Fauna of Ground Beetles (Coleoptera, Carabidae) in Broad-leaved Forests of the Republic of Mordovia (Central European Russia)

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Abstract. The fauna of Carabidae adults in broad-leaved forests of the Republic of Mordovia (central European Russia) was studied. A total of 18210 ground beetle specimens of 104 species (8 subfamilies) were collected. The most numerous species were eight species: *Carabus cancellatus, Pterostichus niger, Pterostichus oblongopunctatus, Limodromus assimilis, Calosoma inquisitor, Carabus granulatus, Pterostichus melanarius, Carabus arvensis*. The basis of the Carabidae fauna consists of 25 species with high occurrence (50% and higher). Among them, four species are characterized by 100% occurrence: *Carabus granulatus, Carabus hortensis, Pterostichus niger, Pterostichus oblongopunctatus*.

1 Introduction

Worldwide, forests cover almost a third of the land area and contain over 80% of terrestrial biodiversity. The extent and quality of forest habitats continue to decline, and the associated loss of biodiversity threatens the functioning of forest ecosystems [1–3]. It is possible that the simultaneous reduction in both quantity and quality of forests will lead to the mass extinction of many species living in forest habitats. Loss of forest biodiversity can seriously impair the functioning of forest ecosystems [4-5]. In the center of European Russia, relatively small massifs represent broad-leaved forests. They are located in watershed areas of secondary moraine and erosion-denudation plains with gray forest soils and podzolized chernozems. In many cases, the ancient broad-leaved forests have been significantly affected by anthropogenic activities [6-7]. Accordingly, the remaining broad-leaved forests have been preserved mainly in inaccessible areas or have been taken under protection in protected areas. Such different areas of forests act as hotspots [8].

Ground beetles (Coleoptera, Carabidae) are suitable for such studies because they are a species-rich group of insects that are common in most terrestrial ecosystems. The high biodiversity of Carabidae species, which have multiple dispersal, feeding, and activity strategies, has contributed to this success. This has led to widespread success in terrestrial

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ecosystems, where they play an important functional role [9-14]. This publication presents the results of a study of the fauna and biology of Carabidae in broad-leaved forests of the Republic of Mordovia (center of European Russia).

2 Materials and methods

The Republic of Mordovia is located in the center of the Eastern European Plain between 42°11' and 46°45' E and 53°38' and 55°11' N. The territory of the republic belongs entirely to the Volga basin. It is located at the junction of forest and forest-steppe zones. Broad-leaved forests are found mainly in the central and eastern part of the republic. However, in many places such forests are secondary forests that have grown after significant mass logging. Such forests are of coppice origin. Intact broad-leaved forests have survived in places where industrial logging was inconvenient or forests became protected by the state. Currently, such forests are found in the floodplains of large rivers. It was in such forests that the ground beetle fauna was investigated.

Studies were conducted in 2008, 2012, 2014, 2015, 2017-2019, 2022. In total, data were obtained from 14 localities situated in the Zubovo-Polyana, Ichalki, Temnikov, Elniki and Bolshoe Ignatovo districts of the republic. The collecting was done with pitfall traps. The pitfall traps were 0.5 L plastic cups with a 4% formalin solution poured into them. The traps were placed in one line of ten traps (from late April to September). One locality exhibited one such line. The distance between the cups was 2-3 meters. The evaluation of the results was expressed in dynamic density (individuals per 100 trap days). Identification was made in accordance with Müller-Motzfeld [15] and Isaev [16]. We followed the nomenclature proposed by Lobl and Lobl [17]. In the list of species, subfamilies are arranged in a systematic order; in subfamilies, species are arranged alphabetically. The life forms of ground beetles were analyzed according to the system [18].

3 Results

According to long-term studies in broad-leaved forests, 18210 specimens of ground beetles were collected. The species diversity of Carabidae in these ecosystems is 104 species from eight subfamilies (table 1).

Table 1. Biodiversity and dynamic density of ground beetles of broad-leaved forests of the Republic of Mordovia.

