GROUND BEETLE (COLEOPTERA, CARABIDAE) DIVERSITY ASSESSMENT IN THE PEAT BOG OF THE STATE HYDROLOGICAL SANCTUARY «BOLOTO MOKH» (BELARUS)

Gennadi G. Sushko

Vitebsk State University named after P.M. Masherov, Belarus
e-mail: gennadisu@tut.by

Received: 19.02.2025. Revised: 21.04.2025. Accepted: 22.04.2025.

Peat bog ecosystems play an important role in biodiversity conservation in the light of current climate changes. They provide appropriate environmental conditions, such as a high water table and acidity, low mineral nutrient content, and specific microclimate characteristics, for cold-adapted plants and animals in the temperate zone of Europe. The very specific environment of peat bogs determines their highly specialised biota. Beetles of the family Carabidae (hereinafter – ground beetles) are among the most numerous inhabitants of terrestrial ecosystems. They are a suitable object for assessing of the diversity patterns. It was suggested that one of the largest protected peatlands in Belarus, which forms the core of the state hydrological sanctuary «Boloto Mokh», reflects the main features of insect biodiversity of peat bogs due to its low disturbance. Using the pitfall trapping method, in six of the most typical peat bog habitats 28 ground beetle species were recorded. The Shannon (H' = 0.26–1.15) and Pielou (J' = 0.33–0.66) index values showed low diversity and evenness in ground beetle assemblages. The significantly ($p < 0.05$) higher diversity was in lagg habitats, whereas the lowest diversity was in hummocks and dome. The Non-metric Multi Dimensional Scaling showed a clear separation of species composition among the ground beetle assemblages of lagg, hummocks, pine bogs, and dome. The diversity parameters of the ground beetle assemblages of the studied peatland are comparable with those in other insect taxa. A similar species composition and low diversity of ground beetle assemblages have also been identified in other European countries. The state hydrological sanctuary «Boloto Mokh» does not contain traces of previous fires, which is also confirmed by the species composition of ground beetles. Therefore, the presented study confirms the high importance of the state hydrological sanctuary «Boloto Mokh» for diversity conservation of unique natural tundra ecosystems in Eastern Europe. The present research of ground beetle diversity of a large intact and protected peat bog, including all main habitat types, can be a starting point for comparative analysis of ground beetle assemblages in various regions of peatland distribution. Moreover, these results are important for assessing the variability of ground beetle assemblages under anthropogenic disturbance, since in many European countries pristine peat bogs that can be used as reference ones are extremely rare nowadays.

Key words: abundance, carabids, peatland, Protected Area, species composition, species richness

Introduction

Beetles of the family Carabidae (hereinafter – ground beetles) are one of the most diverse and numerous taxa in terrestrial ecosystems. Ground beetles are an important functional component of ecosystems, since most species are epigeic predators in food chains and can regulate the number of other invertebrates, including plant pests. Therefore, ground beetles are often used in large-scale ecological and faunistic studies. The study of ground beetles plays an important role in assessing biodiversity and monitoring the ecological state of Protected Areas (Aleksandrowicz, 2014; Ruchin et al., 2016, 2019; Brigić et al., 2017; Lehmitz et al., 2020; Atutova, 2023; Egorov et al., 2024). In this regard, the knowledge of the composition of ground beetle communities is of particular interest in large protected peat bogs of Eastern Europe, which are tundra patches in climate conditions of the temperate zone.

The *Sphagnum* carpet and shrub layer form a specific environment for epigeic invertebrates. *Sphagnum* mosses and peat layers maintain strong acidity and high water tables. Shrubs prevent warming of the soil surface and provide various microclimate conditions depending on the degree of their coverage. The average temperature within a peat bog can be from 5°C to 8°C lower than the temperature outside the bog (Spitzer & Danks, 2006). As it was shown in studies carried out in England, Germany, Poland, the Czech Republic, the Baltic countries, and Russia, such extreme environmental conditions have caused a low species richness and abundance of ground beetles in peat bogs (Maavara, 1957; Mossakowski, 1977; Butterfield & Coulson, 1983; Spitzer et al., 1999;

Mossakowski et al., 2003; Browarski, 2005; Philippov et al., 2021).

Previous studies were mainly faunistic and provided insight into the ground beetle species composition in a limited number of habitats. In particular, in the Czech Republic intact peat bogs occupy small areas (several hundred hectares). As a consequence, the results of studies demonstrated the ground beetle species composition only in two main habitat types (Spitzer et al., 1999; Bezděk et al., 2006). Peat bogs of England, Poland and Germany have been heavily damaged by cultivation and peat extraction. Therefore, the study of ground beetles was conducted in remnants of peat bogs (Butterfield & Coulson, 1983; Mossakowski et al., 2003; Browarski, 2005; Buchholz et al., 2009). In the Kaliningrad Region (Russia), studies of beetles, including ground beetles, were also carried out in small natural sites of degraded peat bogs (e.g. Främbs et al., 2002; Alekseev et al., 2024). Other studies of ground beetles in peat bogs in Russia are presented mainly by faunistic reviews (Philippov & Pestov, 2014; Philippov et al., 2021; Sazhnev & Prokin, 2021). Hence, detailed studies of peat bog ground beetle assemblages, covering the entire range of habitats and characterising alpha and beta diversity patterns, are currently limited. While such studies are needed for comparative analysis of variability of ground beetle assemblages in both pristine and degraded peat bogs. Ground beetles are closely associated with the *Sphagnum* cover, which is the main builder of peatland habitats, and they can reflect the changes occurring here. Therefore, research is needed to characterise their diversity parameters in a reference, an intact peat bog that includes the main typical habitats. The most suitable territories for such studies may be Protected Areas.

Nowadays, the large protected peat bogs of Belarus play an important role in the international conservation of species. They are habitats for many rare and threatened species of animals and plants and play a central role as migration and wintering sites of many bird species of global conservation concern. Of them, there are *Gavia arctica* Linnaeus, 1758, *Lagopus muta* (Montin, 1781), *Numenius arquata* (Linnaeus, 1758), *Clossiana frigga* (Beclin in Thunberg, 1791), *Oeneis jutta* Hübner, 1806 (see Kozulin, 2005). The study of insect diversity of peat bogs in Belarus was started relatively recently. In particular, the first review of Coleoptera species, including ground beetles, was published in 2006 (Sushko, 2006). It should be noted that the main focus in many studies was on the peat bog «Yelnya», since it is the largest wetland in Belarus, occupying 253 km^2 (Sushko, 2012, 2014). A large part of the peat bog «Yelnya» burned down in 2005. However, there are other large peat bogs in Belarus, which are less disturbed, including the state hydrological sanctuary «Boloto Mokh». The core of the state hydrological sanctuary «Boloto Mokh» is a large peat bog surrounded by coniferous and deciduous forests. As in other peat bogs, tundra and taiga vegetation predominates here. In the state hydrological sanctuary «Boloto Mokh», species listed in the Red Data Book of the Republic of Belarus (Kachanovsky et al., 2015), such as plants *Vaccinium microcarpum* (Turcz. ex Rupr.) Schmalh., *Rubus chamaemorus* L., *Gladiolus imbricatus* L., *Huperzia selago* (L.) Bernh. ex Schrank & Mart., *Allium ursinum* L., and birds *Clanga clanga* (Pallas, 1811), *Ciconia nigra* (Linnaeus, 1758), *Pandion haliaetus* (Linnaeus, 1758), and *Asio flammeus* (Pontoppidan, 1763) were found (Kozulin, 2005). Therefore, the state hydrological sanctuary «Boloto Mokh» is an important object for the conservation of unique biodiversity of postglacial genesis, which has preserved populations of many cold-adapted boreal and subarctic species. This is especially important in the light of climate change. The aim of the presented study is to assess the diversity patterns and species composition of ground beetles inhabiting the main habitats of a large intact reference peat bog on the territory of the state hydrological sanctuary «Boloto Mokh» in Belarus.

