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ORIGINAL ARTICLE

Spatial variation in assemblages of Odonata (Insecta) within habitat gradients in large, pristine peat bogs in Belarus

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Abstract

The variation in environmental conditions in peat bogs can be expressed by odonate assemblage composition among habitats or by differences in species richness, abundance and diversity among study sites in a regional context. The adult Odonata of large, pristine peat bogs in Belarus were examined. Adult Odonata were counted along fixed transects in main peat bog habitats under favorable weather conditions. The odonate diversity showed clear differences, affected by distance to the water body, wind speed, and bog water level. The highest diversity was recorded along lakeshores. This study detected distinct odonate assemblage variations among habitats such as lagg zones, lakeshores and hollows. The large areas occupied by pine bogs and open bogs had a very similar species composition and lower diversity. On the other hand, the Shannon diversity index (H′ = 1.433–2.295) and Pielou's evenness index (J' = 0.468–0.507) values were relatively high compared to those of terrestrial insects. The main differences among adult odonate assemblages were driven by cold-adapted, highly specialized species such as *Leucorrhinia albifrons, Leucorrhinia dubia, Sympetrum danae* and two abundant generalist species such as *Sympetrum sanguineum* and *Sympetrum vulgatum*. Peat bog specialists are among the most rapidly declining insects and, therefore, relatively intact Belarusian peat bogs are refuges for many threatened species and have considerable conservation potential.

Keywords Diversity · Environmental factors · Peat bogs · Odonata · Conservation

Introduction

Wetlands play an important role in supporting regional and local hydrological conditions and in maintaining biodiversity. Peatlands comprise over 50% of the world's wetlands and cover approximately 3% of the Earth (Bragg et al. 2003; Rydin and Jeglum 2006; Zeliankevich et al. 2016). Among these peatlands, peat bogs are ecologically valuable because they support a specialized cold-adapted biota, are important greenhouse gas sinks and hold carbon within their depths (Bambalov and Rakovich 2005; Spitzer and Danks 2006). However peatlands are rare and rapidly declining throughout the world because of peat cutting, drainage, pollution or eutrophication, with the most severe losses having occurred in Europe (Joosten and Clarke 2002). In many European countries more than 90% of all peatlands have been destroyed (Joosten 2012).

Only several countries in Europe, including Belarus, Russia and the Nordic countries have maintained more than 50% of their peatlands in a relatively natural condition (Bragg et al. 2003). In Belarus 53.1% of an estimated 314,500 ha of original peat bogs remain intact and, in addition, the area (30.1%) of partially drained bogs with preserved natural areas is high (Zeliankevich et al. 2016). For better protection and restoration of Central European peat bogs, it is necessary to develop knowledge about their biodiversity in natural ecological conditions. Moreover, for the evaluation of peat bog degradation, improving knowledge about typical flora and fauna and corresponding specialized species composition relating to natural environmental conditions is imperative. Accordingly, large, almost intact Belarusian peat bogs are valuable for ecological investigation, whereas in most other countries such studies are not possible. In the context of anthropogenic interference, biodiversity studies of natural peatlands are highly

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valuable, as they are keys to the comparison with degraded habitats.

Peat bogs are ecosystems with very specific environmental conditions. Sphagnum mosses, ericaceous dwarf shrubs, stunted pine predominate in these habitats. As a result, the European peat bogs resemble a tundra landscape (Spitzer and Danks 2006). Therefore, every peat bog in Central Europe can be considered a habitat island (Spitzer et al. 1999; Spitzer and Danks 2006) with microclimate conditions not typical of the temperate zone of Europe. This is very important in the context of global climate warming, since peat bogs may become refugia for cold-adapted biota (Spitzer and Danks 2006). Sphagnum mosses are the main builders of peat bogs, forming an acidic, anoxic, cold, and nutrient-poor environment. The bog dwellers are forced to adapt to these unique and extreme conditions. In addition, the ancient Belarusian peat bogs contain complexes of hollows and hummocks, small lakes and hummocks, and large lakes, which form specific landscape patterns. Their water is brown and has a pH of 3–4, which creates an environment unfavorable for many plants and animals.

Despite the unique character of peat bog environments, knowledge of their invertebrate assemblages is very uneven. In general, most research has focused on the specific spatial distribution of terrestrial peat bog inhabitants (Maavara 1957; Mossakowski et al. 2003; Spungis 2008). In the case of aquatic and semiaquatic insects in peat bogs, published investigations have previously dealt with taxonomic composition (Peus 1928; Maavara 1957; Mielewczyk 1969) and restoration of drained peatlands (D'Amico et al. 2004; Hannigan et al. 2011; Elo et al. 2015; Remm and Sushko 2018; Krieger et al. 2019).

