



Eurasia Specialized Veterinary Publication

Entomological Research Letters

ISSN: 3108-639X

2022, Volume 2, Issue 1, Page No: 1-11

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Available online at: www.esvpub.com/

Diversity and Composition of Carabidae (Coleoptera) in Grassland Habitats

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ABSTRACT

The diversity of ground beetles (Carabidae) was analyzed in meadow ecosystems within central European Russia, focusing on the Nizhniy Novgorod region and the Republic of Mordovia. 17 sites were investigated, with the meadows categorized into 4 types: wet floodplain meadows, dry meadows, dry meadows near forest shelter-belts, and floodplain meadows impacted by livestock grazing. The highest species diversity was observed in dry meadows near forest shelter belts (65 species) and wet floodplain meadows (62 species), while floodplain meadows affected by grazing had the lowest species (24 species). A total of 40 ground beetle species were recorded in dry meadows. Wet floodplain meadows showed the highest Shannon index and the lowest Simpson index. In contrast, dry meadows showed high values for the Simpson and Berger-Parker indices. In these meadows, only 2 species were dominant, while other habitats had 4 to 7 dominant species. Based on the Jaccard similarity index, dry meadows and those adjacent to forest shelter belts had the most similar ground beetle species composition. Livestock trampling was found to significantly reduce the number and diversity of ground beetles, especially in floodplain meadows affected by grazing.

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

Received: 09 January 2022

Revised: 28 February 2022

Accepted: 03 March 2022

How to Cite This Article: Pereira R, Pereira IR, Singh A, Muller NA. Diversity and Composition of Carabidae (Coleoptera) in Grassland Habitats. Entomol Res Lett. 2022;2(1):1-11. <https://doi.org/10.51847/nyTm0cdjCOO>

Introduction

Meadows are vegetative landscapes dominated by perennial herbaceous plants, primarily grasses, and sedges, typically thriving in areas with adequate or abundant moisture. These ecosystems are defined by the presence of turf and plant stands. Meadows can be grouped into three primary categories based on their geographic location. Continental meadows, found in plains outside river floodplains, are further classified into dry and lowland types. Floodplain meadows, which occur in river valleys, are periodically flooded during seasonal high waters. Mountain meadows are located above the forest's upper boundary. Across various regions globally, meadows support a diverse array of perennial plant species [1], including those that are endangered [2] and invasive [3]. These habitats serve as crucial environments for numerous species, including birds [4], mammals [5, 6], reptiles [7], invertebrates [8-10], and more. The recovery potential of different meadow types after disturbances varies, with carbon stock levels playing a significant role in this process [11, 12]. Over the centuries, human activities such as uncontrolled grazing, agricultural practices, afforestation, and urban expansion have severely impacted meadows, leading to a reduction in their natural coverage [13].

Recent modifications in open biocenoses, such as meadows, steppes, and pastures, have been observed across various regions globally [14-18]. The transformation of vegetation cover increasingly affects the ground beetle fauna in these biocenoses, which serve as bioindicators of ecosystem health [19-22]. These ground-dwelling

organisms are found in large numbers across diverse landscapes (both open and closed), including areas with varying degrees of disturbance. Over the past few decades, human activities have significantly altered meadow ecosystems, with high rates of destruction caused by factors like annual grass fires, excessive land plowing, overgrazing, uncontrolled haying, and afforestation of meadows and fields [23-26]. These environmental impacts disrupt natural habitats, foster the development of secondary forest communities, and lead to shifts in the geographic distribution and population structures of some ground beetle species [16, 27-32]. This research focuses on the ground beetle fauna in meadow ecosystems located in central European Russia.

Materials and Methods

Description of biotopes

All biotopes were categorized into four groups based on moisture levels, proximity to forests or afforestation (within 100 meters), and anthropogenic influences such as grazing by livestock.

I – Dry meadows. These habitats consist of grazed meadows and abandoned fields found on dry, sandy soils, exhibiting a noticeable level of aridity. Common plant species in these areas include *Calamagrostis epigejos*, *Achillea millefolium*, *Bromus inermis*, *Trifolium arvense*, *Trifolium pratense*, *Artemisia vulgaris*, *Lathyrus pratensis*, *Leucanthemum vulgare*, *Matricaria matricarioides*, *Dactylis glomerata*, *Cirsium arvense*, *Agrimonia eupatoria*, *Cichorium intybus*, *Pimpinella saxifraga*, *Astragalus danicus*, *Fragaria viridis*, and *Carex spicata*.