Material and Methods

The state hydrological sanctuary «Boloto Mokh» (55.622587° N, 22.478365° E) is located in the northwest of Belarus within the region Belarusian Lake District, where the Eurasian coniferous forest zone closely approaches the European broad-leaved zone (Fig. 1). The study area is characterised by a temperate continental climate. The mean annual temperature is 6°C. The mean temperature of the coldest month (January) is -5.7°C and +18°C for the warmest month (July). The annual mean precipitation is 650 mm (Yakushko, 1971; Zeliankevich et al., 2016). The peat bog that occupies the main part of the state hydrological sanctuary «Boloto Mokh» is one of the oldest in Belarus since it began to form in the Younger Dryas (about 11 000 years ago) after the last glacial period (Zeliankevich et al., 2016). The area of the peat bog is 43 km^2. The peat deposit can be as deep as 4 m. Two rivers flow through the peat bog (Kozulin, 2005).

The studies were conducted in 2019–2023 in six of the most characteristic peat bog habitats: the lagg zone (Lag), pine bog (PB), open bog (OB), hummock (HM), hollow (HL), and dome (DM). The lagg zone is located at the bog margin. These are open sites with a constantly high water level. The dominant plants are *Eriophorum vaginatum* L., *Carex* spp., *Vaccinium oxycoccos* L., and *Andromeda polifolia* L. (plant community: *Eriophorum vaginatum – Sphagnum angustifolium*) (Fig. 2A).

Pine bog is widespread on the slopes of peat bogs. Such sites are covered with short sparse pine (*Pinus sylvestris* L.) trees. The water level is lower compared to the lagg. The herb-shrub layer is well developed, in which plants such as *Eriophorum vaginatum*, *Rhododendron tomentosum* Harmaja, *Chamaedaphne calyculata* (L.) Moench, *Empetrum nigrum* L. and *Calluna vulgaris* L. Hull are most common (plant community: *Pinus sylvestris – Eriophorum vaginatum – Rhododendron tomentosum – Sphagnum magellanicum + S. angustifolium*) (Fig. 2B).

Open treeless sites are also common on the peat slope. In the herb-shrub layer, *Eriophorum vaginatum*, *Andromeda polifolia*, *Rhododendron tomentosum*, *Chamaedaphne calyculata* and *Vaccinium oxycoccos* occur most often (plant community: *Eriophorum vaginatum – Rhododendron tomentosum – Chamaedaphne calyculata – Sphagnum magellanicum*) (Fig. 2C).

The hollow-hummock complexes are represented by a mosaic of elevated and relatively dry hummocks of various size (diameter: 20–100 cm; height: 15–50 cm) and permanently wet depressions. The hummocks are covered mainly with *Eriophorum vaginatum*, *Andromeda polifolia*, *Rhododendron tomentosum*, *Chamaedaphne calyculata* and *Vaccinium oxycoccos* (plant community: *Eriophorum vaginatum – Vaccinium oxycoccos + Andromeda polifolia + Rhododendron tomentosum – Sphagnum magellanicum + S. angustifolium + S. fuscum*) (Fig. 2D). In hollows, *Rhynchospora alba* (L.) Vahl and *Scheuchzeria palustris* L. were most often found (plant community: *Rhynchospora alba – Sphagnum cuspidatum*) (Fig. 2E).

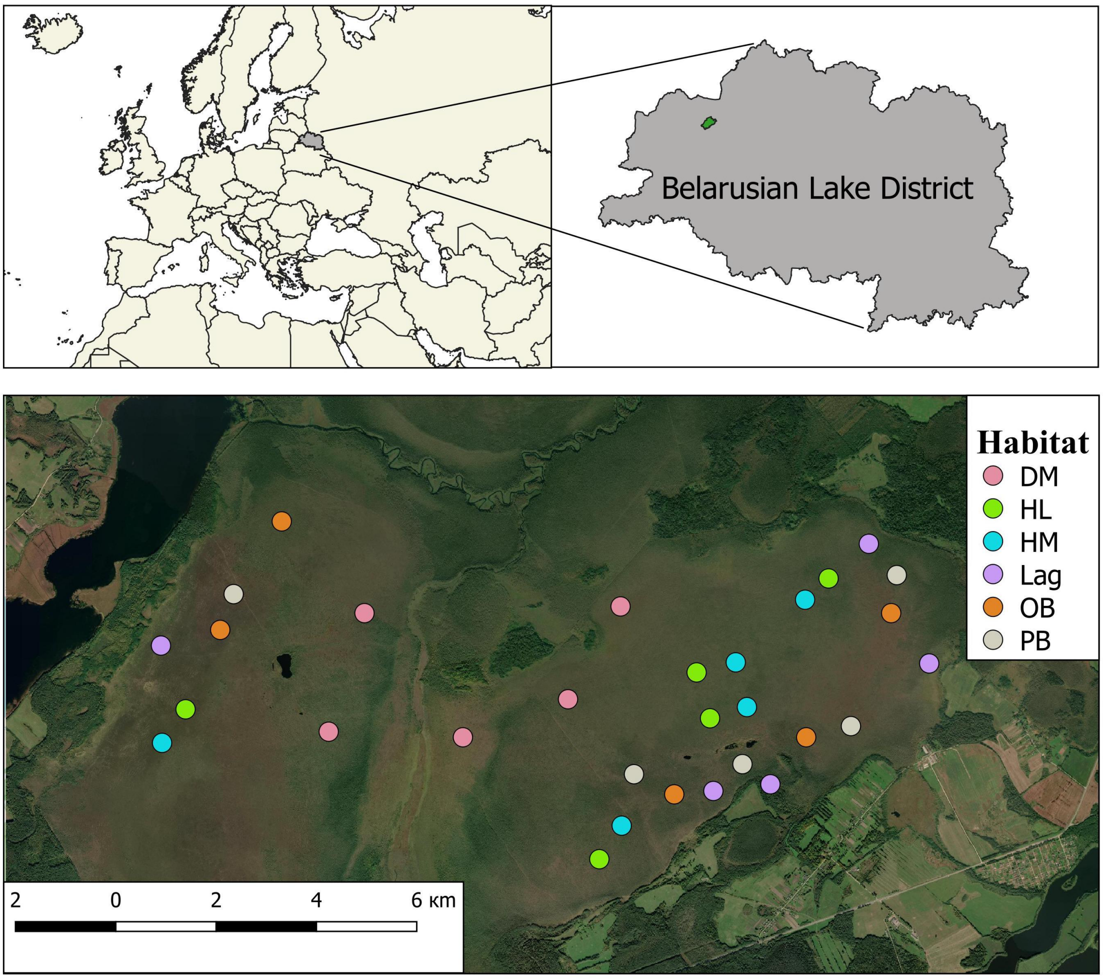

Fig. 1. Location of state hydrological sanctuary «Boloto Mokh», Belarus. Habitat abbreviations: DM – dome, HL – hollow, HM – hummock, Lag – lagg zone, OB – open bog, PB – pine bog.

