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Fauna and Species Diversity of Ground Beetles (Coleoptera, Carabidae) in Meadows

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ABSTRACT

The species diversity of ground beetles (Carabidae) was studied in the meadow ecosystems in the center of European Russia (Nizhniy Novgorod region and the Republic of Mordovia). Seventeen localities were studied. All meadow biotopes were divided into four types: dry meadows, dry meadows adjacent to forest shelter-belts, wet floodplain meadows, and floodplain meadows affected by livestock grazing. The highest species diversity was in dry meadows adjacent to forest shelter-belts (65 species) and wet floodplain meadows (62 species). The lowest number of species was in floodplain meadows affected by livestock grazing (24 species). Forty ground beetle species have been identified in dry meadows. Wet floodplain meadows had the highest Shannon's index, and the lowest Simpson index. The ground beetle fauna had high values of the Simpson and Berger-Parker indices in dry meadows. Only two species dominated in dry meadows, while four to seven species dominated in other habitats. According to the Jaccard similarity index, the most similar species composition of ground beetles was in dry meadows and dry meadows adjacent to forest shelter-belts. By reducing the number of species and specimens of ground beetles, trampling has a great effect on the fauna of floodplain meadows affected by livestock grazing.

Keywords: Abundance, Fauna, Ground beetle, Meadows, Species.

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INTRODUCTION

Meadows are a type of vegetation characterized by the dominance of perennial herbaceous plants, mainly cereals, and sedges, under conditions of sufficient or excessive moisture. The presence of stands and turf is a common feature for all meadows. By location, there are three main meadow groups. Continental meadows are located on plains outside river floodplains. They are divided into dry and lowland meadows. Floodplain meadows are located in river valleys; they are flooded during floods. Mountain meadows are located above the upper border of the forest. In different worldwide regions, meadows are rich in perennial plant species [1] including threatened [2] and invasive [3] ones. They provide areas for the inhabitation of birds [4], mammals [5, 6], reptiles [7], invertebrates [8-10], and others. The various meadow types have different abilities to recover after disturbance due to differences in carbon stock values [11, 12]. Since ancient times, meadows experienced exposure from human activities including unlimited grazing, plowing, afforestation, urbanization. It has resulted in a decline in areas covered by natural meadows [13].

Changes in open biocenoses (e.g. meadows, steppes, pastures) have been recently observed in many regions of the world [14-18]. The transformation of the vegetation cover has an ever-increasing impact on the ground beetle fauna in the biocenoses which are bioindicators of the ecosystem status [19-22]. These ground layer inhabitants of biogeocenoses are found in sufficient quantities in a wide variety of landscapes (open and closed), biocenoses including territories of various destruction degrees. In recent decades, the anthropogenic transformation of meadow ecosystems (annual grass fires, unreasonable plowing of land, significant grazing, uncontrolled haying, afforestation of fields and meadows) has shown high rates [23-26]. The process of environmental impact leads to the disruption of the natural habitat, the emergence of secondary forest communities, and, consequently, changes in the natural ranges of some ground beetle species and population structure [16, 27-32]. This study is aimed to investigate the meadow ecosystems' ground beetle fauna in the center of European Russia.

MATERIALS AND METHODS

Description of biotopes

All biotopes were divided into four types. The main criteria for their distinguishing were the moisture degree, the presence of forest or afforestation near the biotope (within 100 m), anthropogenic impact in the form of grazing farm animals.

I – Dry meadows. These habitats are grazed meadows and abandoned fields located at sites on dry sandy soils. A certain degree of aridity is expressed in such biotopes. The following plant species have been found in these habitats: *Achillea millefolium* L., *Calamagrostis epigejos* (L.) Roth, *Bromus inermis* Leyss., *Trifolium arvense* L., *Trifolium pratense* L., *Artemisia vulgaris* L., *Lathyrus pratensis* L., *Leucanthemum vulgare* (Vaill.) Lam., *Matricaria matricarioides* (Less.) Porter, *Dactylis glomerata* L., *Cirsium arvense* (L.) Scop., *Agrimonia eupatoria* L., *Cichorium intybus* L., *Pimpinella saxifraga* L., *Astragalus danicus* Retz., *Fragaria viridis* Weston, *Carex spicata* Huds.