Dragonflies and damselflies (Insecta: Odonata) are better studied taxonomically than most other orders of aquatic and semiaquatic insects and are easier to identify; they are have been extensively used as indicators of ecological conditions (Samways and Steytler 1996; Bulánková 1997; Gillott 2005; Kadoya et al. 2008; Flenner and Sahlén 2008; Cannings 2014). However, little is known about how adult odonates respond to environmental conditions in large, homogeneous bog spaces and our knowledge of biodiversity and spatial patterns of flying adult odonates in peat bogs is less than adequate. Imagoes of Odonata can show terrestrial and aquatic habitat specificity. The variation in environmental conditions in peat bogs can be expressed by odonate assemblage composition among habitats or by differences in species richness, abundance and diversity among study sites in a regional context. Given the lack of information about the adult Odonata assemblages in pristine peat bogs, the results of the present study may contribute to the development of conservation measures for these vulnerable ecosystems.

In addition, it should be noted that peat bogs have traditionally been classified as habitats with a fairly homogeneous environment, as in their extreme ecological conditions, plant diversity is relatively low (Rydin and Jeglum 2006; Zeliankevich et al. 2016). The plant cover of large, pristine Belarusian peat bogs changes monotonically. Habitat heterogeneity theory presumes that structurally complex areas have a higher biodiversity at the local scale than areas with less complex structural composition (Tews et al. 2003; Legendre et al. 2005). According to this premise, within the herb-shrub layer, the diversity of main consumers, such as insects, was not high and the species composition, especially dominants, changes very slightly (Sushko 2017). The same trends occurred in sphagnum dwellers. In particular, in sphagnum cover in different habitats only 1–3 of the same beetle species were dominants (Mossakowski et al. 2003; Spungis 2008; Sushko 2014, 2019). Assessing distribution patterns of flying adult Odonata species along peat bog habitat gradients helps both to better understand the variation in environmental conditions and to interpret the interactions of actively flying insects and their environments.

This study evaluates the biodiversity of adult odonate assemblages and the heterogeneity of these assemblages along gradients in pristine peat bog habitats. In addition, it examines the factors affecting diversity and species distribution. The working hypothesis formulated was that the species richness, abundance, diversity and species compositions of flying adult odonates would vary in gradients among the peat bog habitats, despite their relatively high landscape homogeneity.

Methods

Study sites

The study was conducted in three large pristine peat bogs: Boloto Moh, Obol 2, and Elnya of 4602 ha, 4900 ha, and 19,984 ha respectively, within the Republic of Belarus (Fig. 1). They are among the few almost intact Central European bogs and are protected as hydrological and landscape reserves (Kozulin 2002). The research was carried out in 2016 and 2018. Peat bog surfaces are typically convex; there are lagg at the edges of the border zone, a slope, and a dome, which can have a height of 3 to 7 m. The distance from the edge to the center in these bogs varied between 2.5 km and 5.9 km (mean: 4.4 km).

Five main habitats: lagg zone (LZ), pine bog (PB), lakeshores (LR), hollows (HOL), and open bog (OB) were selected inside peat bogs (Fig. 2). In each habitat three sites, 500 m apart with an area of 500 m^2 were chosen (3 sites per habitat, 15 sites per bog and 45 sites in total) (see also Section Data sampling).

Lagg zones at the bog margin were covered by *Eriophorum vaginatum*, and the bog water table was at the moss surface at the beginning of the season.