Fig. 2. Study habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: A – lagg zone, B – pine bog, C – open bog, D – hummock, E – hollow, F – dome.

The peat bog dome is the driest ombrotrophic area, where water comes mainly from precipitation. The most common plants of the dome were *Calluna vulgaris*, *Rhododendron tomentosum*, *Chamaedaphne calyculata* and *Eriophorum vaginatum* (plant community: *Eriophorum vaginatum – Calluna vulgaris – Sphagnum fuscum*) (Fig. 2F).

Ground beetles were collected using pitfall traps. The traps were plastic cups (250 cm^3) filled with a 4% formalin solution. At each of the six habitat types, we selected five sampling sites annually in various parts of the state hydrological sanctuary «Boloto Mokh». Ten pitfall traps were placed on each site. Accordingly, a total of five replications in each of the habitat type were used. To reduce the spatial autocorrelation probability, the sampling sites were selected randomly at a distance of at least 50 m from each other. Ground beetles were caught from late April to early November. The traps were checked at 10–14 day intervals. Ground beetles were identified to the species level according to Freude et al. (2004). The list of species is based on the catalogue of Aleksandrowicz et al. (2023). The collected material is stored at the Department of Ecology and Geography of the Vitebsk State University named after P.M. Masherov.

The differences among the alpha-diversity metrics such as species richness, abundances (number of individuals in samples), Shannon and Pielou indexes were tested using Kruskal-Wallis test with Dunn’s post hoc test (Magurran, 2004). Prior to analyses, the data were tested using Shapiro-Wilk's test and normality distribution not detected. Calculations using PAST 4.16c (Hammer et al., 2001) were carried out.

To estimate the true ground beetle species richness and diversity in studied peat bog sample-size-based rarefaction and extrapolation curves based on Hill numbers were constructed using iNEXT.4steps package (Chao, 2024). The first Hill number (q0) describes the species richness. Other Hill numbers according modified diversity indexes: q1 is the exponential term of the Shannon index, q2 is the inverse of the Simpson index (1-D). Curves based on abundance data matrix were constructed with 95% confidence intervals (shaded regions), which were obtained by a bootstrap method based on 100 replications (Chao et al., 2014). Abundance models were constructed using PAST 4.16c (Hammer et al., 2001). These models demonstrated species abundances in descending rank order on a linear scale.

Permutational Analysis of Variance (PERMANOVA) was applied to estimating of differences in ground beetle species composition in all studied habitats (beta-diversity). An analysis was conducted using the Bray-Curtis dissimilarity measure with 999 permutations in the «vegan» R package (Oksanen et al., 2019). For visualisation of differences in species composition, non-metric multidimensional scaling (NMDS) was applied based on Bray-Curtis distance. The abundance of species (number of individuals in samples) were log(x + 1) transformed prior to multivariate ordination analysis (Legendre & Gallagher, 2001). The most characteristic species for studied habitat types were identified using the indicator value procedure (IndVal) with «indicspecies» R package (De Cáceres & Legendre, 2009). Indicator values range from 0 (no indication) to 1 (perfect indicator value) with statistical significance $p < 0.05$. The calculations were performed using the R ver. 4.1.0 programming environment (R Core Team, 2020).

Results

A total of 3975 ground beetle specimens belonging to 19 genera and 28 species were recorded (Table 1). The observed number of species varied from five to 17 in the studied habitats. The mean species richness differed significantly ($\chi^2 = 20.74$, $p < 0.001$) among the study sites. The significantly ($p < 0.05$) highest species richness of ground beetle assemblages was in lagg, pine bog and dome. While in the hummock-hollow complex and on other open sites in the bog slope, as showed the post-hoc test, the number of species was the lowest and did not differ significantly ($p > 0.05$) among ground beetle assemblages of these habitats (Fig. 3). Asymptotic estimates using Hill number q0 were applied for identifying potentially undetected species. The rarefaction and extrapolation accumulation curves for hummocks and hollows reached the asymptote. Therefore, finding other species here is unlikely. For other habitats, accumulation curves do not stay at a fixed level suggesting the possibility of revealing other species (Fig. 4). The observed number of ground beetle species varied between 70.83% and 85.71% of the estimated species richness (Table 1). This indicates a sufficient sample effort.

The mean abundance of ground beetles differed significantly ($\chi^2 = 14.67$, $p = 0.005$) among the assemblages of the six studied habitat types (Table 1). The significantly ($p < 0.05$) highest abundance was in dome and pine bogs. However, among ground beetle assemblages of hummock, hollow and other open sites, where abundance was lower, the mean number of individuals did not differ significantly ($p > 0.05$) (Fig. 5). The abundance distribution curves (Fig. 6) reflect a rapid decrease in species abundances by rank, which corresponds to highly uneven communities with low diversity and the dominance of a few of the most adapted species such as *Agonum ericeti* (Panzer, 1809), *Pterostichus diligens* (Sturm, 1824), and *P. rhaeticus* Heer, 1837.

Table 1. The diversity metrics of ground beetle (Carabidae) assemblages in peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus

Diversity metrics	Habitats					
	Lagg	Pine bogs	Open bogs	Hummocks	Hollows	Dome
Total number of observed species	17	12	6	6	5	10
Mean number of species in samples	9 ± 0.68	6 ± 0.37	4 ± 0.20	4 ± 0.68	4 ± 0.40	5 ± 0.68
Estimates number of species (proportion of the observed number of species, %)	24 (70.83%)	21 (80.95%)	8 (75.00%)	7 (85.71%)	6 (83.33%)	14 (71.42%)
Mean number of individuals in samples	113 ± 7.97	161 ± 24.65	90 ± 9.65	101 ± 10.71	133 ± 14.43	195 ± 10.16
Mean Shannon diversity index values (H')	1.15 ± 0.06	0.73 ± 0.07	0.90 ± 0.04	0.26 ± 0.05	0.54 ± 0.04	0.49 ± 0.02
Mean Pielou evenness index values (J')	0.35 ± 0.03	0.34 ± 0.02	0.66 ± 0.05	0.42 ± 0.07	0.49 ± 0.03	0.33 ± 0.06

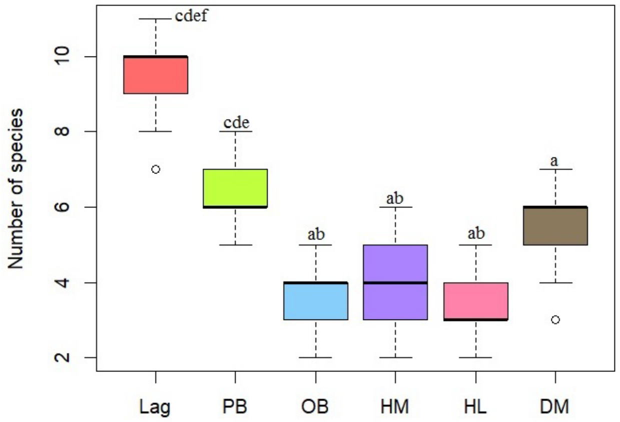

Fig. 3. Mean values (± standard error) of ground beetle (Carabidae) species richness in the peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: Lag (a) – lagg zone, PB (b) – pine bogs, OB (c) – open bogs, HM (d) – hummocks, HL – hollows (e), DM – dome (f). Pairwise comparisons based on Kruskal-Wallis test with Dunn's post hoc test; different letters corresponding to sites denote significant pairwise differences among studied sites of $p < 0.05$.