Species	Number of individuals	Dynamic density, individuals per 100 trap days	Occurrence, %
Carabinae			
Calosoma inquisitor (Linnaeus, 1758)	1418	10.151	35.7
Calosoma investigator (Illiger, 1798)	4	0.018	7.1
Carabus arvensis baschkiricus Breuning, 1932	1070	3.801	64.3
Carabus cancellatus Illiger, 1798	3020	13.074	85.7
Carabus clathratus Linnaeus, 1760	4	0.021	14.2
Carabus convexus Fabricius, 1775	80	0.369	64.3
Carabus coriaceus Linnaeus, 1758	129	0.622	71.4
Carabus hortensis Linnaeus, 1758	384	2.092	100
Carabus glabratus Paykull, 1790	480	2.976	92.8
Carabus granulatus Linnaeus, 1758	1190	6.307	100
Carabus nemoralis O.F. Müller, 1764	378	1.994	14.2
Carabus schoenherri Fischer von Waldheim, 1820	1	0.015	7.1
Cychrus caraboides (Linnaeus, 1758)	31	0.153	50
Elaphrinae			

Elaphrus cupreus Duftschmid, 1812	6	0.039	21.4
Harpalinae			
Agonum fuliginosum (Panzer, 1809)	12	0.059	35.7
Agonum gracilipes (Duftschmid, 1812)	6	0.025	35.7
Agonum micans (Nicolai, 1822)	1	0.005	7.1
Agonum viduum (Panzer, 1796)	16	0.089	35.7
Amara aenea (De Geer, 1774)	29	0.342	35.7
Amara bifrons (Gyllenhal, 1810)	1	0.016	7.1
Amara brunnea (Gyllenhal, 1810)	4	0.026	21.4
Amara communis (Panzer, 1797)	135	0.664	64.3
Amara eurynota (Panzer, 1796)	7	0.030	28.6
Amara familiaris (Duftschmid, 1812)	1	0.004	7.1
Amara lunicollis Schiødte, 1837	3	0.014	7.1
Amara gebleri Dejean, 1831	8	0.077	21.4
Amara ovata (Fabricius, 1792)	7	0.030	28.6
Amara nitida Sturm, 1825	2	0.008	14.2
Amara plebeja (Gyllenhal, 1810)	1	0.004	7.1
Amara similata (Gyllenhal, 1810)	6	0.039	28.6
Amara tibialis (Paykull, 1798)	9	0.095	28.6
Anisodactylus nemorivagus (Duftschmid, 1812)	15	0.221	21.4
Anisodactylus signatus (Panzer, 1796)	1	0.004	7.1
Badister bullatus (Schrank, 1798)	10	0.044	28.6
Badister lacertosus Sturm, 1815	46	0.246	71.4
Badister collaris Motschulsky, 1844	1	0.016	7.1
Badister sodalis (Duftschmid, 1812)	8	0.036	21.4
Calathus erratus (C.R. Sahlberg, 1827)	1	0.004	7.1
Calathus fuscipes (Goeze, 1777)	6	0.093	7.1
Calathus melanocephalus (Linnaeus, 1758)	5	0.078	7.1
Calathus micropterus (Duftschmid, 1812)	36	0.147	28.6
Chlaenius nigricornis (Fabricius, 1787)	6	0.041	7.1
Chlaenius tristis (Schaller, 1783)	2	0.014	7.1
Dromius agilis (Fabricius, 1787)	1	0.011	7.1
Harpalus affinis (Schrank, 1781)	3	0.046	7.1
Harpalus autumnalis (Duftschmid, 1812)	1	0.004	7.1
Harpalus distinguendus (Duftschmid, 1812)	5	0.067	14.2
Harpalus griseus (Panzer, 1796)	1	0.004	7.1
Harpalus laevipes Zetterstedt, 1828	149	0.571	78.6
Harpalus latus (Linnaeus, 1758)	155	0.757	78.6
Harpalus progrediens Schauberger, 1922	19	0.165	21.4
Harpalus pumilus Sturm, 1818	3	0.046	7.1
Harpalus rubripes (Duftschmid, 1812)	17	0.209	28.6
Harpalus rufipes (De Geer, 1774)	299	1.370	50
Harpalus signaticornis (Duftschmid, 1812)	3	0.019	21.4
Harpalus smaragdinus (Duftschmid, 1812)	2	0.019	14.2
Harpalus tardus (Panzer, 1796)	39	0.289	57.1
Harpalus xanthopus winkleri Schauberger, 1923	32	0.131	42.9
Lebia cruxminor (Linnaeus, 1758)	2	0.031	7.1
Lebia cyanocephala (Linnaeus, 1758)	1	0.004	7.1
Licinus depressus (Paykull, 1790)	4	0.017	14.2
Limodromus assimilis (Paykull, 1790)	1674	8.727	71.4
Limodromus krynickii (Sperk, 1835)	182	0.989	35.7
Microlestes maurus (Sturm, 1827)	27	0.414	14.2
Oodes helopioides (Fabricius, 1792)	60	0.369	28.6
Ophonus puncticeps Stephens, 1828	1	0.004	7.1
Ophonus puncticollis (Paykull, 1798)	1	0.004	7.1
Oxypselaphus obscurus (Herbst, 1784)	34	0.171	42.9
Panagaeus bipustulatus (Fabricius, 1775)	9	0.044	35.7
Platynus livens (Gyllenhal, 1810)	1	0.006	7.1
Poecilus cupreus (Linnaeus, 1758)	118	0.582	50