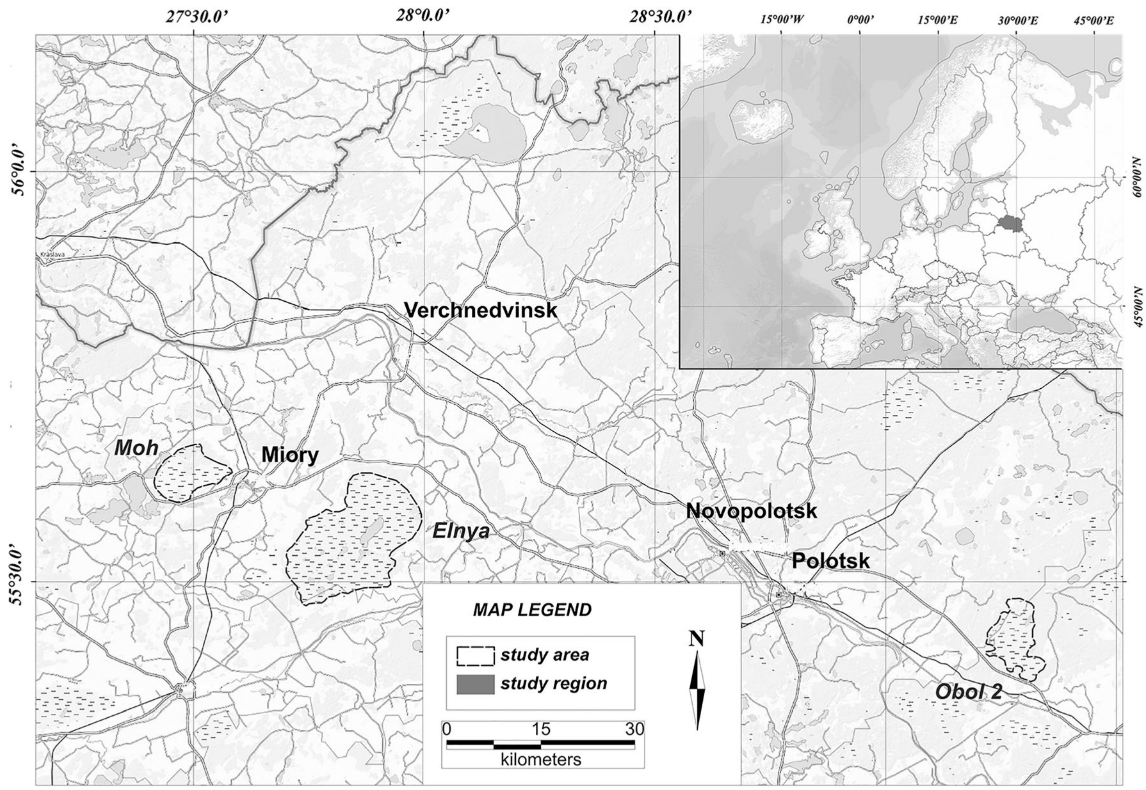

Fig. 1 Map of the study area and location of the peat bogs

Pine bogs and hollows extended several km along the slope of the peat bogs towards the central dome. Besides containing *Pinus sylvestris,* pine bogs supported a heterogeneous plant community characterized by ericaceous dwarf shrubs such as *Ledum palustre*, *Chamaedaphne calyculata, Calluna vulgaris, Vaccinium oxycoccus, V. uliginosum* occurs. Hollows were covered by *Rhynchospora alba,* and were permanently full of water. Hollows contained a mosaic of elevated hummocks. Hummocks were of various sizes (diameter: 20–100 cm; height: 15–50 cm) and covered by dwarf shrubs. Open bogs on the dome were covered by dwarf shrubs and characterized by ombrotrophic conditions. The lakeshores were covered by *Carex limosa* and various dwarf shrubs. The length of the shoreline of the studied lakes ranged from 0.75 to 3.15 km (mean: 2.4 km ± 0.3 SE).

To characterize the environmental conditions, four variables (mean values ± SE) at each site were measured. During each visit, bog water level, air temperature (in shade), wind speed (using anemometer MS 13), and sunshine (using Digital Light Meter MS 6610) were recorded (Table 1).

Data sampling

Adult Odonata were counted along fixed transects in each site under favorable weather conditions (sunny days with cloud cover less than 60% and a minimum air temperature of 17 °C) during the period of maximum activity (10:00 to 16:00) (Smallshire and Beynon 2010). If in-flight species determination was not possible, individuals were caught with a standard entomological net (50 cm in diameter). All observed individuals were identified to species using Dijkstra and Lewington (2006). Surveys were conducted between May and the end of September. Each site was visited every 10–14 days (number of visits per one transect was 10) and the average time spent per transect was approximately 30 min. Transects in all sites had a standardized length of 200 m and were 5 m wide (1000 m^2).

Statistical analysis

The Shannon's diversity (H′) and Pielou's evenness (J') indexes were used as measures of Odonata alpha diversity (Magurran 2004). The data were tested for normality using the Shapiro–Wilks test ($p < 0.05$). Differences among environmental variables and mean species richness, abundance and diversity indexes were tested using Kruskal–Wallis ANOVA with Dunn's post hoc test with Bonferroni correction.

The spatial heterogeneity of odonate assemblages was established using analysis of similarity (ANOSIM) and summarized by non-metric multidimensional scaling (NMDS). NMDS ordination was based on the decomposition Bray-Curtis similarity index. I coded sample scores according to time (three sampling years) by different symbols on the ordination plot. Species recorded with fewer

