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Diversity and Population Density of Ground Beetles (Coleoptera, Carabidae) in Pine Woodland Ecosystems

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ABSTRACT

The ground beetle fauna, including species of different ages and types, was studied in pine forests located in central Russia. The researchers identified fifty-two ground beetle species in 21 genera, with the genera *Carabus*, *Amara*, *Harpalus*, and *Pterostichus* having the highest species richness. Twenty-five species were observed in pine forests located near swampy areas characterized by moderate moisture, while only ten species were found in drier pine forests dominated by *Calamagrostis arundinacea* and *Convallaria majalis* in the understory vegetation. Ground beetle communities in wetter pine forests showed the highest values of the Shannon-Wiener index. Young pine forests had lower species diversity compared to older pine forests, although the Shannon-Wiener index was higher in younger stands, with lower dominance indices than in mature forests. *Pterostichus oblongopunctatus* emerged as the most abundant species in several forest areas.

Keywords: Ground beetle, Carabidae, Pine forests, Central Russia

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Introduction

Ground beetles (Carabidae, Coleoptera) represent one of the most diverse groups within Coleopterans and hold a crucial ecological role as entomophagous predators, helping control populations of terrestrial invertebrates. These beetles are regarded as economically beneficial because both their adult and larval stages contribute to the suppression of certain forestry and agricultural pests, thereby reducing their populations [1, 2]. They inhabit a wide range of biocenoses, including forests, steppes, agroecosystems, and urban environments [3-12]. Thanks to their diverse feeding strategies and adaptability (eurybiontism), ground beetles rank among the dominant organisms in terms of both abundance and biomass within these ecosystems [13-16]. However, many species are considered rare and are restricted to a limited number of biotopes [16-19].

Coniferous forests are found in a natural zone stretching between deciduous forests in the south and the tundra in the north. As the largest biome on Earth, they span vast areas of Eurasia and North America. The primary tree species forming these forests include *Picea*, *Abies sibirica* Ldb., *Pinus*, and *Larix sibirica* Ldb. In many regions, particularly in pine forests, coniferous ecosystems are pyrogenic in origin, developing on sites previously affected by wildfires [20]. In Russia, these forests dominate the taiga zone, covering approximately 70% of the country's total forested area. This region is characterized by low temperatures and high humidity levels. Over the past few decades, human activities have caused significant changes to coniferous forests [21-24]. Factors such as logging, pollution, habitat fragmentation, wildfires, climate aridization, and other environmental pressures have influenced the insect communities within these ecosystems [11, 12, 25-29]. Ground beetles, one of the most prominent families, thrive in a wide variety of forest types [30-34]. Studies comparing Carabidae communities in coniferous and deciduous forests have highlighted notable differences in species diversity, population density, and distribution patterns [35, 36]. The focus of our research was to analyze the species diversity and identify differences in the ground beetle fauna within pine forests.

Materials and Methods

Material was collected between April and August in the years 2009, 2012–2014, and 2018 using pitfall traps. These traps consisted of 0.5-liter cups filled with a four percent formalin solution. In each biocenosis, a total of 10 traps were set up in a single row, with a spacing of 2 to 3 meters between each.

Study area

Pine Forest number one (a pine forest dominated by *Pinus sylvestris, Tilia cordata*, and *Betula pendula*) features *Pinus sylvestris* L. as the primary tree species. The forest's second tier is distinctly marked, with species such as *Betula pendula* Roth, *Tilia cordata* Mill., and occasional *Picea abies* (L.) H. Karst present. The shrub layer includes *Euonymus verrucosus* Scop., *Acer platanoides* L., *Sorbus aucuparia* L., along with young *T. cordata* and *B. pendula* saplings. The herbaceous layer is diverse, featuring species like *Aegopodium podagraria* L., *Pteridium aquilinum* (L.) Kuhn, *Dryopteris carthusiana* (Vill.) H.P. Fuchs, *Convallaria majalis* L., *Glechoma hederacea* L., and various grasses. Soil moisture levels in this forest are relatively low.

Pine Forest Number 2 (a pine forest with well-defined moisture levels due to the proximity of a swamp) is dominated by *Pinus sylvestris*, with an undergrowth of *Alnus glutinosa* (L.) Gaertn., *Populus tremula* L., and *Betula pendula*. The shrub layer includes *Sorbus aucuparia*, *Frangula alnus*, and young *Picea abies*, as well as *Populus tremula*. In the herb layer, species such as *Impatiens noli-tangere* L., *Vaccinium myrtillus* L., *Urtica dioica* L., *Carex pilosa*, and *Athyrium filix-femina* (L.) Roth is present. This forest is classified as mesophytic, with a gradual transition towards hygrophytic conditions.