II – Dry meadows near forest shelter belts. These are similar to dry meadows but are distinguished by the presence of *Betula*-dominated or mixed shelter belts situated 30-50 meters away from the meadows. Plant species identified here include *Cirsium arvense*, *Consolida regalis*, *Achillea millefolium*, *Matricaria matricarioides*, *Calamagrostis epigejos*, *Bromus inermis*, *Thlaspi arvense*, *Brassica rapa*, *Polygonum aviculare*, *Cyanus segetum*, *Leucanthemum vulgare*, *Viola arvensis*, and *Phleum pratense*.

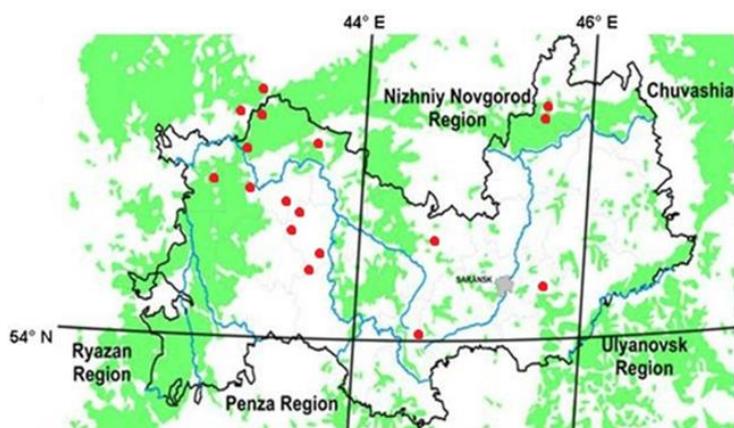
III – Wet floodplain meadows. Found in floodplains of small streams and rivers, these meadows are situated on relatively moist sandy and sandy-loam soils. The species present in these habitats include *Rumex confertus*, *Taraxacum officinale*, *Carex spicata*, *Carex vulpina*, *Agrimonia eupatoria*, *Bromus inermis*, *Tussilago farfara*, *Dactylis glomerata*, *Cichorium intybus*, *Stellaria media*, *Echium vulgare*, *Scorzoneroideis autumnalis*, *Trifolium hybridum*, *Alchemilla* species, *Scirpus sylvaticus*, and *Carex acuta*.

IV – Floodplain meadows influenced by livestock grazing. These habitats are similar to wet floodplain meadows but differ due to greater soil compaction caused by grazing, which affects both the soil and vegetation cover.

Scientific names were referenced from The PlantList database (<http://www.theplantlist.org/>).

Collection methods

We gathered data using pitfall traps from April to September in the years 2009, 2010, 2014, and 2019. The traps used were 0.5-liter cups filled with a 4% formalin solution. Each site contained ten traps arranged in a single row, spaced 2 to 3 meters apart. A total of 17 sites in the Nizhniy Novgorod region and the Republic of Mordovia were surveyed (**Figure 1**). At each site, only one line of ten traps was set up for the study.



a)



b)

Figure 1. Study territory; places, where material is collected, are indicated by red dots.

Data analysis

The diversity of ground beetles in the ecosystems was assessed using two diversity indices: the Shannon-Wiener index (H'), which gives equal weight to both rare and common species, and Simpson's index ($1-D$), which is more sensitive to variations in the most abundant species [33]. The evenness of the beetle populations across the five sampling locations was determined using the Berger and Parker index. Data analysis was conducted using Microsoft Excel, with average values presented in the tables.

A total of over 3,400 specimens were collected over 4,750 trap days. To quantify species abundance, we categorized the species as follows: dominant species (abundance > 5%), subdominant species (abundance between 2% and 5%), moderately abundant species (abundance between 1% and 2%), and rare species (abundance < 1%). Beetle density was measured as the number of beetles captured per one hundred traps per day (exemplars/100 trap-days).

The identification of ground beetle species was performed using the identification keys from the studies by Kryzhanovskij [34], and Kryzhanovskij [35]. The Carabidae classification followed the system provided by the Zoological Institute of the Russian Academy of Sciences [36], supplemented by the catalog of Kryzhanovskij *et al.* [37]. Nomenclature was based on the catalog of Palearctic beetles [38]. Species marked with an asterisk (*) indicate those that were recorded for the first time in the Republic of Mordovia. The collected material is preserved in the Mordovia State Nature Reserve's collection in Pushta, Russia.