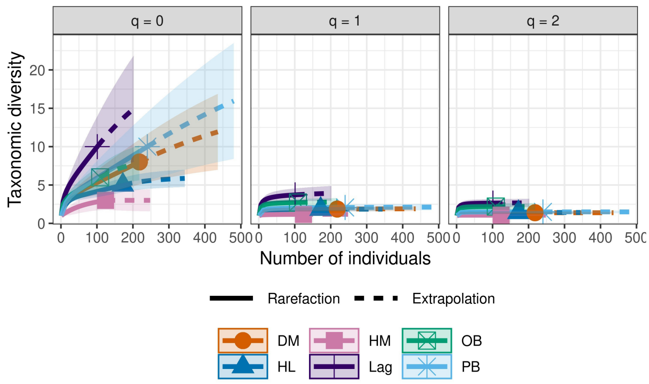

Fig. 4. Estimated diversity based on Hill numbers in ground beetle assemblages in the peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: Lag – lagg zone, PB – pine bogs, OB – open bogs, HM – hummocks, HL – hollows, DM – dome.

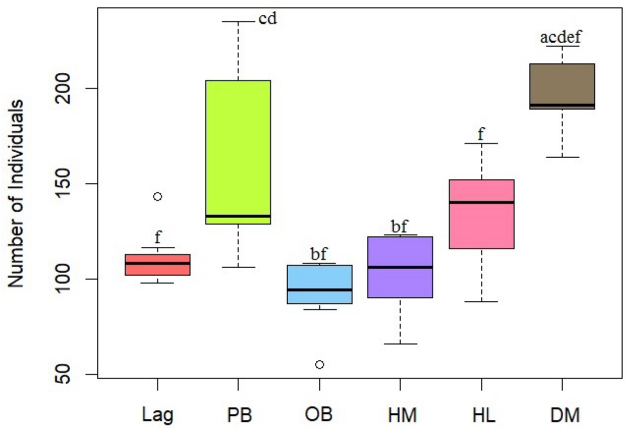

Fig. 5. Mean values (± standard error) of ground beetle (Carabidae) abundance in the peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: Lag (a) – lagg zone, PB (b) – pine bogs, OB (c) – open bogs, HM (d) – hummocks, HL – hollows (e), DM – dome (f). Pairwise comparisons based on Kruskal-Wallis test with Dunn's post hoc test; different letters corresponding to sites denote significant pairwise differences among studied sites of $p < 0.05$.

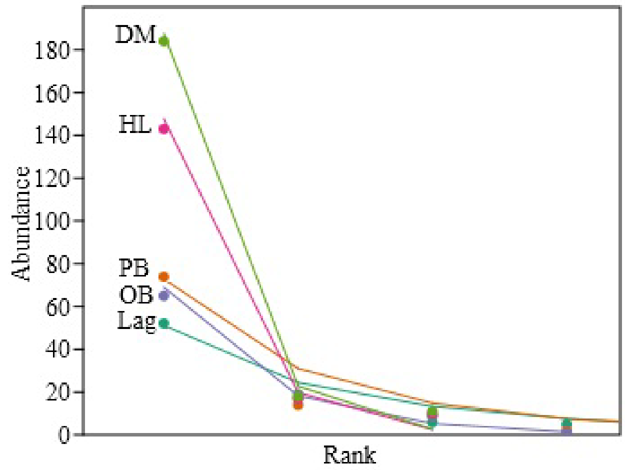

Fig. 6. Abundance distribution models in ground beetle (Carabidae) assemblages in the peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: Lag – lagg zone, PB – pine bogs, OB – open bogs, HM – hummocks, HL – hollows, DM – dome.

The Shannon diversity index differed significantly ($\chi^2 = 25.68$, $p < 0.0001$) and was the highest ($p < 0.05$) in lagg compared to other habitats (Table 1). The lowest mean Shannon index value was in ground beetle assemblages in hummocks and dome (Fig. 7). The studied ground beetle assemblages were characterised by a low level of evenness by abundance based on Pielou index values (Fig. 8). The highest evenness of ground beetle assemblages was detected in open bogs. The low evenness of ground beetle assemblages is caused by the dominance of only a few species in each habitat. Three species, namely *Agonum ericeti* (64.97–95.07% of all collected individuals), *Pterostichus diligens* (3.35–24.17%), and *P. rhaeticus* (0.59–9.76%), were the most abundant in all habitats (Table 2).

Calculated diversity metrics were estimated using Hill numbers such as exponential Shannon's index (Hill number q1) and inverse Simpson index (Hill number q2). Constructed rarefaction and extrapolation accumulation curves based on q1 and q2 for all habitats reached the asymptote. Therefore, the main patterns of diversity in ground beetle assemblages have been identified and presented results satisfactorily to infer true ground beetle diversity (Fig. 4).

Based on PERMANOVA tests, the species composition of ground beetles differed significantly ($F = 8.86$, $p = 0.0001$) among habitat types of the studied peat bog. The NMDS ordination (Fig. 9), showed the clearest separation of species composition among the ground beetle assemblages in lagg, hummocks, pine bogs, and dome. On the other hand, a high similarity was found among species composition in open bogs hollows and dome. Five species that provide the highest differentiation in ground beetle assemblages of studied habitats were identified (IndVal = 0.26–0.80, $p < 0.05$) (Table 3). *Carabus hortensis* Linnaeus, 1758, *Poecilus cupreus* Linnaeus, 1758 and *Pterostichus niger* (Schaller, 1783) were more associated with lagg habitats at the border of the peat bog. *Cychris caraboides* Linnaeus, 1758 was associated with pine bog habitats. *Pterostichus diligens* preferred open bogs, which are less wet. The stenotopic peat bog species *Agonum ericeti* was most associated with dome. Other species were characterised by a low indicator importance.

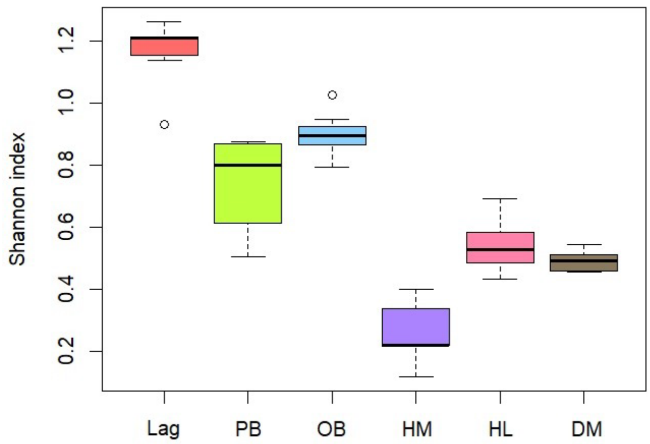

Fig. 7. Mean values (± standard error) of Shannon diversity index in ground beetle (Carabidae) assemblages in the peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: Lag – lagg zone, PB – pine bogs, OB – open bogs, HM – hummocks, HL – hollows, DM – dome.