Pine Forest Number 3 (a pine forest with *Betula pendula*, *Pinus sylvestris*, *Tilia cordata*, and a well-developed herb layer) is characterized by the presence of *Tilia cordata* Mill. and *Betula pendula* in the second tier. The shrub layer is made up of *Euonymus verrucosus*, *Sorbus aucuparia*, and *Corylus avellana* L. The herb layer is clearly defined, with a variety of grasses, *Vaccinium vitis-idaea*, *Convallaria majalis*, *Impatiens noli-tangere*, and *Athyrium filix-femina*. The forest serves as a favorable environment for litter mineralization. It is classified as a mesophytic type, though humidity levels are lower compared to Pine Forest Number 2.

Pine Forest Number 4 (a pine forest with a dominant herb layer of *Convallaria majalis*) is primarily composed of *Pinus sylvestris*, with minimal presence of Betula pendula. The shrub layer includes *Sorbus aucuparia*, *Tilia cordata*, *Frangula alnus*, and young *Picea abies*. A notable characteristic of this forest type is the herb layer, where *Convallaria majalis* is the predominant species. Additionally, individual plants of *Polygontatum odoratum* (Mill.) Druce, *Pulsatilla patens* (L.) Mill., *Calamagrostis arundinacea*, *Geranium sanguineum* L., *Vaccinium vitis-idaea*, *Antennaria dioica* (L.) Gaertn., *Campanula rotundifolia* L., and *Viola canina* L. s. str. were also observed. This biotope is classified as xerophytic.

Pine Forest Number 5 is characterized by *Pinus sylvestris*, with a small proportion of *Betula pendula*. The shrub layer is sparse, consisting mainly of *Sorbus aucuparia* and *Frangula alnus*. The grass-shrub layer is well-developed. The distinguishing characteristic of this forest type is the herb layer, where a significant portion is made up of *Calamagrostis arundinacea*. Other species present include *Vaccinium vitis-idaea*, *V. myrtillus*, *Antennaria dioica*, *Rubus saxatilis*, and *Viola rupestris*. The biotope is classified as xerophytic.

Pine Forest Number 6 is dominated by *Pinus sylvestris*, mixed with *Betula pendula*. The second tier includes *Tilia cordata*, with some *Quercus robur* and *Populus tremula*. The shrub layer features *Sorbus aucuparia*, *Frangula alnus*, and *Acer platanoides*. The distinguishing characteristic of this forest type is the herb layer, where *Carex pilosa* Scop. is a dominant species. Other plants found in this tier include *Mercurialis perennis*, *Asarum europaeum*, *Pulmonaria obscura*, *Rubus saxatilis*, *Convallaria majalis*, and *Viola rupestris*. This biotope is also considered xerophytic.

Several study sites were established in pine forests of varying ages. Young pine forests (Pine Forest Number 7), aged 25-35 years, featured dense stands of trees planted by humans. The shrub and herb layers were typically underdeveloped, and grass growth was minimal due to the large accumulation of needles from the young pine trees. Pine forests over seventy years old (Pine Forest Number 8) were distinguished by a clearly defined second tier, including species such as *Euonymus verrucosus*, *Sorbus aucuparia*, *Frangula alnus* Mill., and occasionally young *Betula pendula* and *Tilia cordata*. The herb layer was well-developed, consisting of various grasses, *Convallaria majalis*, *Pteridium aquilinum*, and other herbaceous plants. Soil moisture levels were moderate across all sites.

Data analysis

Diversity within the ecosystems was assessed using the Shannon-Wiener index (H'), which treats abundant and rare species equally, and Simpson's index (1-D) which is responsive to changes in the composition of the most abundant species [37]. The uniformity of coleopteran species across the 5 sampling areas was evaluated using the Berger and Parker index. We carried out data processing in Microsoft Excel.

Researchers collected and analyzed approximately one thousand five hundred specimens during the study. To classify species based on their numerical abundance, the following categories were used: dominant species (those exceeding 5% in abundance), subdominant species (two percent to five percent), small species (one percent to two percent), and rare species (less than one percent). The dynamic density of beetles was calculated as the number of beetle specimens caught per one hundred traps per day.