Results and Discussion

In total, 110 species of ground beetles from 35 genera were recorded across all meadows (**Table 1**). 4 species were newly identified in the Republic of Mordovia. The genera *Amara* (19 species), *Harpalus* (15 species), and *Pterostichus* (12 species) contained the highest number of species. Many of these species are typical of broad Holarctic and Palearctic distributions. The majority of the collected beetles were common and abundant species found in the forest-steppe zone of 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				
<i>Cylindera germanica</i> (Linnaeus, 1758)		7.58		
<i>Cicindela campestris</i> Linnaeus, 1758	0.07			0.61
Carabinae				
<i>Leistus ferrugineus</i> (Linnaeus, 1758)		0.08		
<i>Notiophilus germinyi</i> Fauvel, 1863		0.33		

<i>Loricera pilicornis</i> (Fabricius, 1775)		0.08	1.05	
<i>Clivina fossor</i> (Linnaeus, 1758)			0.07	
<i>Calosoma maderae</i> (Fabricius, 1775)		0.25		
<i>Carabus cancellatus</i> Illiger, 1798	0.07	0.33	0.46	
<i>Carabus clathratus</i> Linnaeus, 1761	0.07		0.13	
<i>Carabus glabratus</i> Paykull, 1790			0.13	
<i>Carabus granulatus</i> Linnaeus, 1758			1.96	
<i>Trechus secalis</i> (Paykull, 1790)	0.07	0.67	1.18	
<i>Trechus quadristriatus</i> (Schrank, 1781)		0.17		
<i>Bembidion biguttatum</i> (Fabricius, 1779)			1.70	
<i>Bembidion dentellum</i> (Thunberg, 1787)			1.24	
<i>Bembidion gilvipes</i> Sturm, 1825			0.07	
<i>Bembidion lampros</i> (Herbst, 1784)		0.25	0.13	
<i>Bembidion properans</i> (Stephens, 1828)		2.08	0.78	
* <i>Bembidion schuppelii</i> Dejean, 1831			0.72	
<i>Bembidion quadrimaculatum</i> (Linnaeus, 1760)		1.17		
<i>Patrobus atrorufus</i> (Ström, 1768)		0.08	0.07	
<i>Stomis pumicatus</i> (Panzer, 1796)		0.08	0.26	
<i>Poecilus cupreus</i> (Linnaeus, 1758)	0.15	5.25	2.03	0.45
<i>Poecilus lepidus</i> (Leske, 1785)	0.22	0.83		
<i>Poecilus sericeus</i> Fischer von Waldheim, 1824	0.07			
<i>Poecilus versicolor</i> (Sturm, 1824)	6.76	1.58	4.44	1.06
<i>Pterostichus anthracinus</i> (Illiger, 1798)			13.46	
* <i>Pterostichus cursor</i> (Dejean, 1828)			0.13	
<i>Pterostichus gracilis</i> (Dejean, 1828)			4.90	0.15
<i>Pterostichus macer</i> (Marsham, 1802)		0.17		
<i>Pterostichus mannerheimii</i> (Dejean, 1831)			0.13	
<i>Pterostichus melanarius</i> (Illiger, 1798)	0.07	13.08	5.75	
<i>Pterostichus minor</i> (Gyllenhal, 1827)	0.07		0.39	
<i>Pterostichus niger</i> (Schaller, 1783)	0.07	0.17	1.44	
<i>Pterostichus nigrata</i> (Paykull, 1790)			3.20	
<i>Pterostichus oblongopunctatus</i> (Fabricius, 1787)	0.15	0.42		
<i>Pterostichus strenuus</i> (Panzer, 1796)		0.08	0.46	
<i>Pterostichus vernalis</i> (Panzer, 1796)			1.96	
<i>Calathus erratus</i> (C. Sahlberg, 1827)	1.25	13.25		3.79
<i>Calathus fuscipes</i> (Goeze, 1777)	2.94	3.83	3.01	0.61
<i>Calathus melanocephalus</i> (Linnaeus, 1758)	1.32	3.33	1.31	2.27
<i>Dolichus halensis</i> (Schaller, 1783)		0.08		
<i>Limodromus krynickii</i> (Sperk, 1835)		0.17		
<i>Agonum duftschmidii</i> J. Schmidt, 1994			3.07	
<i>Agonum fuliginosum</i> (Panzer, 1809)		1.92	0.13	
<i>Agonum viduum</i> (Panzer, 1796)			0.33	
<i>Oxypselaphus obscurus</i> (Herbst, 1784)		0.58	0.39	
<i>Synuchus vivalis</i> (Illiger, 1798)		0.25	0.20	
<i>Amara aenea</i> (De Geer, 1774)	0.81	2.92	0.33	1.36
<i>Amara apricaria</i> (Paykull, 1790)		0.25		
<i>Amara aulica</i> (Panzer, 1796)	0.22	0.08	0.72	