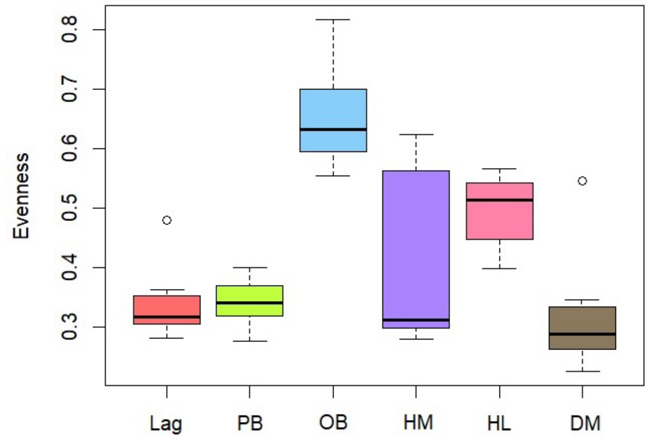

Fig. 8. Mean values (± standard error) of Pielou evenness index in ground beetle (Carabidae) assemblages in the peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: Lag – lagg zone, PB – pine bogs, OB – open bogs, HM – hummocks, HL – hollows, DM – dome.

Table 2. Relative abundance (%) of ground beetle (Carabidae) species collected in habitats in the peat bog in the state hydrological sanctuary «Boloto Mokh», Belarus

Species	Lagg	Pine bogs	Open bogs	Hummocks	Hollows	Dome
Leistus ferrugineus Linnaeus, 1758	–	–	–	–	–	0.10
Notiophilus palustris (Duftschmid, 1812)	–	–	0.22	0.39	0.15	–
Carabus arvensis Herbst, 1784	0.18	–	–	–	–	–
Carabus granulatus Linnaeus, 1758	0.53	0.25	–	–	–	–
Carabus menetriesi Hummel, 1827	0.18	0.12	–	–	–	–
Carabus hortensis Linnaeus, 1758	1.06	–	–	–	–	–
Carabus cancellatus Illiger, 1798	0.35	–	–	–	–	–
Cychris caraboides Linnaeus, 1758	0.53	0.87	–	–	–	–
Cicindela campestris Linnaeus, 1758	–	–	–	–	–	0.20
Loricera pilicornis (Fabricius, 1775)	–	–	–	–	–	0.10
Blethisa multipunctata (Linnaeus, 1758)	–	0.12	–	–	–	–
Asaphidion flavipes Linnaeus, 1761	0.35	–	–	–	–	–
Bembidion quadrimaculatum (Linnaeus, 1761)	–	–	0.22	–	–	–
Bembidion gutulla (Fabricius, 1792)	0.35	–	–	–	–	–
Anisodactylus binotatus (Fabricius, 1787)	0.18	–	–	–	–	–
Harpalus rufipes (Degeer, 1774)	0.53	–	–	–	–	–
Ophonus rufibarbis (Fabricius, 1792)	–	0.12	–	–	–	–
Bradycellus ruficollis (Stephens, 1828)	–	–	–	–	–	0.20
Lebia cruxminor (Linnaeus, 1758)	–	0.12	–	–	–	0.10
Agonum ericeti (Panzer, 1809)	67.55	81.04	64.75	95.07	85.16	88.25
Platynus assimilis (Paykull, 1790)	0.18	0.12	–	–	–	–
Poecilus cupreus Linnaeus, 1758	5.32	0.25	0.89	–	–	0.20
Pterostichus niger (Schaller, 1783)	0.71	0.25	–	0.20	–	–
Pterostichus rhaeticus Heer, 1837	6.74	6.07	9.76	0.59	7.95	5.41
Pterostichus diligens (Sturm, 1824)	15.07	10.54	24.17	3.35	6.45	5.01
Amara communis (Panzer, 1797)	0.18	–	–	–	0.30	–
Amara ovata (Fabricius, 1792)	–	–	–	0.39	–	–
Amara brunnea (Gyllenhal, 1810)	–	–	–	–	–	0.41

Table 3. Indicator values (IndVal) of ground beetle (Carabidae) species in assemblages of habitats in the peat bog (state hydrological sanctuary «Boloto Mokh», Belarus)

Species	Habitats	IndVal	p-value
Carabus hortensis	Lagg	0.80	0.003
Poecilus cupreus	Lagg	0.78	0.032
Cychris caraboides	Open bog	0.70	0.002
Pterostichus niger	Lagg	0.45	0.006
Pterostichus diligens	Pine bog	0.28	0.004
Agonum ericeti	Dome	0.26	0.032

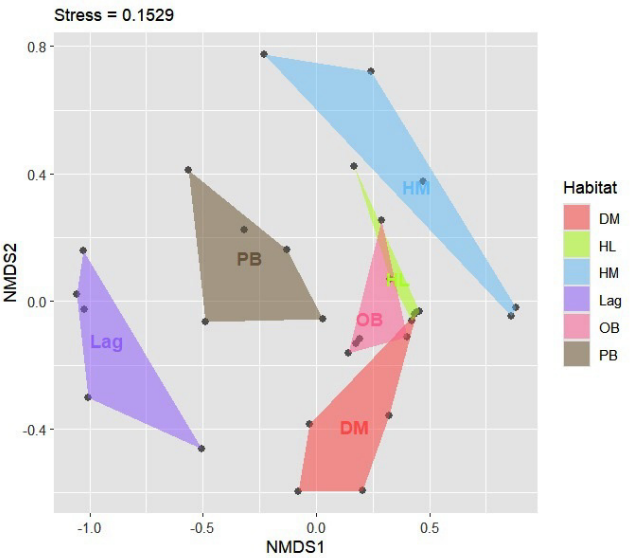

Fig. 9. Non-metric multidimensional scaling (NMDS) of ground beetle (Carabidae) assemblages in the peat bog habitats in the state hydrological sanctuary «Boloto Mokh», Belarus. Designations: Lag – lagg zone, PB – pine bogs, OB – open bogs, HM – hummocks, HL – hollows, DM – dome.

Discussion

The obtained results showed a poor diversity of ground beetles and a high abundance of several specialised hygrophilic species in various habitats of large intact peat bog in the state hydrological sanctuary «Boloto Mokh» (Belarus). Such insect diversity patterns including low diversity and assemblage evenness are typical for peat bogs in general. Similar diversity features were also found in other insect taxa. In particular, 2–3 species specialised on peat bogs were the most abundant among Lepidoptera, Hemiptera and Hymenoptera and other Coleoptera taxa (Maavara, 1957; Mossakowski, 1977; Spitzer & Danks, 2006; Sushko, 2016, 2017, 2022), including *Catoptria margaritella* (Denis & Schiffermuller, 1775), *Macaria carbonaria* (Clerck, 1759), *Vacciniina optilete* (Knoch, 1781) (Lepidoptera), *Cixius similis* Kirschbaum, 1868, *Cacopsylla ledi* (Flor, 1861), *Stephanitis oberti* (Kolenati, 1857) (Hemiptera), *Formica forsslundi* Lohmander, 1949, *F. uralensis* Ruzsky, 1895 (Hymenoptera). Several eurytopic and oligotopic species were also noted with high abundance, for instance, *Callophris rubi* (Linnaeus, 1758), *Plebeius argus* (Linnaeus, 1758), *Ematurga atomaria* (Linnaeus, 1758) (Lepidoptera), *Neophilaenus lineatus* (Linnaeus, 1758), *Lepyronia coleoptrata* (Linnaeus, 1758), *Lygus pratensis* (Linnaeus, 1758), *Cymus grandicolor* Hahn, 1833 (Hemiptera) (Mikkola & Spitzer, 1983; Spitzer & Danks, 2006; Sushko, 2017, 2022). Nevertheless, the insect assemblages of these taxa, as well as the ground beetle assemblages, were characterised by a low species diversity and evenness (Sushko, 2017, 2022). In contrast, in the pine forests in the vicinity of bogs, a higher diversity and evenness of species were revealed (Sushko et al., 2024).