In this study, the Carabidae system adopted was based on the Zoological Institute of the Russian Academy of Sciences website [38] and referenced the widely used catalog [39]. The nomenclature follows that of the Palearctic beetles catalog [40].

Results and Discussion

A total of fifty-two species of ground beetles from twenty-one genera were recorded, with the highest species diversity found in the genera *Harpalus*, *Amara*, *Pterostichus*, and *Carabus*. Species diversity varied across different pine forests **(Table 1)**. In pine forest number one, located near a swamp with moderate moisture, researchers collected 25 species. In contrast, only ten species were recorded in drier environments, such as pine forests number four and number six.

Table 1. Fauna and dynamic density (ex./100 trap-days) of species gathered from various pine forests (during May-June)

Species	Pine for-Est. number one	Pine for-Est. number two	Pine for-Est. number three	Pine for-Est. number four	Pine for-Est. number five	Pine for-Est. number six
Leistus terminatus			0.45			
Notiophilus aquaticus		0.74	0.45			
***Notiophilus germinyi* Fauvel**						0.87
Notiophilus palustris		0.37				
Loricera pilicornis			1.82			
Calosoma inquisitor	1.58			5.21		
Calosoma investigator					0.43	
Calosoma sycophanta	0.26					
***Carabus cancellatus* Illiger**					1.74	3.91
***Carabus coriaceus* Linnaeus**			0.91	0.43		0.87
***Carabus glabratus* Paykull**	3.42		1.82	0.43	2.17	2.61
***Carabus granulatus* Linnaeus**	9.47		12.27		3.04	22.17
***Carabus hortensis* Linnaeus**			2.73			
Cychrus caraboides			0.91			
***Elaphrus cupreus* Duftschmid**			0.45			

Trechus secalis	0.79			2.17	5.21	
Bembidion quadrimaculatum		0.37				
Patrobus assimilis Chaudoir		1.11				
Poecilus cupreus	1.05					
Poecilus lepidus	0.26	0.74				
Poecilus versicolor	0.26		0.45		0.43	
Pterostichus diligens			3.64			
Pterostichus melanarius	4.76		4.09			2.17
Pterostichus minor			2.27			
Pterostichus niger	1.32	0.37	12.73		0.43	9.13
Pterostichus nigrita		0.37	4.09			
Pterostichus oblongopunctatus	2.11	1.85	25.00	6.09	5.21	13.48
***Pterostichus rhaeticus* Heer**			7.73			
Pterostichus vernalis			1.82			
Calathus melanocephalus	0.53					
Calathus micropterus			1.82	2.61	3.48	
Limodromus assimilis			0.45			
***Agonum duftschmidi* Schmidt**			0.45			
Agonum fuliginosum	0.26		2.27			
Agonum obscurum			2.73	0.87	1.74	
Agonum sexpunctatum		0.37				
Synuchus vivalis					0.87	0.43
Amara bifrons		0.37				
Amara brunnea	0.53					
Amara communis	2.11					
Amara erratica		0.37				
Amara similata	0.26					
***Harpalus calathoides* Motschulsky**				0.43		
Harpalus latus	1.32				3.48	
Harpalus picipennis		1.11				
***Harpalus progrediens* Schauberger**		0.37				
Harpalus rubripes						0.43
Harpalus rufipes		0.74	0.45			
Harpalus tardus		0.37				
***Harpalus laevipes* Zetterstedt**			1.37	1.74	2.61	
Ophonus subquadratus				0.43		
Microlestes maurus		0.74				
Total number of exemplars	115	28	205	47	71	129
Shannon-Wiener index	2.26	2.61	2.53	1.88	2.32	1.66
1-D	0.16	0.09	0.13	0.19	0.11	0.25
Berger and Parker index	0.31	0.18	0.29	0.30	0.17	0.40
Number of species	17	16	25	10	13	10

The only species consistently found across all pine forest types was *Pterostichus oblongopunctatus*. *Carabus glabratus* and *Pterostichus niger* appeared in four out of five biotopes. The ground beetle communities of pine forest number two and pine forest number three exhibited the highest Shannon-Wiener index values. In addition to the common pine forest species, we also observed species associated with moist biotopes. It is known that a rise in the Simpson index and Berger-Parker index indicates reduced community diversity and greater dominance by certain species [41]. According to **Table 1**, the highest values for these indices were recorded in the ground beetle communities of pine forest number 6, pine forest number 4, and pine forest number 1. Dominant species in these communities included *Carabus granulatus*, *Pterostichus niger*, and *Pterostichus oblongopunctatus* in the first community, *Calosoma inquisitor* and *Pterostichus oblongopunctatus* in the second, and *Carabus granulatus* in the third **(Table 2)**.