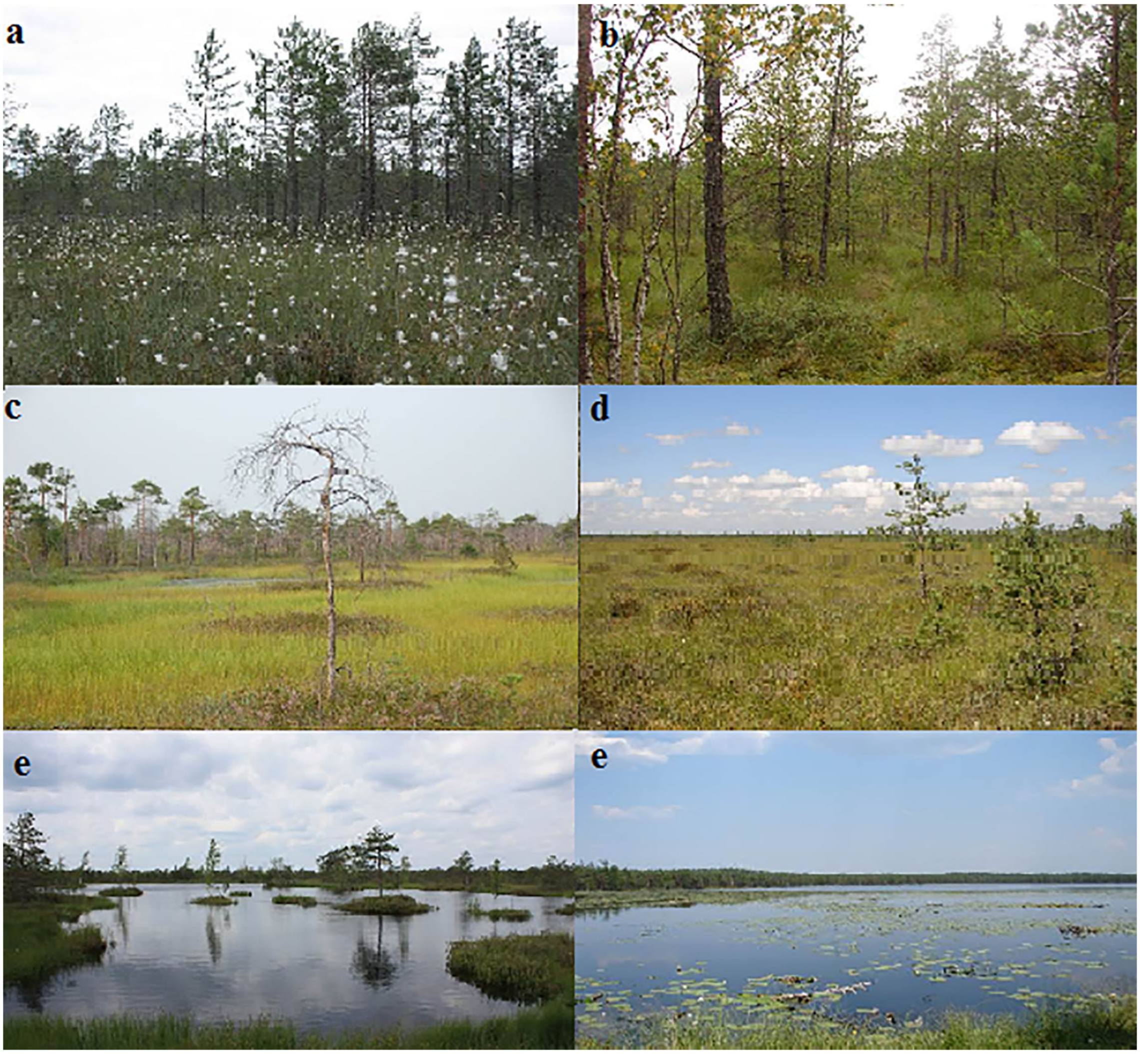

Fig. 2 Study habitats. **a** Lagg zone, **b** pine bog, **c** hollows, **d** open bog, **e** lakeshores

than five individuals were omitted from analysis. The odonate numbers were square root transformed. Similarity percentage analysis (SIMPER) based on the Bray-Curtis index was applied to detect the most influential species, which contributed the main differences in composition of the assemblages. Prior to analysis, data were square-root transformed (Warton et al. 2012).

Effect of habitat type and year of investigation on abundance, species richness and diversity were tested using two-way ANOVA in order to analyze of potential spatial autocorrelation (Online Resource 1, Table 1S). The influences of measured environmental variables and distance to the closest water body on odonate diversity (species richness, abundance and Shannon index average) were tested using Generalized

Table 1 Habitat overview and environmental parameters (mean ± SE)

Habitat	Location	Most common plant species	Bog water level, cm	Air temperature, °C	Wind speed m/s	Sun-shine, klk	Distance to the bog edge, m
Lagg	margin	*Eriophorum vaginatum*	5 ± 0.2	24 ± 0.2	4.2 ± 0.4	5 ± 0.2	7 ± 0.7
Pine bog	slope	*Pinus sylvestris, Ledum palustre, Chamaedaphne calyculata*	14 ± 0.4	22 ± 0.5	2.5 ± 0.2	3 ± 0.2	408 ± 13
Hollows	slope	*Rhynchospora alba*	1.7 ± 0.3	22.5 ± 0.5	4.7 ± 0.3	4.6 ± 0.2	1032 ± 10
Lakeshores	slope	*Chamaedaphne calyculata, Carex limosa*	5.8 ± 0.7	23 ± 0.5	5.2 ± 0.4	4.6 ± 0.3	1022 ± 12
Open bog	dome	*Ledum palustre, Chamaedaphne calyculata, Calluna vulgaris*	21.5 ± 0.5	25 ± 0.2	5.2 ± 0.2	5.5 ± 0.2	1588 ± 55

