* Linnaeus, 1758 | S                       | Zfe               | +            |
| *C. campestris* Linnaeus, 1758  | Mf                      | Zfe               | +            |
| *C. germanica* Linnaeus, 1758   | M                       | Zfe               | +            |
| *C. solute* Dejean, 1822       | M                       | Zfe               | +            |
| *Notiophilus laticollis* Chaudoir, 1850 | F0                  | Zfss              | +            |
| *Calosoma denticolle* Gebler, 1833 | S                       | Zge               | +            |
| *C. investigator* Illiger, 1798 | E                       | Zge               | +            |
| *C. auropunctatum* Herbst, 1784 | F1                      | Zge               | +            |
| *C. inquisitor* Linnaeus, 1758  | F0                      | Zge               | +            |
| *C. sycophanta* Linnaeus, 1758  | F0                      | Zge               | +            |
| *Carabus hungaricus* Fabricius, 1792 | S                       | Zge               | +            |
| *C. estreicheri* Fischer von Waldheim, 1822 | E                       | Zge               | +            |
| *Brosus semistriatus* Dejean, 1828 | F0                  | Zr                | +            |
| *Bembidion gilvipes* Sturm, 1825 | F0                      | Zfs               | +            |
| *B. properans* Stephens, 1828  | Mf                      | Zsss              | +            |
| *B. quadrimaculatum* Linnaeus, 1761 | Mf                  | Zfss              | +            |
| *Poechius cupreus* Linnaeus, 1758 | Mf                      | Zfss              | +            |
| *P. punctatus* Schaller, 1783   | F1                      | Zfss              | +            |
| *P. versicolor* Sturm, 1824     | Mf                      | Zfs               | +            |
| *P. crenuliger* Chaudoir, 1876  | S                       | Zfs               | +            |
| *P. sericeus* Fischer von Waldheim, 1824 | S                       | Zfs               | +            |
| *P. puncticolli* Dejean, 1828   | S                       | Z. fs             | +            |
| *Pterostichus anthracitus* Illiger, 1798 | F0                  | Zsss              | +            |
| *Pt. melanarius* Illiger, 1798  | F0                      | Zsss              | +            |
| *Calathus distinguendus* Chaudoir, 1846 | E                       | Zfs               | +            |
| *C. ambiguus* Paykull, 1790     | E                       | Zfs               | +            |
| *C. cinctus* Motschulsky, 1850  | F0                      | Zfs               | +            |
| *C. halensis* Schaller, 1783    | F0                      | Zfs               | +            |