Table 2. Fauna and dynamic density (ex./100 trap-days) of species gathered from pine forests of varying ages (young and mature)

Species	Pine forest number 7	Pine forest number 8
Notiophilus aquaticus	0.07	0.49
Carabus arcensis **Herbst**	3.95	3.24
Carabus cancellatus **Illiger**	0.26	
Carabus convexus **Fabricius**	0.07	0.20
Carabus coriaceus **Linnaeus**	0.39	0.10
Carabus hortensis **Linnaeus**	0.99	0.88
Carabus glabratus **Paykull**	0.53	1.18
Carabus granulatus **Linnaeus**		0.10
Cychrus caraboides	0.13	
Elaphrus cupreus **Duftschmid**		0.20
Poecilus cupreus	0.53	0.49
Poecilus lepidus	0.07	
Poecilus versicolor	0.26	0.20
Pterostichus anthracinus	0.39	0.78
Pterostichus gracilis		0.10
Pterostichus melanarius	0.86	0.10
Pterostichus minor	0.53	0.78
Pterostichus oblongopunctatus	8.03	28.04
Pterostichus nigrita	0.66	0.29
Pterostichus niger	0.20	0.10
Pterostichus strenuus	0.07	0.78
Pterostichus quadrifoveolatus **Letznner**	0.33	0.59
Calathus micropterus	1.64	3.53
Agonum gracilipes		0.20
Agonum lugens		0.78
Agonum obscurum	0.39	
Agonum sexpunctatum		0.20
Synuchus vivalis		0.10
Amara aenea	0.07	
Amara communis	0.07	
Amara familiaris		0.10
Amara ovata		0.20

Amara similata	0.13	
Amara tibialis		0.29
Anisodactylus binotatus		0.10
Anisodactylus nemorivagus	0.13	0.10
Harpalus latus	0.53	0.78
***Harpalus laevipes* Zetterstedt**	0.79	1.37
***Harpalus progrediens* Schauberger**		0.20
Harpalus rubripes	0.07	0.10
Harpalus rufipes		0.20
***Harpalus xanthopus winkleri* Schauberger**	0.13	
Panagaeus bipustulatus		0.10
Chlaenius tristis		0.10
Licinus depressus	0.07	
Badister bullatus	0.13	
***Badister lacertosus* Sturm**	0.13	0.49
Microlestes minutulus		0.10
Total number of exemplars	343	486
Shannon-Wiener index	2.43	1.90
1-D	0.17	0.36
Berger and Parker index	0.34	0.54
Number of species	33	39

Conclusion

The diversity of ground beetle species was reduced in young pine forests (pine forest number seven) compared to older ones (pine forest number eight). However, the Shannon-Wiener index was higher in the young forests, with lower dominance indices in comparison to the older forests. This suggests that young pine forests do not have a special dominant species in their ground beetle communities. *Pterostichus oblongopunctatus* was the most prevalent species in both forest types, with a numerical abundance of 57.8% in the older forests and 34.1% in the younger forests. This species is a trans-Palaearctic, non-moral species with spring reproduction, mesophilic, burrowing, and found in temperate zone forests [12, 42-45]. *Calathus micropterus* and *Carabus arcensis* were subdominant in the older forests, while *Carabus arcensis* was subdominant in the younger forests, and *Calathus micropterus* was categorized as a small species (its abundance in young forests was half that of older forests). The abundance of *Carabus arcensis* was nearly the same in both forest types. This trans-arctic forest species with spring breeding is found in various habitats, though its abundance has decreased in many areas [46]. In Central Russia's pine forests, it remains relatively common. The ground beetle fauna of the studied pine forests shows a typical species composition, with certain differences across various biotopes, suggesting that some species groups might have special habitat preferences, particularly for mesophytic and hygrophytic environments. Both species abundance and ground beetle numbers were lower in forests with higher xerophytization compared to those in mesophytic biotopes. *Pterostichus oblongopunctatus* was the most widespread species and a dominant presence in some forest masses. The observed differences in species diversity, dominance, and the range of dominant species across pine forests of different ages are significant.

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