II – Dry meadows adjacent to forest shelter-belts. These are similar to the previous type but these differ by presence of *Betula*-formed or mixed shelterbelts in 30–50 m apart of the meadows. The following plant species have been found in these habitats: *Cirsium arvense* (L.) Scop., *Consolida regalis* Gray, *Matricaria matricarioides*, *Achillea millefolium*, *Calamagrostis epigejos*, *Bromus inermis*, *Thlaspi arvense* L., *Brassica rapa* L., *Polygonum aviculare* L., *Cyanus segetum* Hill, *Leucanthemum vulgare* (Vaill.) Lam., *Viola arvensis* Murray, *Phleum pratense* L.

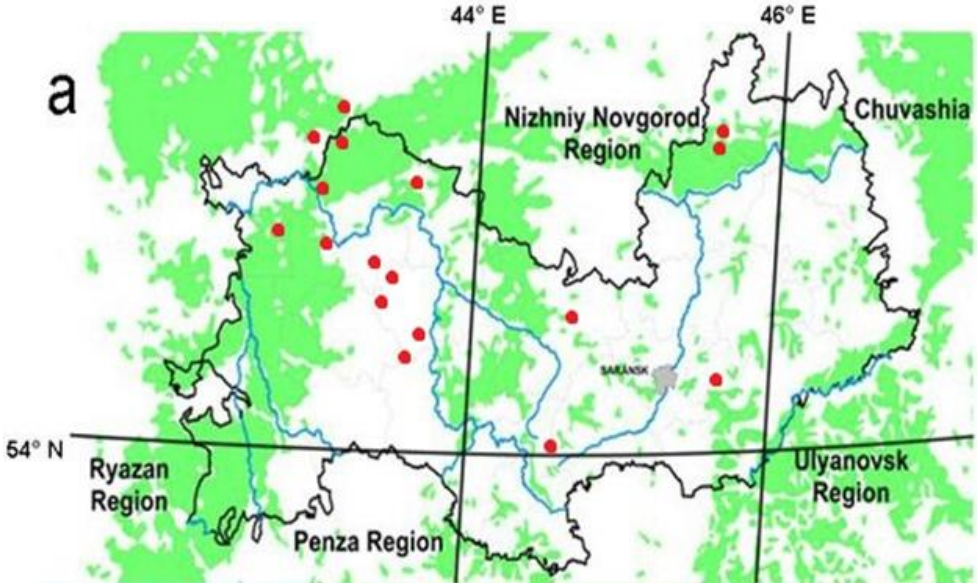
III – Wet floodplain meadows. They are located in floodplains of streams and small rivers on the relatively wet sandy and sandy-loam soils. The following plant species have been found in these habitats: *Rumex confertus* Willd., *Taraxacum officinale* (L.) Weber ex F.H.Wigg., *Carex spicata* Huds., *Carex vulpina* L., *Agrimonia eupatoria* L., *Bromus inermis*, *Tussilago farfara* L., *Dactylis glomerata* L., *Cichorium intybus* L., *Stellaria media* (L.) Vill., *Echium vulgare* L., *Scorzoneroides autumnalis* (L.) Moench, *Trifolium hybridum* L., *Alchemilla* sp., *Scirpus sylvaticus* L., *Carex acuta* L.

IV – Floodplain meadows affected by livestock grazing. These habitats are similar to the previous type. But IV type differs from type III by the higher ground compaction due to grazing impact on the soil and vegetation cover.

Scientific names were used according to The PlantList database (http://www.theplantlist.org/).

Collection methods

We collected the material using pitfall traps from April to September in 2009, 2010, 2014, 2019. They were represented by 0.5-liter cups with 4% formalin solution. There were ten traps in each locality, they were installed in one line with a distance of two to three meters between them. In total, we studied 17 localities located in the Nizhniy Novgorod region and the Republic of Mordovia **(Figure 1)**. The study was conducted in each locality with only one line, consisting of ten traps.



a)

b)

Figure 1. Study Territory. Places, where Material Is Collected, Are Indicated by Red Dots.