| *Amara pastica* Dejean, 1831    | F0                      | Mhg               | +            |
| *A. equestris* Duftschmid, 1812 | Mf                      | Mhg               | +            |
| *A. aenea* DeGeer, 1774         | Mf                      | Mhg               | +            |
| *A. apricaria* Paykull, 1790    | Mf                      | Mhg               | +            |
| *A. bifrons* Gyllenhal, 1810    | Mf                      | Mhg               | +            |
| *A. ingemia* Duftschmid, 1812   | Mf                      | Mhg               | +            |
| *A. consularis* Duftschmid, 1812 | Mf                      | Mhg               | +            |
| *A. matuscula* Chaudoir, 1850   | Mf                      | Mhg               | +            |
A. littorea C.G. Thomson, 1857  M  Mhg  +  +  
A. eryvnota Pazer, 1797  Mf  Mhg  +  
A. similata Gyllenhal, 1810  Mf  Mhg  +  
Zabrus tenebrioides Goeze, 1777  Fo  Mhg  +  +  +  +  
Anisodactylus signatus Panzer, 1796  Fi  Mhg  +  
Harpalus froelichi Sturm, 1818  Fo  Mhg  +  +  +  +  +  
H. smaragdinus Duftschmid, 1812  Mf  Mhg  +  +  +  +  
H. rubripes DeGeer, 1774  Fi  Msch  +  +  +  +  
H. serripes Quensel in Schonherr, 1806  Fi  Msch  +  +  +  
H. distinguendus Duftschmid, 1812  Mf  Mhg  +  +  +  
H. hirtipes Panzer, 1796  S  Mhg  +  
H. anxius Duftschmid, 1812  Fo  Mhg  +  +  +  
H. albanicus Reitter, 1900  Fo  Mhg  +  +  +  +  
H. alpinae Dejean, 1829  S  Mhg  +  +  +  
H. grizeus Panzer, 1796  Mf  Msch  +  +  +  
H. rubripes Duftschmid, 1812  Mf  Mhgr  +  
H. subcylindricus Dejean, 1829  Mf  Mhgr  +  
H. affinis Schrank, 1781  Mf  Mhgr  +  
H. calceatus Duftschmid, 1812  S  Mhg  +  
Acinopus striolatus Zoubkoff, 1833  S  Mhg  +  
A. laevinus Menetries, 1832  S  Mhg  +  +  +  +  
Acupalpus meridianus Linnaeus, 1761  Mf  Msch  +  +  +  +  
Anisodactylus signatus Panzer, 1796  Fi  Mhgr  +  +  +  +  
Ophonus azureus Fabricius, 1775  E  Zlch  +  +  +  +  +  
Chlaenius vestitus Paykull, 1790  Fi  Zfs  +  +  +  +  
Licinus cassidens Faricius, 1792  S  Zfs  +  +  +  +  +  
L. depressus Paykull, 1790  Fo  Zfs  +  +  +  +  +  
Badister bullatus Schrank, 1798  Fo  Zfs  +  +  +  +  
Lebia chlorocephala Hoffmann, 1803  M  Zlch  +  
L. cyanocephala Linnaeus, 1758  Fi  Zlch  +  
Syntomus truncatellus Linnaeus, 1761  Fo  Zsfs  +  +  +  +  +  
Cymindis angularis Gyllenhal, 1810  S  Zsfs  +  +  +  +  +  +  
C. miliaris Fabricius, 1801  Fo  Zsfs  +  +  +  +  +  
C. humeralis Geoffroy, 1785  Fo  Zsfs  +  +  +  +  +  +  
Curtonotus aculeatus, Panzer 1797  Mf  Mhgr  +  
C. picta Pallas, 1771  Mf  Mhgr  +  
Microlestes minutulus Goze, 1777  Mf  Zsfs  +  +  +  +  +  
Dixus obscurus Dejean, 1825  Fo  Mdg  