On the other hand, in the *Sphagnum* carpet, among beetles of other families only one species, *Drusilla canaliculata* (Fabricius, 1787) (Staphylinidae), was found in high abundance (Sushko, 2014). Therefore, it can be assumed that for most insects (at least Ectognatha) the habitat conditions of the moss layer are less favourable compared to the herb-shrub and tree layers. It should also be noted that ground beetles were able to adapt to the extreme environmental conditions of the *Sphagnum* mat, such as high acidity, humidity and sudden temperature fluctuations (Främbs et al., 2002; Spitzer & Danks, 2006; Dapkus & Tamutis, 2008). Nevertheless, with the exception of a few species, most ground beetles were low in abundance in all studied habitats. Previous studies showed that among the environment variables driving peat bog ground beetle diversity were herb and scrub cover, pH, and the conductivity (salinity) of the *Sphagnum* mat water, while the water level was an important factor only for the hollow dwellers (Sushko, 2019). Therefore, abundant species such as *Agonum ericeti*, *Pterostichus diligens*, and *P. rhaeticus* were the most adapted to extreme habitat conditions. The relative abundance of these three species in all studied habitats varied from 89.36% to 99.56%.

Analysis of the ground beetle spatial distribution showed that the diversity, based on Shannon index values, was higher in lagg habitats at the peat bog border, where the proportion of forest and eurytopic species was higher, in particular, *Carabus hortensis*, *Poecilus cupreus* and *Pterostichus niger* (see Aleksandrowicz, 2014). With increasing distance from the peat bog boundary, the number of such species and abundance decreased. The lowest ground beetle diversity in hollow-hummock complexes can be explained by the constant stagnant moisture of the *Sphagnum* carpet (Sushko, 2019). The highest abundance was found in the dome ground beetle assemblages, which is apparently also related to moisture conditions. At the same time, the vast majority of individuals collected in the dome belonged to peat bog specialists. Species found only in the dome, such as *Leistus ferrugineus* Linnaeus, 1758, *Cicindela campestris* Linnaeus, 1758, *Loricera pilicornis* (Fabricius, 1775), *Bradycellus ruficollis* (Stephens, 1828), and *Amara brunnea* (Gyllenhal, 1810), associated with other habitats, are represented sporadically. These species were probably able to appear in the dome due to their high dispersal ability. Since, with the exception of *Leistus ferrugineus*, they are dimorphic or macropterous species. A similar trend was found in other large peatbogs in Belarus (Sushko, 2006, 2014). This indicates that the least humid domes are a suitable environment for not only specialised species. However, due to large distances, it is difficult for the imagoes of ground beetles to reach these habitats located in the peat bog centre. On the other hand, domes of the peat bog that are smaller in size were characterised by a higher diversity of ground beetles (Spitzer et al., 1999).

Despite the dominance of three specialised peat bog dwellers (*Agonum ericeti*, *Pterostichus diligens*, and *P. rhaeticus*) in all habitats, the species composition varied considerably. NMDS ordination showed the most distinct differences among the lagg, hollow and dome habitats, which indicates the highest differences in their environmental conditions.

Comparing the species composition of ground beetles of the studied peat bog with another, the largest in Belarus, «Yelnya» peat bog, some differences should be noted. Tyrphophilous species *Carabus clatratus* Linnaeus, 1760, *C. nitens* Linnaeus, 1758, and *Dicheirotrichus cognatus* (Gyllenhal, 1827) were not recorded. According to our observations, over the last decade *C. clatratus* has been rare in the peatlands of Belarus. *Dicheirotrichus cognatus* and *C. nitens* were found in «Yelnya» peat bog mainly in post-fire sites with high heather cover (Sushko, 2012, 2014). Such habitats are not typical in the state hydrological sanctuary «Boloto Mokh». The higher ground beetle species richness in the «Yelnya» sanctuary can be explained by the presence of large post-pyrogenic sites covered with *Betula pubescens* Ehrh., as well as various sized mineral forest islands within the peat bog. Like in other countries (e.g. Främbs et al., 2002; Spitzer & Danks, 2006; Dapkus & Tamutis, 2008; Sazhnev & Prokin, 2021), the primary ecological indicators of studied peat bog were the tyrphobiontic species *Agonum ericeti* and the tyrphophilous species *Pterostichus diligens* and *P. rhaeticus.*

Many studies of European peat bogs, conducted in Germany, the Czech Republic, the Baltic States, and Russia, showed low species richness of ground beetles (15–20 species), diversity and evenness of their assemblages, which is in accordance with our results. These also revealed that only a few ground beetle species dominated in peat bog habitats, such as *Agonum ericeti*, *Pterostichus diligens*, and *P. rhaeticus* (Mossakowski, 1977; Spitzer et al., 1999; Främbs et al., 2002; Mossakowski et al., 2003; Dapkus & Tamutis, 2008; Philippov & Pestov, 2014; Philippov et al., 2021). There are some differences in proportions of these species in assemblages. In particular, in Central Europe, a decrease in the abundance of *Agonum ericeti* was noted due to high degradation of habitats as a result of anthropogenic impact (Aleksandrowicz, 2002; Lehmitz et al., 2020).

Among recorded ground beetles protected in Belarus species was *Carabus menetriesi* (VU) (Kachanovsky et al., 2015). In Belarus, *Carabus menetriesi* is confined to waterlogged habitats such as mires, swamps, wet floodplain meadows, swampy forests and reservoir shores (Aleksandrowicz, 2014).

Conclusions

The state hydrological sanctuary «Boloto Mokh» is characterised by a ground beetle species composition, typical for the pristine peat bog temperate zone of Europe. Ground beetle assemblages showed low diversity and evenness. Three specialised species, *Agonum ericeti, Pterostichus diligens*, and *P. rhaeticus*, were the most abundant in all habitats in the study area. Species composition of ground beetles differed significantly among the six main habitat types. However, these differences provide only five species, which are most adapted to varying environmental conditions in the range of habitats. The parameters of the ground beetle diversity of the studied peatland are comparable with those of other insect taxa. A similar species composition and low diversity of ground beetles assemblages have also been identified in other European countries. It is important to note that the state hydrological sanctuary «Boloto Mokh» does not contain traces of previous fires, which is also confirmed by the species composition of ground beetles. Therefore, the presented studies confirm the high importance of the state hydrological sanctuary «Boloto Mokh» for conservation of unique natural tundra ecosystems in Eastern Europe. The presented research of ground beetle diversity in a large intact and protected peat bog, including all main habitat types, can be a starting point for comparative analysis of ground beetle assemblages in various regions of peatland distribution. Moreover, these results are important for assessing the variability of ground beetle assemblages under anthropogenic disturbance, since in many European countries pristine peat bogs, which can be used as reference sites, are extremely rare nowadays.