Data analysis

The diversity analysis of ground beetles in the ecosystems was evaluated by the following diversity indexes: Shannon-Wiener (H'), which considers equal weight to the rare and abundant species, and Simpson's index (1-D), which is sensitive to changes in the most abundant species composition [33]. The uniformity among the coleopterans caught in the five sampling sites was calculated with the Berger and Parker index. Mathematical processing was carried out in Microsoft Excel. The tables show the average values.

In total, we have collected more than 3400 specimens during 4750 trap-days of the study. The following scheme was adopted to characterize the numerical abundance of species: dominant species had numerical abundance exceeded 5%; subdominant species had numerical abundance from 2% to 5%; inconsiderable in number species had numerical abundance from 1% to 2%; rare species had numerical abundance less than 1%. The dynamic density of beetles was recognized as many beetle specimens caught per 100 traps per one day (exemplars / 100 trap-days, hereafter – ex./100 trap-days).

Species identification of ground beetles was carried out using the identification tables from the works [34, 35]. We used the Carabidae system according to the website of the Zoological Institute of RAS [36] and based on a catalog of Kryzhanovskij *et al.* [37]. The nomenclature is given according to the catalog of the Palearctic beetles [38]. The asterisk "*" marks the species that were first registered in the Republic of Mordovia. The material is stored in the collection of the Mordovia State Nature Reserve (Pushta settlement, Russia).

RESULTS AND DISCUSSION

We caught 110 species of ground beetles belonging to 35 genera **(Table 1)** in all meadows. Four species were first registered in the Republic of Mordovia. The genera Amara (19 species), Harpalus (15 species), and Pterostichus (12 species) included the largest number of species. Wide holarctic and palearctic ranges are characteristic of many species. The most number of collected ground beetles were common and mass species in the forest-steppe zone in European Russia.

Table 1. The Fauna and Dynamic Density (ex./100 Trap-days) of Species Collected in Four Types of Meadow Biotopes

Species	Dry meadows	Dry meadows adjacent to forest shelter-belts	Wet floodplain meadows	Floodplain meadows affected by livestock grazing
Cicindelinae				
Cylindera germanica (Linnaeus, 1758)		7.58		
Cicindela campestris Linnaeus, 1758	0.07			0.61
Carabinae				
Leistus ferrugineus (Linnaeus, 1758)		0.08		
Notiophilus germinyi Fauvel, 1863		0.33		
Loricera pilicornis (Fabricius, 1775)		0.08	1.05	
Clivina fossor (Linnaeus, 1758)			0.07	
Calosoma maderae (Fabricius, 1775)		0.25		
Carabus cancellatus Illiger, 1798	0.07	0.33	0.46	
Carabus clathratus Linnaeus, 1761	0.07		0.13	
Carabus glabratus Paykull, 1790			0.13	
Carabus granulatus Linnaeus, 1758			1.96	
Trechus secalis (Paykull, 1790)	0.07	0.67	1.18	
Trechus quadristriatus (Schrank, 1781)		0.17		
Bembidion biguttatum (Fabricius, 1779)			1.70	
Bembidion dentellum (Thunberg, 1787)			1.24	
Bembidion gilvipes Sturm, 1825			0.07	
Bembidion lampros (Herbst, 1784)		0.25	0.13	
Bembidion properans (Stephens, 1828)		2.08	0.78	
**Bembidion schuppelii* Dejean, 1831			0.72	
Bembidion quadrimaculatum (Linnaeus, 1760)		1.17		
Patrobus atrorufus (Ström, 1768)		0.08	0.07	
Stomis pumicatus (Panzer, 1796)		0.08	0.26	
Poecilus cupreus (Linnaeus, 1758)	0.15	5.25	2.03	0.45
Poecilus lepidus (Leske, 1785)	0.22	0.83		
Poecilus sericeus Fischer von Waldheim, 1824	0.07			
Poecilus versicolor (Sturm, 1824)	6.76	1.58	4.44	1.06
Pterostichus anthracinus (Illiger, 1798)			13.46	
**Pterostichus cursor* (Dejean, 1828)			0.13	
Pterostichus gracilis (Dejean, 1828)			4.90	0.15
Pterostichus macer (Marsham, 1802)		0.17		
Pterostichus mannerheimii (Dejean, 1831)			0.13	
Pterostichus melanarius (Illiger, 1798)	0.07	13.08	5.75	