Linear Mixed Models (GLMM) with a Poisson distribution (Zuur et al. 2009), performed with the function “glmer” in the lme4 R package. Colinearity in the environmental variables was assessed calculating variation inflation factors (VIF). Among measured environmental parameters, highly correlated variables (VIF > 5) were not detected (Zuur et al. 2010). The time (year) and habitat type were random factors; the fixed factors, included in models, were bog water level, air temperature, wind speed, sunshine level and distance to the closest water body.

Canonical correspondence analysis (CCA) was applied to visualize the relationships among species and environmental variables. Species recorded with fewer than five individuals were omitted from analysis. The odonate numbers were log10 (n + 1) transformed since many species had a zero-value (Lepš and Šmilauer 2003). Since significant differences in the species composition and abundance among three sampling years were not found (Online Resource 1, Table 4S), I used only 2017 data as the analysis baseline. Analyses were performed in R software (R Development Core Team 2011) using the packages vegan (Oksanen et al. 2007), lme4 (Bates et al. 2015), car (Fox and Weisberg 2019), and software Past (Hammer et al. 2001).

Results

Odonate species richness, abundance and diversity

In total, 33 dragonfly and damselfly species from seven families and two suborders were recorded. The largest numbers of species were sampled from the order Anisoptera (22) and family Libellulidae (12). *Leucorrhinia albifrons, Leucorrhinia dubia, Leucorrhinia rubicunda, Sympetrum danae, Sympetrum sanguineum* and *Sympetrum vulgatum* were the most abundant species (Online Resource 1, Table 2S).

The species richness of dragonflies and damselflies significantly differed among the habitats (Kruskal–Wallis test H = 35.68, $p < 0.001$). The assemblages of odonates per habitat ranged fom 18 to 27 species. The highest number of species was captured along the shoreline of lakes and in lagg zones, whereas the lowest species richness was recorded in the open sites of the bog dome (Fig. 3).

Odonata abundance significantly differed among the studied habitats (Kruskal–Wallis test H = 31.23, $p < 0.001$) and was the highest along lake shores and in lagg zones, while the lowest abundance was in the hollows (Fig. 4).

Shannon diversity significantly differed among the study sites (Kruskal–Wallis test H = 16.74, $p < 0.005$). The highest diversity (H′ = 2.315–2.080) was recorded along the shorelines of lakes and in lagg zones, whereas the lowest Shannon index value was in the open bogs (H′ = 1.828) (Fig. 5).

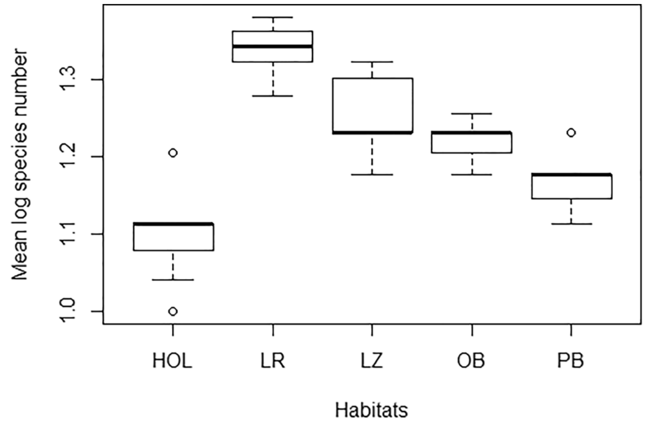

Fig. 3 Mean number of species (± SE) of odonates in different peat bog habitats: HOL – hollows, LR– lakeshores, LZ – lag zones; OB – open bogs; PB – pine bogs

Pielou’s evenness index peaked for the hollows (J’ = 0.507); the lowest value was for the open bogs (J’ = 0.382). In other habitats odonate assemblage evenness was J’ = 0.468–0.491. However, the differences in the Pielou’s index values were not significant (Kruskal–Wallis test H = 31.23, $p < 0.0001$).

Among the variables included in the GLMM models, wind speed ($p < 0.05$) was related positively significantly to species richness and abundance in the gradient of peat bog habitats. Whereas, the distance to the closest water body had a significant negative effect on odonate abundance. The significant predictor variable for Shannon diversity was bog water level ($p < 0.01$) (Table 2).