Acknowledgements

I thank Oleg Sozinov (Grodno State University named after Y. Kupala, Belarus) for the help in identification of plant communities. I also thank Igor Solodovnikov (Vitebsk State University named after P.M. Masherov, Belarus) for help in identification of some ground beetle species. I acknowledge to the editor and reviewers of the Nature Conservation Research for the valuable contribution to the main text. This research was funded by the State Program for Scientific Research of Belarus «Natural Resources and Environment» (grant number: 20210710).

References

Aleksandrowicz O.R. 2002. Changes in the carabid fauna of Polesie peat-bog due to drainage, ploughing and agricultural development. In: J. Szyszko, P.J. den Boer, T. Bauer (Eds.): *How to Protect or What We Know about Carabid Beetles*. Warsaw: Agricultural University Press (Poland). P. 171–184.

Aleksandrowicz O.R. 2014. *Ground beetles (Coleoptera, Carabidae) of the West Part of Russian Plain. Fauna, zoogeography, ecology.* Saarbrücken: Lambert Academic Publishing. 456 p. [In Russian]

Aleksandrowicz O., Pisanenko A., Ryndevich S., Saluk S. 2023. *The Check-List of Belarus Coleoptera*. Słupsk: Publishers Pomeranian University in Słupsk. 189 p.

Alekseev V., Napreenko M., Napreenko-Dorokhova T. 2024. Ecological Groups of Coleoptera (Insecta) as Indicators of Habitat Transformation on Drained and Rewetted Peatlands: A Baseline Study from a Carbon Supersite, Kaliningrad, Russia. *Insects* 15(5): 356. DOI: 10.3390/insects15050356

Atutova Zh.V. 2023. Post-fire restoration of pine forests in the Badary area, Tunkinskiy National Park, Russia. *Nature Conservation Research* 8(2): 22–32. DOI: 10.24189/ncr.2023.010

Bezděk A., Jaroš J., Spitzer K. 2006. Spatial distribution of ground beetles (Coleoptera: Carabidae) and moths (Lepidoptera) in the Mrtvý luh bog, Šumava Mts (Central Europe): a test of habitat island community. *Biodiversity and Conservation* 15: 381–395. DOI: 10.1007/s10531-005-3435-z

Brigić A., Bujan J., Alegro A., Šegota V., Ternjej I. 2017. Spatial distribution of insect indicator taxa as a basis for peat bog conservation planning. *Ecological Indicators* 80: 344–353. DOI: 10.1016/j.ecolind.2017.05.007

Browarski B. 2005. The carabid fauna of «Torfiaki» raised peat-bog (north-eastern Poland). In: J. Skłodowski, S. Huruk, A. Barševskis, S. Tarasiuk (Eds.): *Protection of Coleoptera in the Baltic Sea Region*. Warsaw: Agricultural University Press (Poland). P. 137–145.

Buchholz S., Hannig K., Schirmel J. 2009. Ground beetle assemblages of peat bog remnants in Northwest Germany (Coleoptera: Carabidae). *Entomologia Generalis* 32(2): 127–144. DOI: 10.1127/entom.gen/32/2009/127

Butterfield J., Coulson J.C. 1983. The carabid communities on peat and upland grasslands in northern England. *Ecography* 6(2): 163–174. DOI: 10.1111/j.1600-0587.1983.tb01078.x

Chao A. 2024. *iNEXT.4steps software*. Anne Chao's Web site. Available from https://chao.shinyapps.io/iNEXT_4steps/

Chao A., Gotelli N.J., Hsieh T.C., Sander E.L., Ma K.H., Colwell R.K., Ellison A.M. 2014. Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. *Ecological Monographs* 84(1): 45–67. DOI: 10.1890/13-0133.1

Dapkus D., Tamutis V. 2008. Assemblages of beetles (Coleoptera) in a peatbog and surrounding pine forest. *Baltic Journal of Coleopterology* 8(1): 31–40.

De Cáceres M., Legendre P. 2009. Associations between species and groups of sites: indices and statistical inference. *Ecology* 90(12): 3566–3574. DOI: 10.1890/08-1823.1

Egorov L.V., Ruchin A.B., Fayzulin A.I. 2024. Post-Fire Coleoptera Fauna in Central Russian Forests after the 2021 Fires (Study Using Beer Traps). *Insects* 15(6): 420. DOI: 10.3390/insects15060420

Främbs H., Dormann W., Mossakowski D. 2002. Spatial distribution of carabid beetles on Zehlau Bog. *Baltic Journal of Coleopterology* 2(1): 7–13.

Freude H., Harde K., Lohse G.A. 2004. *Die Käfer Mitteleuropas. Band 2. Adephaga 1. Carabidae (Laufkäfer)*. Heidelberg-Berlin: Spektrum-Verlag. 521 p.

Hammer Ø., Harper D.A.T., Ryan P.D. 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaentologia Electronica* 4(1): 1–9.

Kachanovsky I.M., Nikiforov M.E., Parfenov V.I. (Eds.). 2015. *Red Data Book of the Republic of Belarus.*

Animals: rare and endangered species of wild animals. Minsk: Belarusian Encyclopedia named after P. Brouka. 320 p.

Kozulin A.V. 2005. *Treasures of Belarusian Nature: Areas of inter-national significance for conservation of biological diversity*. Minsk: Vydavetstva Belarus. 215 p.

Legendre P., Gallagher E.D. 2001. Ecologically Meaningful Transformations for Ordination of Species Data. *Oecologia* 129: 271–280. DOI: 10.1007/s004420100716

Lehmitz R., Haase H., Otte V., Russell D. 2020. Bioindication in peatlands by means of multi-taxa indicators (Oribatida, Araneae, Carabidae, Vegetation). *Ecological Indicators* 109: 105837. DOI: 10.1016/j.ecolind.2019.105837

Maavara V. 1957. Endla rabade entomofauna. *Eestj NVS Teeaduste Akadeemia Juures asuva loodusuurijate seeltsi* 50: 119–140.

Magurran A.E. 2004. *Measuring Biological diversity*. Oxford: Blackwell Publishing. 256 p.

Mikkola K., Spitzer J. 1983. Lepidoptera associated with peatlands in central and northern Europe: a synthesis. *Nota Lepidopterologica* 6: 216–229.

Mossakowski D. 1977. Die Kaferfauna wachsender Hochmoorflachen in der Ersterweger Dose. *Drosera* 19: P. 63–72.

Mossakowski D., Främbs H., Lakomy W. 2003. The Carabid and Staphylinid fauna of raised bogs. A comparison of Northwest Germany and the Baltic region. *Baltic Journal of Coleopterology* 3(2): 137–144.