Pterostichus minor (Gyllenhal, 1827)	0.07		0.39	
Pterostichus niger (Schaller, 1783)	0.07	0.17	1.44	
Pterostichus nigrita (Paykull, 1790)			3.20	
Pterostichus oblongopunctatus (Fabricius, 1787)	0.15	0.42		
Pterostichus strenuus (Panzer, 1796)		0.08	0.46	
Pterostichus vernalis (Panzer, 1796)			1.96	
Calathus erratus (C. Sahlberg, 1827)	1.25	13.25		3.79
Calathus fuscipes (Goeze, 1777)	2.94	3.83	3.01	0.61
Calathus melanocephalus (Linnaeus, 1758)	1.32	3.33	1.31	2.27
Dolichus halensis (Schaller, 1783)		0.08		
Limodromus krynickii (Sperk, 1835)		0.17		
Agonum duftschmidi J. Schmidt, 1994			3.07	
Agonum fuliginosum (Panzer, 1809)		1.92	0.13	
Agonum viduum (Panzer, 1796)			0.33	
Oxypselaphus obscurus (Herbst, 1784)		0.58	0.39	
Synuchus vivalis (Illiger, 1798)		0.25	0.20	
Amara aenea (De Geer, 1774)	0.81	2.92	0.33	1.36
Amara apricaria (Paykull, 1790)		0.25		
Amara aulica (Panzer, 1796)	0.22	0.08	0.72	
Amara bifrons (Gyllenhal, 1810)		2.42	0.07	
Amara communis (Panzer, 1797)	1.25		4.12	0.76
Amara consularis (Duftschmid, 1812)		0.67	0.07	
Amara equestris (Duftschmid, 1812)	8.24	2.08	0.65	3.03
Amara eurynota (Panzer, 1796)		0.08		
Amara fulva (Müller, 1776)				0.15
Amara ingenua (Duftschmid, 1812)	0.22			0.30
Amara littorea C.G. Thomson, 1857		0.08		
Amara montivaga Sturm, 1825		1.08		
Amara nitida Sturm, 1825	0.07	0.08		
Amara ovata (Fabricius, 1792)		20.58		0.15
Amara plebeja (Gyllenhal, 1810)	0.07		0.13	
Amara praetermissa (C.Sahlberg, 1827)			0.07	
Amara similata (Gyllenhal, 1810)		0.67		
Amara spreta Dejean, 1831			0.13	
Amara tibialis (Paykull, 1798)		0.08		
Acupalpus meridianus (Linnaeus, 1761)			0.07	
Anisodactylus binotatus (Fabricius, 1787)	0.07			
Anisodactylus nemorivagus (Duftschmid, 1812)		5.25		
Anisodactylus signatus (Panzer, 1796)		0.08		0.61
Harpalus affinis (Schrank, 1781)	0.59	0.92		1.06
Harpalus calathoides Motschulsky, 1844				1.36
Harpalus calceatus (Duftschmid, 1812)		0.17		
Harpalus distinguendus (Duftschmid, 1812)	0.66	0.67		
Harpalus griseus (Panzer, 1796)			0.07	
Harpalus latus (Linnaeus, 1758)	2.94	0.08	1.31	
Harpalus luteicornis (Duftschmid, 1812)		0.17		
Harpalus progrediens Schauberger, 1922	0.37			0.91
Harpalus pumilus Sturm, 1818		0.08		
Harpalus rubripes (Duftschmid, 1812)	0.59	3.25	0.59	1.21