Odonate species composition across the habitat gradient

A significant difference in odonate species composition among study habitats was detected (ANOSIM, R = 0.858, $p < 0.0001$). NMDS revealed that species composition varied

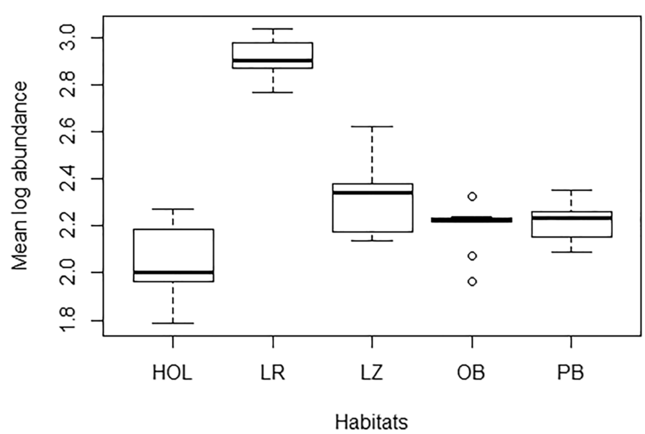

Fig. 4 Mean number of individuals (± SE) of odonates in different peat bog habitats: HOL – hollows, LR– lakeshores, LZ – lag zones; OB – open bogs; PB – pine bogs

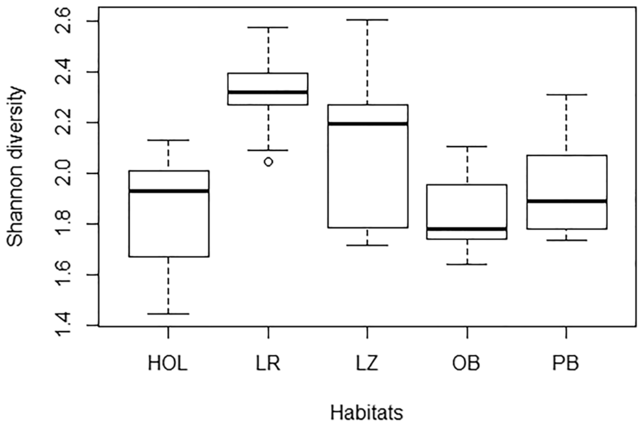

Fig. 5 Mean value of Shannon index (± SE) in odonate assemblages in different peat bog habitats: HOL – hollows, LR– lakeshores, LZ – lag zones; OB – open bogs; PB – pine bogs

across the gradient of habitats from edge (LZ) to dome (OB) of the peat bog. Lagg zones (LZ), together with lakeshores (LR) and hollows (HOL), were widely dispersed, indicating higher odonate assemblage heterogeneity. On the other hand, open (OB) and pine (PB) bogs were less different (Fig. 6).

SIMPER analysis revealed that differences in odonate assemblages were driven by higher abundances of a few species. Along lake shores (in relation to other habitats) such species were *Sympetrum sanguineum* (23.34% to the dissimilarity), *Leucorrhinia albifrons* (9.98% to the dissimilarity), *Leucorrhinia dubia* (6.51% to the dissimilarity). In lagg zones the relevant abundant species was *Sympetrum danae* (12.04% to the dissimilarity) and in hollows it was *Sympetrum vulgatum* (11.01% to the dissimilarity) (Online Resource 1, Table 3S).

According to the CCA ordination (Fig. 7), many species respond to environmental variables. *Libellula quadrimaculata* and *Sympetrum flaveolum* were positively associated with bog water level. *Lestes sponsa, Somatochlora flavomaculata*, and *Sympetrum danae* showed a positively response to air temperature. *Aeshna subarctica* and *Cordulia aenea* preferred more sunny conditions. Wind speed positively affected distribution in of *Leucorrhinia dubia*. *Leucorrhinia albifrons*, *Aeshna cyanea, Somatochlora metallica, Sympetrum danae* and *Lestes dryas* were positively associated with a distance to the closest water body.

Table 2 Results of multiple regression analysis (GLMM) of odonate diversity to environmental variables

Variables	Estimate	SE	z	p
Abundance				
intercept	5.205	1.798	2.904	**
bog water level, cm	0.032	0.014	2.169	n.s
air temperature, °C	0.044	0.073	0.651	n.s
wind speed, m/s	0.124	0.090	1.358	*
sunshine, klk	0.099	0.113	0.849	n.s
distance to the closest water body, m	−0.002	0.005	−3.520	**
Species richness				
intercept	1.814	0.520	3.487	***
bog water level, cm	0.005	0.004	1.110	n.s
air temperature, °C	0.042	0.022	1.790	n.s
wind speed, m/s	0.031	0.027	1.091	*
sunshine, klk	0.005	0.055	0.158	n.s
distance to the closest water body, m	−0.001	0.003	−0.880	n.s
Shannon diversity				
intercept	4.568	3.394	1.346	**
bog water level, cm	6.950	2.931	2.273	**
air temperature, °C	2.034	1.506	1.350	n.s
wind speed, m/s	2.084	1.872	0.001	n.s
sunshine, klk	3.215	2.371	1.356	n.s
distance to the closest water body, m	−1.181	1.082	−0.033	n.s

Significance codes: ***$p \leq 0.0001$, **$p \leq 0.001$, *$p \leq 0.05$

Discussion

In this study, I focused on the diversity of adult odonates along habitat gradients in large, pristine peat bogs. Earlier studies showed low diversity in terrestrial insect assemblages and strong associations with plant cover, which was the main driver of environment heterogeneity (Sushko 2016, 2017, 2018). With a focus on diversity patterns and the composition of assemblages of flying, predatory, semi-aquatic insects, other parameters of affected spatial distribution were detected.