<i>Amara bifrons</i> (Gyllenhal, 1810)		2.42	0.07	
<i>Amara communis</i> (Panzer, 1797)	1.25		4.12	0.76
<i>Amara consularis</i> (Duftschmid, 1812)		0.67	0.07	
<i>Amara equestris</i> (Duftschmid, 1812)	8.24	2.08	0.65	3.03
<i>Amara eurynota</i> (Panzer, 1796)		0.08		
<i>Amara fulva</i> (Müller, 1776)				0.15
<i>Amara ingenua</i> (Duftschmid, 1812)	0.22			0.30
<i>Amara littorea</i> C.G. Thomson, 1857		0.08		
<i>Amara montivaga</i> Sturm, 1825		1.08		
<i>Amara nitida</i> Sturm, 1825	0.07	0.08		
<i>Amara ovata</i> (Fabricius, 1792)		20.58		0.15
<i>Amara plebeja</i> (Gyllenhal, 1810)	0.07		0.13	
<i>Amara praetermissa</i> (C. Sahlberg, 1827)			0.07	
<i>Amara similata</i> (Gyllenhal, 1810)		0.67		
<i>Amara spreta</i> Dejean, 1831			0.13	
<i>Amara tibialis</i> (Paykull, 1798)		0.08		
<i>Acupalpus meridianus</i> (Linnaeus, 1761)			0.07	
<i>Anisodactylus binotatus</i> (Fabricius, 1787)	0.07			
<i>Anisodactylus nemorivagus</i> (Duftschmid, 1812)		5.25		
<i>Anisodactylus signatus</i> (Panzer, 1796)		0.08		0.61
<i>Harpalus affinis</i> (Schränk, 1781)	0.59	0.92		1.06
<i>Harpalus calathoides</i> Motschulsky, 1844				1.36
<i>Harpalus calceatus</i> (Duftschmid, 1812)		0.17		
<i>Harpalus distinguendus</i> (Duftschmid, 1812)	0.66	0.67		
<i>Harpalus griseus</i> (Panzer, 1796)			0.07	
<i>Harpalus latus</i> (Linnaeus, 1758)	2.94	0.08	1.31	
<i>Harpalus luteicornis</i> (Duftschmid, 1812)		0.17		
<i>Harpalus progrediens</i> Schaubberger, 1922	0.37			0.91
<i>Harpalus pumilus</i> Sturm, 1818		0.08		
<i>Harpalus rubripes</i> (Duftschmid, 1812)	0.59	3.25	0.59	1.21
<i>Harpalus rufipes</i> (DeGeer, 1774)	0.74	1.75	2.42	1.52
<i>Harpalus smaragdinus</i> (Duftschmid, 1812)				0.45
<i>Harpalus tardus</i> (Panzer, 1796)				0.45
<i>Harpalus xanthopus winkleri</i> Schaubberger, 1923	0.07	3.67	2.16	
<i>Harpalus zabroides</i> Dejean, 1829		0.17		
<i>Ophonus azureus</i> (Fabricius, 1775)		2.08		
<i>Ophonus cordatus</i> (Duftschmid, 1812)	0.07	4.08		
* <i>Ophonus diffinis</i> (Dejean, 1829)		0.33		
<i>Ophonus puncticeps</i> Stephens, 1828	0.07			
<i>Ophonus rufibarbis</i> (Fabricius, 1792)			0.20	0.15
<i>Ophonus stictus</i> Stephens, 1828	0.07			
* <i>Ophonus subquadratus</i> (Dejean, 1829)		11.83		
<i>Panagaeus bipustulatus</i> (Fabricius, 1775)	0.07	3.50	0.07	0.15
<i>Panagaeus cruxmajor</i> (Linnaeus, 1758)			0.13	
<i>Callistus lunatus</i> (Fabricius, 1775)	0.15			
<i>Chlaenius nigricornis</i> (Fabricius, 1787)			5.82	
<i>Oodes helopioides</i> (Fabricius, 1792)			0.13	