Amount of species – 74  
Total population – 7614.0  
Note. Biotopic group: Fo – forest; M – meadow; Fi – field; Mf – meadow and field; S – steppe; E – eurybiontne.  
Life forms: Z – zoophages (ge - gressorial epigeobionts walking, fe - flying epigeobionts, fs – floor stratobionts, bs – bark stratobionts, sfs - floor surface stratobionts, sfs - soil surface stratobionts, rdg - running-digging geobionts, lch – leaf chortobionts). M – myxophytophages (ss - slit stratobionts, sch - stratochortobionts, hg - harpaloid geochortobionts, dg - ditomoid geochortobionts).  

The relation between the variability of diversity on the one hand and the conditions of the habitats on the other hand was clearly traced on the base of the values of the ecological and faunistic indicators of the ground beetles population (Table 3). The minimum of the abundance of species was noted in squares (DMg = 2.11), where plantings were under the influence of constant stress, which significantly limits the accumulation of ground beetles.
Table 3. Variations of the structural characteristics of complexes of carabids.

| Kind of plantings | Parameter | Recreation and greening plantings | Forest belts |
|-------------------|-----------|-----------------------------------|--------------|
|                   |           | Forest park                       | Park         | Square | Roadside | Field protective |
| Number of species. S | 30        | 26                                | 14           | 39     | 53       |
| S total            |           | 74                                |              |        |          |                |
| Number. N          | 2191.5    | 868.5                             | 472.5        | 820.5  | 3261.0   |
| N total            |           | 7614.0                            |              |        |          |                |
| Margalef Index. DMg| 3.77      | 3.69                              | 2.11         | 5.66   | 6.43     |
| Shannon index. H   | 1.76      | 2.04                              | 1.07         | 1.0    | 2.48     |
| Index Pielu. 1     | 0.52      | 0.63                              | 0.41         | 0.27   | 0.62     |
| Berger-Parker index. d | 0.48 | 0.47 | 0.60 | 0.38 | 0.24 |
| The reciprocal of the Berger-Parker index. 1-d | 0.52 | 0.53 | 0.62 | 0.62 | 0.76 |
| Pearson correlation coefficient. rxy |               |                                   |              |        | 0.972     |

The relationship of the variability of biodiversity with ecological conditions was clearly observed on the basis of the values of ecological and faunal indicators of the ground beetle population (table 3). The minimum of abundance of species was observed in the squares (DMg = 2.11), where the plantings experienced constant anthropogenic stress, which significantly limited the maintenance of biodiversity and the preservation of natural regulatory mechanisms.

The reduction of anthropogenic press and recreational load promotes the full development of herbage; so it leads to the expansion of the living space of insects. Active accumulation of wealth of species and numerical wealth of ground beetles complexes were observed in a forest park, parks and roadside forest belts (DMg = 3.77, 3.69 and 5.66, respectively). The most favourable conditions for the vital activity of those insects were formed in forest shelter belts (DMg = 6.43).

An assessment of the level of diversity of local groups of ground beetles which took into account the equality and dynamic change in the number of rare species in the community showed that the most balanced community of ground beetles was also targeted to forest belts (H = 2.48). Communities of parks and forest parks were less harmonious in this respect (2.04 and 1.76 respectively). The measure of the diversity of the population of Carabidae of roadside forest belts and park was much poorer (1.0 and 1.07, respectively).

The distribution of the ratio of species and quantitative abundance in communities of ground beetles in different habitats was not uniform (Pielou index, l). This fact evidences to the impact of the degree of disturbance of biocenosis on complexes of Carabidae in the case of recreational plantings, which are under constant negative pressure. The level of formation of biocenosis affects the complexes of Carabidae in the case of field forest belt: it promotes the permanent formation of biocenosis, depending on the age of plants, design parameters, and crops in the adjacent fields.

Relationships of ground beetles within the framework of local complexes were distinguished by the intensity of communication. The maximum pressure of the dominant species in the communities (Berger-Parker index, d) was manifested in the group of beetles living in squares (d = 0.60). Also, the dominant load of the species was among ground beetles in parks (d = 0.47) and forest parks (d = 0.48). The role of the dominants in the community of forest plantations was minimal, i.e. the community was heterogeneous.

4. Conclusions

Results of the present research allowed getting the following conclusions. The field protective forest belts were distinguished by the richness of the Carabidae species composition in protective plantings of
the urbanized territory of Volgograd. The Amara and Harpalus genera were the leaders in the fauna diversity of ground beetles in recreational plantings and forest belts. That fact was typical for the dry-steppe zone in which the biotopes were located.

Obtained data indicated that an increase of the level of technogenic and recreational load on urban plantings was accompanied by an increase in the number of predatory ground beetles – zoophages. In our opinion, this phenomenon occurred due to the design features, the light intensity, and microclimate of the plantings, as well as due to the types of toxic effects.

Anthropogenic arrangement of the urban area caused a significant change in the structure of the population of ground beetles of certain types of plantings. First of all, this was due to a decrease in the number of dominants caused by the increase in the level of technogenic and recreational press. The common dominant species in the plantations of different categories in the urbanized territory of Volgograd were C. distinguendus and C. ambiguus.

Meadow-field species predominated in species abundance in the ecological structure of ground beetle complexes inhabiting habitats with an elevated level of anthropogenic press, and eurybiont species predominated in numerical abundance in the same ecological structure. The spectrum of life forms of the fauna of Carabidae was represented by two classes: zoophages and myxophytophages, with the dominance of the quantitative abundance of predatory ground beetles.

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