Despite the relatively similar environmental conditions of large bog habitats, extending for several kilometers, diversity patterns clearly showed in the habitat gradients. Adult odonate

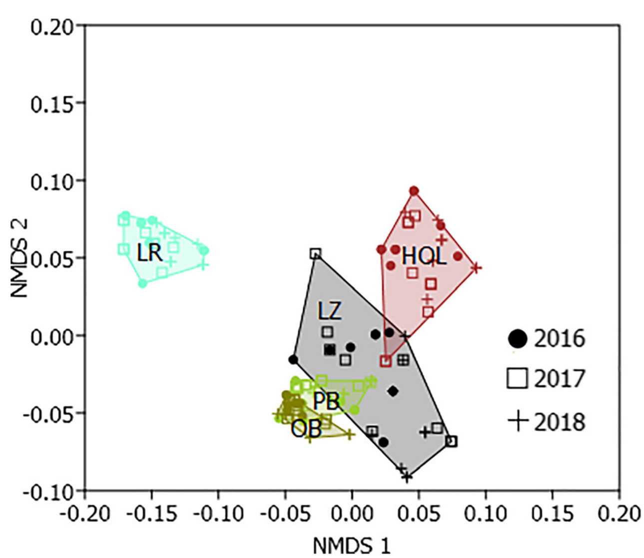

Fig. 6 NMDS (stress = 0.16; 3 dimensions) plot of odonate assemblages in different peat bog habitats: HOL – hollows (brown), LR– lakeshores (aquamarine), LZ – lag zones (black); OB – open bogs (olive); PB – pine bogs (green)

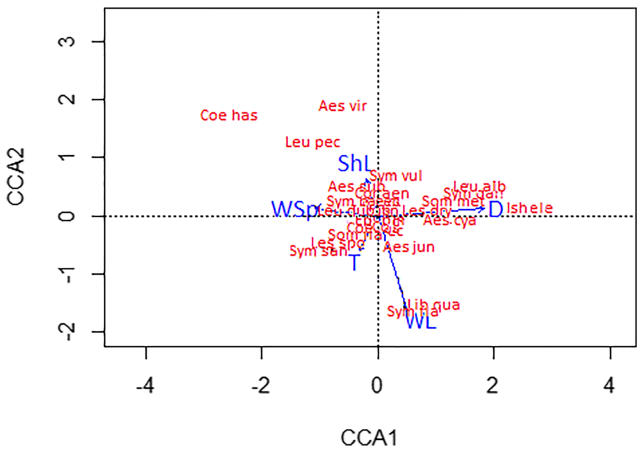

Fig. 7 CCA plot based on relationship of odonate species and environmental parameters (the first two axes of the ordination explained 57.08 and 36.15% of the variation). WL water level, T – air temperature, D – distance to the bog edge, WSp – wind speed, ShL – sunshine level. For abbreviations of the species names see Online Resource 1, Table 2S

species richness and abundance were highest within lagg zones and along lake shores. The increase of species richness in border lagg zones and along lake shores probably was caused by edge effects. Habitat edges (ecotones) are important because of the modification of abiotic condition gradients and variations in food availability (Delcourt and Delcourt 1992). Also likely, lagg zones are favorable for dragonflies because of relatively sunny but also low wind conditions. Moreover, lakes may better suit the development of aquatic odonate larvae, causing a high diversity of adults along the shoreline. Adult dragonflies spend a large part of their time near the breeding water bodies. Apparently, peat bog lakes are no exception. Thus higher diversity and abundance near water bodies is no surprise. Moreover, males occur even more time near water bodies than females and are more easily detectable. On the other hand, females, spend more time in other habitats, but are more cryptic.

Shannon diversity showed similar patterns; the highest diversity was recorded along lake shores. In the hollows, open and pine bogs, the adult odonate diversity was lower, but overall was relatively high and even compared to terrestrial insect assemblages. In particular, the value of the Shannon index (H′ = 1.433–2.295) in odonate assemblages was distinctly higher than that of the insect assemblages in the moss cover (H′ = 0.746–1.280) and in the grass-shrub cover (H′ = 1.509–1.979) (Sushko 2017, 2019). In addition, the evenness of the adult odonate assemblages was higher compared to that of terrestrial insects, as shown the Pielou's index values (J' = 0.468–0.507) (Sushko 2017, 2019). The observed pattern of biodiversity can possibly be explained if such habitats are characterized by conditions generally favorable for Odonata larvae and adults.