Harpalus rufipes (DeGeer, 1774)	0.74	1.75	2.42	1.52
Harpalus smaragdinus (Duftschmid, 1812)				0.45
Harpalus tardus (Panzer, 1796)				0.45
Harpalus xanthopus winkleri Schauberger, 1923	0.07	3.67	2.16	
Harpalus zabroides Dejean, 1829		0.17		
Ophonus azureus (Fabricius, 1775)		2.08		
Ophonus cordatus (Duftschmid, 1812)	0.07	4.08		
**Ophonus diffinis* (Dejean, 1829)		0.33		
Ophonus puncticeps Stephens, 1828	0.07			
Ophonus rufibarbis (Fabricius, 1792)			0.20	0.15
Ophonus stictus Stephens, 1828	0.07			
**Ophonus subquadratus* (Dejean, 1829)		11.83		
Panagaeus bipustulatus (Fabricius, 1775)	0.07	3.50	0.07	0.15
Panagaeus cruxmajor (Linnaeus, 1758)			0.13	
Callistus lunatus (Fabricius, 1775)	0.15			
Chlaenius nigricornis (Fabricius, 1787)			5.82	
Oodes helopioides (Fabricius, 1792)			0.13	
Licinus depressus (Paykull, 1790)	0.07	0.17	0.59	
Badister bullatus (Schrank, 1798)		0.58		
Badister lacertosus Sturm, 1815			0.72	
Badister meridionalis Puel, 1925		0.50		
Badister peltatus (Panzer, 1796).			0.26	
Badister unipustulatus Bonelli, 1813		0.17	3.86	
Lebia chlorocephala (Hoffmann, 1803)	0.07	0.08	0.07	
Lebia cruxminor (Linnaeus, 1758)	0.66	0.08	0.07	
Philorhizus sigma (Rossi, 1790)			0.07	
Microlestes maurus (Sturm, 1827)			0.13	
Microlestes minutulus (Goeze, 1777)	0.22			
Cymindis angularis Gyllenhal, 1810	0.07			0.15
Total number of exemplars	**433**	**1547**	**1249**	**150**
Shannon index	**2.52**	**3.14**	**3.29**	**2.78**
Simpson index (1–D)	**0.14**	**0.07**	**0.06**	**0.08**
Berger and Parker index	**0.26**	**0.16**	**0.16**	**0.17**
Number of species	**40**	**65**	**62**	**24**

Only nine ground beetle species were captured in all the studied meadow biocenoses (8.2% of the total fauna): *Poecilus cupreus*, *Poecilus versicolor* (meadow mesophile), *Amara aenea*, *Amara equestris*, *Harpalus rubripes*, *Harpalus rufipes*, *Calathus fuscipes*, *Calathus melanocephalus,* and *Panagaeus bipustulatus* (all of them are eurybionts). Fifty-four species (49.1%) were found in only one meadow type.

Dominant species and their number differed in biocenoses. *Amara equestris* and *Poecilus versicolor* (25.9% and 21.2%, respectively) dominated with considerable numerical abundance in dry meadows. From these calculations, it is seen that these two dominant species accounted for almost half of the studied specimens in dry meadows in terms of numerical abundance. This was reflected in the calculation results of the dominance indices.

Four dominant species were found in dry meadows adjacent to forest shelter-belts: *Amara ovata* 16.0%, *Pterostichus melanarius* 10.1%, *Ophonus subquadratus* 9.2%, and *Calathus erratus* 10.3%. All these species are meadow mesoxerophiles and eurybionts. Five species dominated in wet floodplain meadows: *Pterostichus anthracinus* 16.5%, *Pterostichus melanarius* 7.0%, *Pterostichus gracilis* 6.0%, *Chlaenius nigricornis* 7.1%, and *Poecilus versicolor* 5.4% (forest species were also present). Seven species dominated in floodplain meadows affected by livestock grazing: *Amara equestris* 13.3%, *Harpalus rufipes* 6.7%, *Harpalus rubripes* 5.3%, *Amara aenea* 6.0%, *Harpalus calathoides* 6.0%, *Calathus erratus* 16.7%, and *Calathus melanocephalus* 10.0%. Such a diverse composition of dominants and subdominants (we will not give their names) indicated a high level of species in abundance in three communities and is an indicator of a wide variety of ground beetle complexes.