<i>Licinus depressus</i> (Paykull, 1790)	0.07	0.17	0.59	
<i>Badister bullatus</i> (Schrank, 1798)		0.58		
<i>Badister lacertosus</i> Sturm, 1815			0.72	
<i>Badister meridionalis</i> Puel, 1925		0.50		
<i>Badister peltatus</i> (Panzer, 1796).			0.26	
<i>Badister unipustulatus</i> Bonelli, 1813		0.17	3.86	
<i>Lebia chlorocephala</i> (Hoffmann, 1803)	0.07	0.08	0.07	
<i>Lebia cruxminor</i> (Linnaeus, 1758)	0.66	0.08	0.07	
<i>Philorhizus sigma</i> (Rossi, 1790)			0.07	
<i>Microlestes maurus</i> (Sturm, 1827)			0.13	
<i>Microlestes minutulus</i> (Goeze, 1777)	0.22			
<i>Cymindis angularis</i> 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

In the studied meadow biocenoses, only 9 ground beetle species were recorded, making up 8.2% of the total fauna. These included *Poecilus cupreus*, *Poecilus versicolor* (a meadow mesophile), *Amara equestris*, *Amara aenea*, *Harpalus rufipes*, *Harpalus rubripes*, *Calathus melanocephalus*, *Calathus fuscipes*, and *Panagaeus bipustulatus*, all of which are eurybionts. Additionally, 54 species (49.1%) were exclusive to a single meadow type.

The abundance and dominance of species varied across biocenoses. In dry meadows, *Amara equestris* and *Poecilus versicolor* were the most prevalent, comprising 25.9% and 21.2% of the population, respectively. Together, these two species accounted for nearly half of the beetle specimens in dry meadows by numerical abundance. This pattern was also evident in the dominance index results.

In dry meadows near forest shelter belts, 4 dominant species were recorded: *Amara ovata* (16.0%), *Pterostichus melanarius* (10.1%), *Ophonus subquadratus* (9.2%), and *Calathus erratus* (10.3%). All of these species are meadow mesoxerophiles and eurybionts. In wet floodplain meadows, five species dominated: *Pterostichus anthracinus* (16.5%), *Pterostichus melanarius* (7.0%), *Pterostichus gracilis* (6.0%), *Chlaenius nigricornis* (7.1%), and *Poecilus versicolor* (5.4%), with forest species also present. In floodplain meadows influenced by livestock grazing, seven species were most abundant: *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%). The diverse range of dominant and subdominant species (which are not listed here) highlights the richness of species in these communities, reflecting a varied ground beetle population structure.

The number of ground beetle species in individual meadow biocenoses ranged from 24 to 65 (**Table 1**). The wet floodplain meadows showed the highest Shannon index, indicating maximum species diversity with the lowest Simpson index, signifying minimal species dominance at this site (**Table 1**). A similarly high Shannon index was observed in dry meadows near forest shelter belts, while the dry meadows had the lowest value for this index.

An increase in the Simpson index and Berger-Parker index reflects a decline in biocenose diversity and a rise in the dominance of specific species [39]. In dry meadows, a notable rise in these indices was observed, indicating a significant reduction in biodiversity and a higher dominance of 1–2 species, compared to dry meadows near forest shelter-belts. As mentioned previously, *Amara equestris* and *Poecilus versicolor* were the dominant species in this case.

Cluster analysis, utilizing the Jaccard similarity index, revealed that dry meadows and dry meadows near forest shelter belts had the most similar ground beetle species composition (**Figure 2**). The species count in dry meadows was 40, whereas it was significantly higher in the meadows near the shelter belts, with 65 species (**Table 1**). Despite the differences in the fauna of these biotopes, this similarity can be attributed to the presence of certain species that prefer to remain under tree canopies and do not migrate toward open meadows. Floodplain meadows

impacted by livestock grazing showed the most distinct difference from all other meadow types. The intense grazing pressure significantly alters the ground beetle fauna in these areas.