Oksanen J., Blanchet F.G., Friendly M. 2019. *vegan: Community ecology package (Version 2.5-5)*. Available from http://CRAN.R-project.org/package=vegan

Philippov D.A., Pestov S.V. 2014. Preliminary checklist of insects of mire biotopes of the Vologda Region. *Proceedings of Instorf* 10(63): 3–19. [In Russian]

Philippov D.A., Ermilov S.G., Zaytseva V.L., Pestov S.V., Kuzmin E.A., Shabalina J.N., Sazhnev A.S., Ivicheva K.N., Sterlyagova I.N., Leonov M.M., Boychuk M.A., Czhobadze A.B., Prokina K.I., Dulin M.V., Joharchi O., Shabunov A.A., Shiryaeva O.S., Levashov A.N., Komarova A.S., Yurchenko V.V. 2021. Biodiversity of a boreal mire, including its hydrographic network (Shichengskoe mire, north-western Russia). *Biodiversity Data Journal* 9: e77615. DOI: 10.3897/BDJ.9.e77615

R Core Team. 2020. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation For Statistical Computing. Available from https://www.r-project.org

Ruchin A.B., Egorov L.V., Alexeev S.K., Artaev O.N. 2016. *Carabid beetles of the Mordovia State Nature Reserve (annotated list of species).* Moscow. 36 p. [In Russian]

Ruchin A.B., Alekseev S.K., Khapugin A.A. 2019. Post-fire fauna of carabid beetles (Coleoptera, Carabidae) in forests of the Mordovia State Nature Reserve (Russia). *Nature Conservation Research* 4(Suppl.1): 11–20. DOI: 10.24189/ncr.2019.009

Sazhnev A.S., Prokin A.A. 2021. Notes to the Terrestrial Beetles Fauna (Coleoptera) of Zorinskie Mires (Kursk Oblast). *Field Biologist Journal* 3(3): 239–247. DOI: 10.52575/2658-3453-2021-3-3-239-247 [In Russian]

Spitzer K., Danks H.V. 2006. Insect biodiversity of boreal peat bogs. *Annual Review of Entomology* 51: 137–161. DOI: 10.1146/annurev.ento.51.110104.151036

Spitzer K., Bezděk A., Jaroš J. 1999. Ecological Succession of a Relict Central European Peat Bog and Variability of Its Insect Biodiversity. *Journal of Insect Conservation* 3: 97–106. DOI: 10.1023/A:1009634611130

Sushko G.G. 2006. *Fauna and ecology of beetles (Ectognatha, Coleoptera) of peat bogs of the Belarusian Poozerie: monograph*. Vitebsk: Vitebsk State University. 247 p. [In Russian]

Sushko G.G. 2012. *The insect fauna of «Yelnia» peat bog (North-West Belarus)*. Saarbrücken: LAP LAMBERT. 114 p. DOI: 10.13140/RG.2.1.2937.1366

Sushko G.G. 2014. Spatial distribution of epigeic beetles (Insecta, Coleoptera) in the «Yelnia» peat bog. *Baltic Journal of Coleopterology* 14(2): 151–161.

Sushko G.G. 2016. Species composition and diversity of the true bugs (Hemiptera, Heteroptera) of a raised bog in Belarus. *Wetlands* 36(6): 1025–1032. DOI: 10.1007/s13157-016-0816-x

Sushko G.G. 2017. Taxonomic composition and species diversity of insect assemblages in grass-shrub cover of peat bogs in Belarus. *Contemporary Problems of Ecology* 10(3): 259–270. DOI: 10.1134/S1995425517030106

Sushko G. 2019. Key factors affecting the diversity of Sphagnum cover inhabitants with the focus on ground beetle assemblages in Central-Eastern European peat bogs. *Community Ecology* 20(1): 45–52. DOI: 10.1556/168.2019.20.1.5

Sushko G. 2022. Assessing butterfly diversity and their response to habitat condition in pristine peat bogs in Belarus. *Journal for Nature Conservation* 69(5): 126250. DOI: 10.1016/j.jnc.2022.126250

Sushko G.G., Buga S.V., Novikova Y.I. 2024. Comparison of the diversity of ground beetle (Coleoptera: Carabidae) assemblages in small and large temperate peat bogs. *Mires and Peat* 31(2): 02. DOI: 10.19189/MaP.2023.MEH.Sc.2126779

Yakushko O.F. 1971. *Belarusian Poozerie*. Minsk: Navuka. 336 p. [In Russian]

Zeliankevich N., Grummo D., Sozinov O., Galanina O. 2016. *Flora and Vegetation of the Raised Bogs of Belarus*. Minsk: Story Media Proekt. 244 p. [In Russian]

ОЦЕНКА РАЗНООБРАЗИЯ ЖУЖЕЛИЦ (COLEOPTERA, CARABIDAE) ВЕРХОВОГО БОЛОТА ГОСУДАРСТВЕННОГО ГИДРОЛОГИЧЕСКОГО ЗАПОВЕДНИКА «БОЛОТО МОХ» (БЕЛАРУСЬ)

Г. Г. Сушко

Витебский государственный университет имени П.М. Машерова, Беларусь
e-mail: gennadisu@tut.by

Экосистемы верховых болот играют важную роль в сохранении биоразнообразия в свете современных изменений климата. Они обеспечивают подходящие экологические условия, такие как высокий уровень болотных вод и кислотность, низкое содержание минеральных питательных веществ и специфические показатели микроклимата, для адаптированных к холоду растений и животных в условиях умеренной зоны Европы. Специфические экологические условия верховых болот определяют их специализированную биоту. Виды семейства Carabidae (далее – жужелицы), которые являются одними из самых многочисленных обитателей наземных экосистем, могут быть подходящим объектом для оценки закономерностей разнообразия. Мы предположили, что один из крупнейших в Беларуси охраняемых торфяников, составляющий ядро гидрологического заказника «Болото Мох», отражает основные черты биоразнообразия насекомых верховых болот в связи с его малой нарушенностью. С помощью почвенных ловушек в шести наиболее типичных местообитаниях верховых болот зарегистрировано 28 видов жужелиц. Значения индексов Шеннона (H’ = 0.26–1.15) и Пиелу (J’ = 0.33–0.66) показали низкое разнообразие и выравненность в сообществах жужелиц. Достоверно ($p < 0.05$) наибольшее разнообразие было в местообитаниях окрайки, наименьшее – на грядах грядово-мочажинного комплекса и вершине болота. Неметрическое многомерное шкалирование показало четкие различия видового состава между сообществами жужелиц окрайки, кочек, сосняков и вершины болота. Параметры разнообразия жужелиц изученного торфяника сопоставимы с таковыми других таксонов насекомых. Сходный видовой состав и низкое разнообразие сообществ жужелиц выявлены также в других странах Европы. Важно отметить, что гидрологический заказник «Болото Мох» не содержит следов прошлых пожаров, что также подтверждается и видовым составом жужелиц. Таким образом, представленные исследования указывают на высокую значимость государственного гидрологического заказника «Болото Мох» для сохранения биоразнообразия уникальных природных тундровых экосистем Восточной Европы. Представленные исследования разнообразия жужелиц крупного нетронутого и охраняемого торфяника, включающего все основные типы местообитаний, могут стать отправной точкой для сравнительного анализа их сообществ в различных регионах распространения верховых болот. Кроме того, эти результаты важны для оценки изменчивости сообществ жужелиц в условиях антропогенного нарушения, поскольку во многих европейских странах естественные торфяники, которые можно использовать в качестве эталонных, встречаются крайне редко.

Ключевые слова: видовое богатство, видовой состав, жужелицы, обилие, особо охраняемая природная территория, торфяник