In separate meadow biocenoses, the number of ground beetle species varied from 24 to 65 **(Table 1)**. The Shannon index was the highest in wet floodplain meadows, and the Simpson index was minimal, i.e. maximum species diversity was recorded in this site with minimal dominance of species **(Table 1)**. In addition, a high Shannon index was recorded in dry meadows adjacent to forest shelter-belts. The minimum value of this index was obtained in the dry meadow fauna.

It is known that an increase in the Simpson index and the Berger-Parker index means a decrease in biocenose diversity and an increase in the dominance of some species [39]. A significant increase in these indices was obtained in dry meadows. This means that a significant decrease in biodiversity while increase in dominance degree of 1–2 species occurs in dry meadows as opposed to dry meadows adjacent to forest shelter-belts. As we indicated earlier, *Amara equestris* and *Poecilus versicolor* were such dominant species.

Cluster analysis based on Jaccard similarity index showed that the most similar species composition of ground beetles was in dry meadows and dry meadows adjacent to forest shelter-belts **(Figure 2)**. Species diversity was 40 species in the first biotope while it was significantly higher and amounted to 65 species in the second one **(Table 1)**. This similarity under significant differences in the fauna of these biotopes can be explained by the fact that a certain number of species that prefer to keep under the tree crowns and not migrate towards open meadow stations are present in dry meadows adjacent to forest shelter-belts. Floodplain meadows affected by livestock grazing differed most significantly from all other meadow biotopes. Intensive grazing has a serious effect on the ground beetle fauna in local natural conditions.

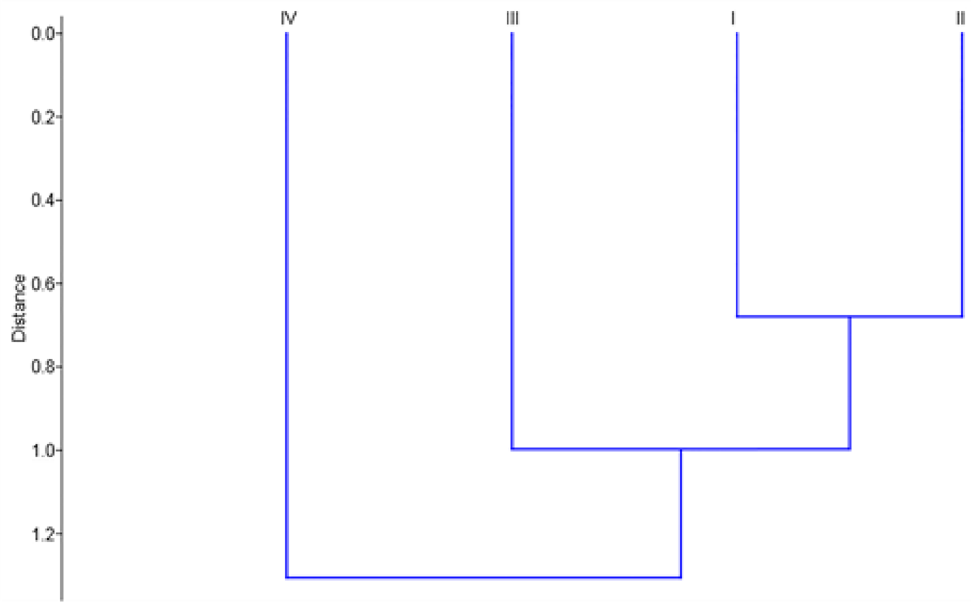


Figure 2. The Similarity of Four Meadow Biotope Types based on Jacquard Index: I – Dry Meadows; II – Dry Meadows Adjacent to Forest Shelter-belts; III – Wet Floodplain Meadows; IV – Floodplain Meadows Affected by Livestock Grazing

The species diversity of the genera *Amara*, *Harpalus*, and *Pterostichus* was considerable being represented by a total of 46 species. A similar dependence was noted in meadow biotopes in the north and southwest of European Russia [40]. An analysis of the data showed that when forming the population of ground beetles, the main importance belongs to the species groups of open habitats (meadows, meadow fields, and fields groups).