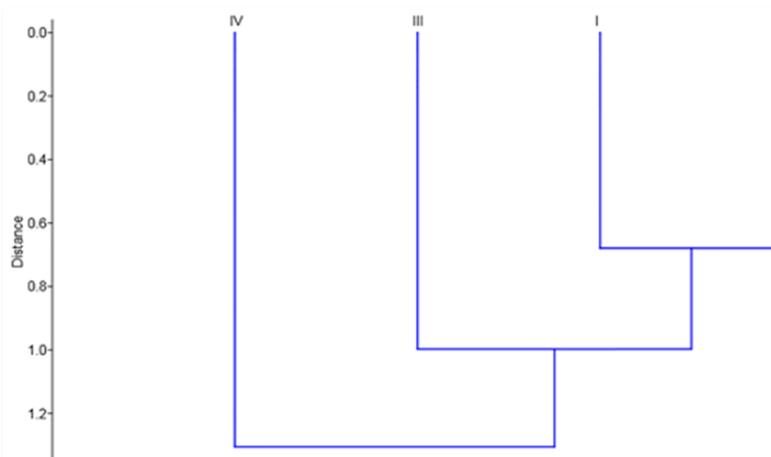


Figure 2. The similarity of four meadow biotope types based on the Jaccard index; I: dry meadows; II: dry meadows adjacent to forest shelter-belts; III: wet floodplain meadows; IV: floodplain meadows affected by livestock grazing

The genera *Amara*, *Harpalus*, and *Pterostichus* exhibited notable species diversity, with a total of 46 species represented. A similar trend was observed in meadow biotopes across northern and southwestern European Russia [40]. Data analysis revealed that, in the formation of ground beetle populations, the primary influence comes from species groups associated with open habitats, such as meadows, meadow fields, and fields.

Dry meadows stand out from other biotopes studied due to their distinct moisture conditions. These meadows are relatively drier, which allows herbaceous Poaceae species, as well as weed species, to thrive more abundantly. Typically, these meadows are not mowed and are not used for grazing. Under these conditions, the ground beetle species composition is dominated by species from the meadow complex and eurybionts [40]. Our findings aligned with these observations.

Forest edges and shelter belts influence insect diversity by providing additional habitats, including summer hibernation sites, wintering grounds, mating areas, and feeding locations. These ecotones can limit migration and alter the daily and seasonal movements of insects. Consequently, the species diversity of insects near forest biotopes is typically higher [41-43]. Our study confirmed this trend, as the presence of forest shelter belts near dry meadows significantly enhanced the species diversity of ground beetles, which utilize these shelter belts for various life processes.

In our study, wet floodplain meadows had a well-developed herbaceous layer and moderate moisture levels. The species diversity of ground beetles was notably high, with 62 species identified. Similar species numbers were observed in floodplain meadows in Belarus [44], the Kirov region of Russia [45], and Poland's Masovian Lowland [46]. However, floodplain meadows in the Ryazan region (central European Russia) exhibited even greater ground beetle diversity. Researchers linked this to the varied topography and the patchy nature of vegetation in that area [47]. The presence of habitats with different soil and plant characteristics allows for the migration and exchange of species, contributing to a higher diversity of ground beetles across various habitats [47]. In our study, the wet floodplain meadows were fairly uniform, with little variation in their plant diversity.

In central European Russia, floodplain meadows impacted by livestock grazing serve as summer pastures for herbivores, typically utilized throughout the growing season. Daily grazing leads to the gradual degradation of the meadow ecosystem. It is well-established that excessive soil pressure from grazing can cause significant damage to floodplain meadows, including physical compaction of the soil and partial destruction of vegetation cover [48, 49]. Additionally, the large volume of manure deposited in these areas can have varying impacts on different insect groups, though its effects are less pronounced than the damage caused by trampling [50]. We believe that the decline in species diversity of ground beetles in these biotopes is primarily due to the intense grazing pressure.

Conclusion

A total of 110 ground beetle species across 35 genera were recorded in the meadow biocenoses of the Nizhniy Novgorod region and the Republic of Mordovia. The genera *Amara*, *Harpalus*, and *Pterostichus* showed the greatest species diversity. Eurybionts and meadow species formed the core of the meadow carabid fauna. The greatest diversity was observed in dry meadows near forest shelter belts and wet floodplain meadows. Forest shelter belts introduced a level of habitat variability in otherwise uniform meadows, boosting both species richness and beetle population density. Wet floodplain meadows, with their dense herbaceous layers and higher moisture levels, also supported greater species diversity of ground beetles. In contrast, floodplain meadows impacted by livestock grazing exhibited the fewest species, likely due to the damaging effects of trampling and soil degradation.

In wet floodplain meadows, the Shannon index was the highest, and the Simpson index was the lowest, indicating the greatest species diversity and minimal dominance. Dry meadows, however, exhibited higher Simpson and Berger-Parker indices, with only two species showing dominance. Other meadow types saw dominance from 4 to 7 species. This variety in dominant species suggests a high species abundance and diversity within these biotopes. The Jaccard similarity index revealed that dry meadows and those near forest shelter belts shared the most similar ground beetle species composition, while floodplain meadows subjected to grazing stood apart from all other biotopes.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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