In this study wind speed was important factor determining higher mean number of individuals and species. Wind speed, which was highest along the open lake surface, appeared to be positively related to abundance and species richness. Usually dragonflies avoid very windy conditions, but water body provided the most favorable for breeding of dragonfly larvae. However, the abundance is significantly negatively affected by the distance to the open lake surface. On the other hand, on the CCA diagram the arrows corresponding to wind speed and distance to open water form an obtuse angle. This indicates a negative correlation between them, i.e. the wind speed increases with decreasing distance to the water body. Apparently, the abundance of adult dragonflies is more related to the distance to the breeding site. Whereas wind speed is "disturbing factor".

Not surprisingly, Shannon's diversity affected high bog water level. The water habitats suitable for odonate larval development occurred in the lakes and in the hollows. Possibly larvae also occurred in some very wet areas of the lagg zone. For adult dragonflies, the water level can indirectly modify flight activity. Temperature and sunshine level did not significantly influence on diversity values as their gradient among peat bog habitats varies only slightly (Online Resource 1, Table 4S). Such biotopes are open or have a very sparse cover of short pine trees; therefore they are well insolated and warmed.

The composition of assemblages along local ecological peat bog gradients provides important information that such extremely "tundra patches" in the temperate zone of Europe (Spitzer and Danks 2006) may become a refuge for cold-adapted species during future climate change. Specialized peat bog dragonflies among them.

This study detected distinct variation in odonate assemblages among habitats such as lagg zones, lakeshores and hollows. These differences are likely a result of contrasting habitat structure. At the same time, the large areas occupied by pine bogs and open bogs, which were characterized by very homogenous habitat conditions, had very similar species compositions. The presence of such habitats provides refuges for odonates. Lakeshores, especially, with the highest diversity values, formed hot spots of semi-aquatic insect biodiversity, including highly specialized species. In the phase of reproductive activity, dragonflies are concentrated near their breeding habitats and thus are most numerous along the shores of waterbodies and less numerous far from water. On the other hand, large areas of pine bogs and open bogs, which do not have permanent water on the sphagnum surface, play an important role for dragonflies. They are used for foraging and resting during the maturation phase of many Odonata species.

In the studied peat bogs adults of 55% of all odonate species recorded in Belarus (Buczynski et al. 2006) were found. Of course, not all the 33 odonate species recorded in this study, develop in peat bog waters. It should be noted that earlier studies of peat bog odonate larvae revealed 26 species in Belarus and 27 species in Poland (Mielewczyk 1969; Sushko 2010). Among odonate species recorded in this study

78.78% develop in peat bog waters (Sushko 2010; Remm and Sushko 2018).

Peatlands support a very high proportion of specialized inhabitants (tyrphobionts and tyrpophiles) in comparison with other ecosystems (Peus 1928; Spitzer and Danks 2006). Such species are cold-adapted and range mainly in northern latitudes (Spitzer and Danks 2006). Among recorded in this study Odonata specialized peat bog dwellers in Europe are *Enallagma cyathigerum, Aeshna subarctica, Aeshna juncea, Somatochlora arctica, Leucorrhinia albifrons, Leucorrhinia dubia, Leucorrhinia rubicunda, Sympetrum danae* (22.8% of all recorded species) (Mielewczyk 1969; Dijkstra and Lewington 2006). Species protected in Belarus that were recorded in this study are *Nehalennia speciosa* (EN, endangered)*, Sympecma paedisca* (VU, vulnerable), and *Aeschna viridis* (VU) (Red Book of the Republic Belarus 2015). The main differences among adult odonate assemblages were driven by cold-adapted, highly specialized species such as *Leucorrhinia albifrons, Leucorrhinia dubia, Sympetrum danae* and two abundant generalist species such as *Sympetrum sanguineum* and *Sympetrum vulgatum* as shown in the results of the SIMPER analysis.

Specialized peat bog odonates are among the most rapidly declining insect groups throughout Europe (Kalkman et al. 2010). The loss of peat bog water bodies, which are the environment for dragonfly larvae development, and the lowering of their water levels as a result of draining can the main reasons for this decline (Remm and Sushko 2018). The results of this study clearly show that large, almost intact, Belarusian peat bogs have considerable conservation potential; bog lakes, in particular, are refuges for many threatened species.

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verifying various species of Odonata. I would like to thank Rob Cannings (Royal BC Museum, Canada) for English language editing. Moreover, I grateful to two anonymous referees for valuable comments on an earlier version of the manuscript.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

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