Dry meadows differ from other types of studied biotopes by the moisture regime. They are less humid and, therefore, herbaceous Poaceae species grow there much more frequently, as well as weed species. Typically, such meadows do not mow, and they do not serve as pastures. The ground beetle species composition is formed in such conditions by species of the meadow complex and eurybionts [40]. Similar results were obtained in our studies.

Forest edges and forest shelter-belts can also affect insect diversity by offering additional habitats such as wintering grounds, summer hibernation sites, mating sites, or feeding places. Such ecotones can reduce migration, change the daily and seasonal movements of insects. An increase in the species diversity of insects adjacent to the biotope forest is the most likely result [41-43]. This is exactly what was obtained in our conditions. The presence of forest shelter belts near dry meadows remarkably increases the species diversity of ground beetles that can use these belts for their life.

Wet floodplain meadows have a good herb layer and moderate humidity in our study sites. The species diversity of ground beetles was quite high in our research (62 species). A similar number of species was recorded in floodplain meadows in Belarus [44], Kirov region in Russia [45], Masovian Lowland in Poland [46]. On the other hand, a more considerable species diversity of ground beetles was found in floodplain meadows in the Ryazan region (center of European Russia), where authors attributed the obtained results to the heterogeneity of the relief and the strongly mosaic vegetation diversity [47]. The proximity of habitats with different soil and plant conditions ensures the migration and exchange of species, which also increases the species diversity of ground beetles both in general and in individual habitats [47]. In our conditions, wet floodplain meadows were quite similar to each other and did not differ in the diversity of vegetation.

In the center of European Russia, floodplain meadows affected by livestock grazing are summer pastures for these herbivores. They are usually used during the growing season. Cattle grazing is carried out daily leading to a gradual degradation of the meadow system. It is known that under excessive soil pressure, floodplain meadows affected by livestock grazing can be severely crushed with mechanical damage to the soil cover and partial destruction of vegetation [48, 49]. An important role is played by a significant amount of manure, which may also not equally affect different insect groups, but not as obvious as trampling [50]. We think that in such biotopes the decrease in the species diversity of ground beetles is explained by extremely strong grazing.

CONCLUSION

Thus, 110 species of ground beetles belonging to 35 genera were recorded in meadow biocenoses in the Nizhniy Novgorod region and Republic of Mordovia. The genera *Amara*, *Harpalus*, and *Pterostichus* are represented by the highest species richness. The basis of meadow carabid fauna consisted of eurybionts and meadow species. The highest species diversity was noted in dry meadows adjacent to forest shelter-belts and wet floodplain meadows. Forest shelter-belts created heterogeneity in uniform meadow biotopes and therefore increased the number of species and abundance of ground beetles. Wet floodplain meadows are distinguished by well-developed herb layers and humidity, which also affects the species diversity of ground beetles. The lowest number of species was in floodplain meadows affected by livestock grazing. We attribute this to the significant trampling and the soil cover degradation in these meadows. In wet floodplain meadows, the Shannon index was the highest, while the Simpson index was the lowest. The ground beetle fauna had high values of the Simpson and Berger-Parker indices in dry meadows. Only two species dominated in dry meadows, while four to seven species dominated in other habitats. Such a diverse composition of dominants and subdominants indicated a high level of species abundance in three communities, and it is an indicator of a wide variety of ground beetle complexes. The highest similarity of species composition of ground beetles was noted between dry meadows and dry meadows adjacent to forest shelter-belts according to the Jaccard similarity index. Floodplain meadows affected by livestock grazing differed significantly from all other types of meadow biotopes.

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