Poecilus lepidus (Leske, 1785)	1	0.016	7.1
Poecilus punctulatus (Schaller, 1783)	2	0.031	7.1
Poecilus versicolor (Sturm, 1824)	304	2.028	64.3
Pterostichus anthracinus (Illiger, 1798)	161	1.032	50
Pterostichus diligens (Sturm, 1824)	2	0.011	7.1
Pterostichus gracilis (Dejean, 1828)	1	0.006	7.1
Pterostichus mannerheimii (Dejean, 1831)	316	1.633	35.7
Pterostichus minor (Gyllenhal, 1827)	37	0.179	50
Pterostichus melanarius (Illiger, 1798)	1104	6.211	92.8
Pterostichus niger (Schaller, 1783)	2070	10.36	100
Pterostichus nigrita (Paykull, 1790)	128	0.663	35.7
Pterostichus oblongopunctatus (Fabricius, 1787)	2007	12.935	100
Pterostichus rhaeticus Heer, 1837	18	0.119	14.2
Pterostichus strenuus (Panzer, 1796)	146	0.753	57.1
Pterostichus quadrifoveolatus Letzner, 1852	16	0.091	28.6
Pterostichus uralensis (Motschulsky, 1850)	9	0.041	7.1
Stomis pumicatus (Panzer, 1796)	4	0.014	7.1
Synuchus vivalis (Illiger, 1798)	9	0.063	50
Loricerinae			
Loricera pilicornis (Fabricius, 1775)	11	0.054	28.6
Nebriinae			
Leistus terminatus (Panzer, 1793)	11	0.048	21.4
Notiophilus aquaticus (Linnaeus, 1758)	1	0.004	7.1
Notiophilus germinyi Fauvel, 1863	7	0.030	14.2
Notiophilus palustris (Duftschmid, 1812)	56	0.243	57.1
Patrobinae			
Patrobus atrorufus (Strøm, 1768)	185	0.936	28.6
Scaritinae			
Clivina fossor (Linnaeus, 1758)	1	0.016	7.1
Trechinae			
Asaphidion flavipes (Linnaeus, 1761)	7	0.042	28.6
Bembidion biguttatum (Fabricius, 1779)	5	0.035	7.1
Bembidion guttula (Fabricius, 1792)	1	0.004	7.1
Bembidion fumigatum (Duftschmid, 1812)	1	0.006	7.1
Bembidion lampros (Herbst, 1784)	41	0.188	7.1
Bembidion mannerheimii C.R. Sahlberg, 1827	4	0.019	14.2
Bembidion properans (Stephens, 1828)	39	0.530	21.4
Trechus secalis (Paykull, 1790)	82	0.439	42.9
Total of trap-days	18830		
Total of individuals	18210		

The most numerous species (in terms of total number of more than 1000 specimens) were eight species: *Carabus cancellatus, Pterostichus niger, Pterostichus oblongopunctatus, Limodromus assimilis, Calosoma inquisitor, Carabus granulatus, Pterostichus melanarius*, *Carabus arvensis*. They accounted for 13,553 specimens (74.4%). Single specimens represented 21 species of ground beetles.

The dominant species (catchability from 5 to 20%) were seven species. These are the same numerous species except for *Carabus arvensis*, which was the subdominant species in broad-leaved forests (catchability from 3 to 5%). Seven species were classified as rare (recedents) (catchability from 1 to 3%). The greatest number of the ground beetle fauna was represented by incidental species (subrecedents) (catchability of less than 1%) – 89 species.

The basis of the ground beetle fauna consists of 25 species with a high occurrence (50% and higher). Among them, four species are characterized by 100% occurrence: *Carabus granulatus, Carabus hortensis, Pterostichus niger, Pterostichus oblongopunctatus; Carabus glabratus* and *Pterostichus melanarius* are very slightly inferior to them in occurrence.

4 Discussion

To understand the peculiarities of the ground beetle fauna in broad-leaved forests of Republic of Mordovia, it is advisable to consider it from the aspect of life forms. Adults of 104 species of ground beetles in broad-leaved forests Republic of Mordovia are represented by 12 groups of life forms from two classes – zoophagous and myxophytophagous. By feeding on various invertebrates, zoophages are the most important regulators of the number of forest soil mesofauna. Their dominance (both in terms of species abundance and dynamic density) is established in all broad-leaved forests of the region without exception. This trophic group accounts for 70.2% of the species and 95% of the numerical abundance of ground beetles in broad-leaved forests. In the study area, zoophages were represented by nine groups of life forms living mainly in the upper layers of the soil and on its surface. In general, the identified spectrum of life forms is typical for the zone of mixed and broad-leaved forests [18].

Among species with high abundance and occurrence, a notable place is occupied by zoophagous large walking epigeobionts, uniting the largest ground beetles, representatives of the genus *Carabus* and *Cychrus*. The species of this group mentioned above, which are characterized by 100% occurrence, have an optimum precisely in the zone of broad-leaved forests [19], although *Carabus granulatus* is widely distributed and inhabits a diverse spectrum of biotopes in the zone of broad-leaved forests. *C. glabratus*, which generally has an optimum in the zone of coniferous forests, turned out to be a recedent in broad-leaved forests with a high occurrence. Compared to the more western regions [20, 21], the high abundance of *C. cancellatus* and *C. arvensis*, species characteristic of drier and warmer biotopes, attracts attention. The largest ground beetle in the region, *C. coriaceus* is found in most broad-leaved forests, but it is not abundant. This species feeds mainly on terrestrial molluscs [19], and due to its size, it needs a structured space that would provide appropriate shelters (depressions in the microrelief, crevices in the butts of trees, cracks along the roots, etc.). Its low abundance may be due to both the dryness of the climate and the structural features of the forests. The low occurrence of *C. nemoralis*, which is undoubtedly of anthropogenic origin in this region, indicates that the studied broad-leaved forests are well preserved.

The high abundance of the zoophagous dendroepigeobiont *Calosoma inquisitor* attracts attention. In many regions of Russia, it is considered a rare species and it is included in the Red Books. Probably, it may very often be underestimated by soil traps, as it prefers to live in crowns and on tree trunks in broad-leaved forests for part of the year. At the same time, in terms of occurrence, it is a much more local species than the representatives of the genus *Carabus* mentioned above.

The second largest group of life forms, zoophagous litter and soil-dwelling stratobionts are characterized by the predominance of widespread species that can inhabit different types of forest: *P. niger, P. melanarius, P. oblongopunctatus* (the first two species can also inhabit many non-forest biotopes). A prominent place in the population of ground beetles in terms of occurrence and dynamic density is also occupied by *Poecilus versicolor*, which is generally more characteristic of open biotopes.

Among zoophagous litter-dwelling stratobionts, Limodromus assimilis occupies the first place in terms of occurrence and abundance. It is an unspecialized predator that inhabits various habitats with deciduous woody vegetation. Ground beetles specialized in feeding on molluscs (*Badister*), as well as consumers of springtails (*Leistus terminatus, Loricera pilicornis*) and other small objects (*Trechus secalis*) are much less numerous.

Zoophagous surface and litter-dwelling stratobionts are diverse in terms of number of species, however, none of the representatives of this group reached a high abundance and occurrence. *Notiophilus palustris* was the only constant species of this group for broad-

leaved forests. In part, this may be due to the underestimation of such small ground beetles by soil traps [22], and in part, to the biological characteristics of these species, which prefer to hunt in more sparse, predominantly moist areas of the soil surface.

Mixophytophages – ground beetles adapted to feeding mainly on plant foods – accounted for 29.8% of the species abundance and about 5% of the numerical abundance. A high percentage of the species abundance of mixophytophages at a low average dynamic density indicates insufficiently suitable conditions for living of ground beetles of this class in the forests. Only two species of this class, *Harpalus latus* and *H. laevipes*, are present in the vast majority of habitats. They are typical for the forests and in other regions [20, 21]. A relatively high occurrence is also characteristic of two typical inhabitants of open biotopes, *Harpalus rufipes* and *Amara communis*. It is partly explained by the good migratory abilities of these species, but in combination with their relatively high abundance in some biotopes, it indicates the anthropogenic pressure on these forests, which led to the formation of elements of an open landscape. Other mixophytophages, including numerous representatives of the genera *Harpalus* and *Amara*, can be considered as random species for broad-leaved forests that live in open biotopes and, due to their good migratory abilities, have a high chance of being observed in the forests.

Species with low occurrence and abundance can be divided into several groups. 1. Ground beetles that are poorly taken into account by soil traps, e.g., the zoophagous litter and bark-dwelling stratobiont *Dromius agilis* and the zoophagous geobiont *Clivina fossor*. 2. Species living in specific habitats that occupy a small area in broad-leaved forests and are not represented in every forest, or migrate from forest biotopes of other types. In particular, *Pterostichus anthracinus, P. nigrita, P. rhaeticus*, some representatives of the genus *Agonum, Limodromus krynickii* are confined to humid, often swampy, biotopes. *Microlestes maurus* lives in warm areas with exposed substrate. *Pterostichus quadrifoveolatus* is typical of fire-affected areas and may also be a migrant in broad-leaved forests. 3. Random species that are clearly characteristic of other types of habitats (for example, the above-mentioned mixophytophages, characteristic of open biotopes).

The peculiarity of the fauna of broad-leaved forests of Republic of Mordovia, in contrast to the more western regions of Russia [20, 21], is given by species located here on the western periphery of the range – the southern forest *Pterostichus uralensis* and the polyzonal *Pterostichus mannerheimii*. In general, for the east of the European part of Russia, they cannot be considered rare [23, 24], however, the relatively low abundance and occurrence of these species in broad-leaved forests of Mordovia indicates the need for a more thorough study of their ecology in this region. *Carabus schoenherri* also lives here on the western periphery of the range, but in different parts of the range, it is characterized as a meadow species or an inhabitant of coniferous and mixed forests [19], and its extremely low occurrence and dynamic density in the studied forests confirm the randomness of this species for broad-leaved forests.

Undoubtedly, a rare species, the find of which deserves attention, is *Carabus clathratus*, although it is difficult to attribute it to the typical inhabitants of broad-leaved forests. This species lives in open swampy areas along riverbanks, it is vulnerable in different parts of its range [19], and it is listed in the Red Books of many regions of the Russian Federation. In our localities, it was typical for broad-leaved forests situated in floodplains.

5 Conclusion

Overall, the ground beetle fauna of broad-leaved forests of Republic of Mordovia is typical of broad-leaved forests of the Russian Plain. Regional specificity is given to it by: the presence of relatively xero-thermophilic species in the composition of dominants and subdominants; the presence of some eastern species located on the western periphery of

their range. A significant part of ground beetles found in broad-leaved forests is random species living in open biotopes or in forests of other types. Despite some signs of anthropogenic transformation, the fauna of ground beetles in broad-leaved forests of Republic of Mordovia reflects the natural features of this region well.

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